

COLORADO DROUGHT MITIGATION AND RESPONSE PLAN



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Disaster Mitigation Act 2000 & Section 409, PL 93-288

Prepared by
Colorado Water Conservation Board
Department of Natural Resources

In Cooperation with
The Department of Public Safety
Division of Homeland Security & Emergency Management
and the Drought Mitigation and Response Planning Committee

The Colorado Drought Mitigation and Response Plan

Drought Annex to the State Hazard Mitigation Plan ANNEX VII to the State Emergency Operations Plan

Colorado Department of Natural Resources
Colorado Water Conservation Board

Updated in 2018 and 2013 by the CWCB and Wood Environment & Infrastructure
Solutions, Inc. in coordination with the Drought Mitigation and Response Planning
Committee

and the National Drought Mitigation Center

Drought Mitigation and Response Plan Comprehensive Revision by the CWCB and
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in 2001.

Revised by J. Truby, L. Boulas, and R. Kistner in 1986 and 1990.

Original document developed by J. Truby, L. Boulas 1981
Colorado Department of Local Affairs
Division of Local Government
Office of Emergency Management

Table of Contents

1	PREREQUISITE	1
1.1	Adoption by the State	1
1.1.1	Formal Adoption by the State	1
1.1.2	Assurance of Continued Compliance with Federal Requirements	1
2	PLANNING PROCESS	3
2.1	Documentation of the Planning Process	3
2.1.1	Description of Plan Preparation Process	3
2.1.2	Involvement in Planning Process	7
2.1.3	Agency Involvement in Plan Preparation Process	9
2.1.4	Description of Plan Review and Analysis	9
2.1.5	Indication of Section Revisions	10
2.2	Coordination among Agencies	11
2.2.1	Involvement of Federal and State Agencies	11
2.2.2	Involvement of Interested Groups	11
2.2.3	Changes in Coordination	13
2.3	Program Integration	14
2.3.1	Integration of Mitigation Planning with other State Planning Efforts	14
2.3.2	Integration of Mitigation Planning with FEMA Mitigation Programs and Initiatives	15
3	RISK ASSESSMENT	17
3.1	Identifying the Drought Hazard	17
3.2	Drought Hazard Profile	20
3.2.1	Location of Drought Hazards in Colorado	22
3.2.2	Monitoring Drought in Colorado	24
3.2.3	Drought Indicators Modernization	28
3.2.4	Drought History in Colorado	28
3.2.5	Other Drought Implications in Colorado	51
3.3	Assessing Vulnerability by Jurisdiction	53
3.3.1	Vulnerability Based on Local and State Risk Assessment	55

3.3.2	Jurisdictions Most Threatened and Most Vulnerable to Damage or Loss	57
3.3.3	Process Used to Analyze Information from Local Mitigation Plans	64
3.3.4	Changes in Development Patterns.....	65
3.4	Assessing Vulnerability of State Facilities.....	70
3.4.1	Types of State Owned/Operated Facilities	71
3.5	Estimating Potential Losses by Jurisdiction.....	72
3.5.1	Overview and Analysis of Potential Losses	72
3.5.2	Potential Losses Based on Estimates in Local Risk Assessments.....	83
3.5.3	Impacts on Losses from Changes in Development	84
3.5.4	Estimating Potential Losses of State Facilities.....	84
4	MITIGATION STRATEGY	90
4.1	Hazard Mitigation Goals	90
4.1.1	Description of State Mitigation Goals.....	90
4.1.2	Reassessment of Goals for Validity or Need for Revision	90
4.2	State Drought Mitigation Capability Assessment.....	91
4.2.1	Introduction.....	91
4.2.2	Pre-disaster Hazard Management Policies, Programs, Capabilities.....	92
4.2.3	Post-disaster Hazard Management Policies, Programs, Capabilities	93
4.2.4	State Policies Related to Development in Drought Prone Areas	96
4.2.5	State Funding Capabilities for Drought Hazard Mitigation Projects	97
4.2.6	Changes in Hazard Management Capabilities of the State	97
4.3	Local Capability Assessment	98
4.3.1	Local Mitigation Policies, Programs, and Capabilities.....	98
4.3.2	Effectiveness of Local Mitigation Policies, Programs, and Capabilities	101
4.4	Mitigation Actions	103
4.4.1	Identification of Actions under State Consideration	104
4.4.2	Progress in Statewide Mitigation Efforts	121
4.4.3	Evaluation and Selection of Actions and Activities.....	127
4.4.4	Prioritization of Actions and Activities.....	127
4.4.5	Contribution of Each Activity to Overall State Drought Mitigation Strategy	129

4.4.6	Integration of Local Plans into Mitigation Strategy	130
4.5	Funding Sources.....	133
4.5.1	Identification of Existing Federal, State, Local Funding Sources	133
4.5.2	Identification of Potential Federal, State, Local Funding Sources	138
4.5.3	Sources of Funding Used to Implement Previous Mitigation Activities	140
5	COORDINATION OF LOCAL MITIGATION PLANNING.....	143
5.1	Local Funding and Technical Assistance	143
5.1.1	Description of State Process to Support Local Plan Development	143
5.2	Local Plan Integration.....	146
5.2.1	Process and Timeframe to Review Local Plans	146
5.2.2	Process and Timeframe to Coordinate and Link Local Plans to State Mitigation Plan	147
5.3	Prioritizing Local Assistance	147
5.3.1	Description of Criteria for Prioritizing Planning and Project Grants	147
5.3.2	Cost-Benefit Review of Non-Planning Grants	148
5.3.3	Criteria Regarding Areas of High Risk and Intense Development Pressures.....	148
6	PLAN MAINTENANCE PROCESS.....	149
6.1	Monitoring, Evaluating and Updating the Plan.....	149
6.1.1	Method and Schedule for Monitoring Plan.....	149
6.1.2	Method and Schedule for Evaluating Plan.....	150
6.1.3	Method and Schedule for Updating Plan	151
6.1.4	Evaluation of Methods, Schedule, Elements, and Processes Identified in Previous Plan	151
6.2	Monitoring Progress of Mitigation Activities	152
6.2.1	Monitoring Mitigation Measures and Project Closeouts	152
6.2.2	Reviewing Progress on Achieving Goals in Mitigation Strategy	152
6.2.3	Changes in System for Tracking Mitigation Activities.....	152
6.2.4	System for Reviewing Progress on Implementing Activities and Projects of Mitigation Strategy	153
6.2.5	Implementation of Previously Planned Mitigation Actions	153

Annexes

Annex A – Drought Response Plan

Annex B – Drought Vulnerability Assessment Technical Information

Annex C – Climate Change Implications

Annex D – Drought Monitoring Indices

Appendices

Appendix A – Drought Mitigation and Response Planning Committee

Appendix B – Actions Taken to Reduce Drought Impacts in Previous Droughts

Appendix C – Drought Mitigation Capabilities Summary

Appendix D – References

Appendix E – Definitions and Acronyms

Executive Summary

The Colorado Drought Mitigation and Response Plan (Plan) was developed to provide an effective and systematic means for the State of Colorado to reduce the impacts of water shortages over the short and long term. The Plan outlines a mechanism for coordinated drought monitoring, impact assessment, response to emergency drought problems, and mitigation of long term drought impacts. There are three major components of the plan: mitigation, response and vulnerability assessment. The mitigation component of the Plan conforms to the standard and enhanced state hazard mitigation planning requirements of the Disaster Mitigation Act of 2000 and serves as the Base Plan. Included is a description of the process used to prepare the Plan and a profile of the drought hazard in Colorado, including the nature of impacts and probability of occurrence. A detailed vulnerability assessment discusses the past and potential impacts to Colorado's economy, environment, state assets, and water providers. The vulnerability assessment is covered in detail in Annex B, and summarized in Sections 3.4 and 3.5 of the Plan. The mitigation strategy outlines the goals of the Plan and specific action items intended to meet those goals. Many of these mitigation actions are ongoing and can occur during drought and non-drought times. A capability assessment describes the State's plans, policies, and procedures in place that already help manage and reduce drought impacts. The Plan describes funding sources that can be used to implement local mitigation projects and plans and a description of the process for implementation, monitoring and evaluating the Plan.

The response component of the Plan is detailed in Annex A and includes monitoring, assessment, and response. This Annex guides State and partner agency response actions during times of drought. Monitoring is ongoing and accomplished by regular meetings of the Water Availability Task Force (WATF). This task force is comprised of Colorado's water supply specialists from state, local, and federal governments, as well as experts in climatology and weather forecasting. This task force monitors snowpack, precipitation, reservoir storage, and streamflow and provides a forum for synthesizing and interpreting water availability information. When the WATF determines that drought conditions are reaching significant levels the Governor is notified and activation of the Plan is recommended.

When Annex A is activated, assessment begins with activation of the relevant Impact Task Forces (ITFs). These task forces convene on an as needed basis to determine existing or potential impacts within specific sectors. Impact Task Forces include Municipal Water, Agricultural Industry, Wildlife, and Energy. Assessment coordination is handled by the Drought Task Force. This task force is comprised of directors from the Departments of Natural Resources, Agriculture, Public Safety, and Local Affairs, and chairpersons of the WATF and the Impact Task Forces. They review reports from the WATF and ITFs, aggregate impact assessments and projections, evaluate overall conditions, develop recommendations for drought response, and make timely reports to leadership, the media, the response agencies, and others. The response process consists of coordinated drought response activities amongst the lead state agencies under leadership of the Governor and recommendations of the ITFs.

1 PREREQUISITE

1.1 Adoption by the State

1.1.1 Formal Adoption by the State

Adoption by the Office of the Governor empowers the Colorado Water Conservation Board (CWCB) and the Colorado Division of Homeland Security and Emergency Management's Office of Emergency Management (DHSEM) to execute their responsibilities with respect to disaster preparedness, response, recovery, and mitigation. The Drought Mitigation and Response Plan (hereinafter referred to as the Plan or Drought Plan; the mitigation component only is referred to as the Base Plan) was reviewed and formally approved by the board of the CWCB in September 2018. As an annex to the State of Colorado Hazard Mitigation Plan (SHMP), this Plan is on a five-year update cycle and will be re-adopted by the Governor each cycle.

1.1.2 Assurance of Continued Compliance with Federal Requirements

This Plan was prepared pursuant to the requirements of the Disaster Mitigation Act of 2000 (DMA or DMA 2000) (Public Law 106-390) and the implementing regulations set forth by the Interim Final Rule published in the Federal Register on February 26, 2002 (44 CFR §201.6) and finalized on October 31, 2007. (hereafter, these requirements and regulations will be referred to collectively as the Disaster Mitigation Act). While the Disaster Mitigation Act emphasized the need for mitigation plans and more coordinated mitigation planning and implementation efforts, the regulations established the requirements that local hazard mitigation plans must meet in order for a state jurisdiction to be eligible for certain federal disaster assistance and hazard mitigation funding under the Robert T. Stafford Disaster Relief and Emergency Act (Public Law 93-288).

The State of Colorado assures it will comply with all applicable federal statutes and regulations in effect with respect to the periods for which it receives grant funding in compliance with 44 CFR Part 13.11(c). The State will amend the SHMP whenever necessary to reflect changes in state or federal laws and statutes, as required in 44 CFR Part 13.11(d). The adoption of this SHMP demonstrates the State of Colorado's commitment to fulfilling the mitigation objectives in the SHMP and authorizes the agencies identified in the SHMP to execute their responsibilities. While not a federal requirement, the Drought Mitigation Plan complies with and adheres to the Emergency Management Accreditation Program, or EMAP, standard. The EMAP is a voluntary review process for state and local emergency management programs. Accreditation is a means of demonstrating, through self-assessment, documentation and peer review, that a program meets national standards for emergency management programs. The Drought Response Plan Annex (Annex A) has been designed to comply with the National Response Framework (NRF) and National Incident Management System (NIMS) protocols.

According to Federal Emergency Management Agency (FEMA) state hazard mitigation planning guidance which became effective in 2016, climate change consideration must be integrated into

state hazard mitigation plan updates. What this means for Colorado plans, including this Drought Mitigation and Response Plan update, is that climate change effects must be discussed and addressed with regards to the hazard/s in question. Specifically, plans must incorporate “a summary of the probability of future hazard events that includes projected changes in occurrences for each natural hazard in terms of location, extent, intensity, frequency, and/or duration; and considerations of changing future conditions, including the effects of long-term changes in weather patterns and climate on the identified hazards” (FEMA, 2016). The Drought Plan has addressed climate change since the 2010 update, and continues to in the 2018 update. Another change in federal requirements is the requirement for state hazard mitigation plans to be updated every three years. Since 2014 the requirement is every five years due to a FEMA policy change.

2 PLANNING PROCESS

2.1 Documentation of the Planning Process

2.1.1 Description of Plan Preparation Process

The process established for this planning effort is based on the Disaster Mitigation Act of 2000 (DMA) planning and update requirements and FEMA's associated guidance for state hazard mitigation plans. The Drought Mitigation and Response Planning Committee (DMRPC), convened by CWCB, followed FEMA's recommended four phase mitigation planning process:

- Identify and organize available resources
- Identify hazards and assess risk
- Develop a mitigation strategy and mitigation plan
- Implement the Plan and monitor progress

The Colorado statewide mitigation planning program is designed to coordinate the efforts of many state agencies and organizations in mitigation planning and programming on an ongoing basis. It is also intended to actively promote and coordinate mitigation planning and programming by local jurisdictions. The DHSEM took the lead on the 2018 update of the State of Colorado Hazard Mitigation Plan umbrella document. The original umbrella document was created in 2001, was updated in 2007, 2010, 2013 and 2018 and was designed as a way to tie together various hazard-specific documents that had been developed over the previous years.

The DHSEM coordinated with other agencies on concurrent state planning and risk management efforts, including the Drought Plan and Flood Hazard Mitigation Plan as stand-alone hazard specific annexes to the SHMP. CWCB's Office of Water Conservation and Drought Planning took the lead on the 2007, 2010, 2013 and 2018 updates to the Drought Plan. The 2010 update cycle was a comprehensive revision and will be referred to as such in the remainder of the Plan. A consulting firm, Wood Environment and Infrastructure Solutions, Inc (Wood)) was selected to coordinate and facilitate the 2018 update process to the Plan.

Evolution of the Colorado Drought Mitigation and Response Plan

Drought planning has been evolving in Colorado since the late 1970s. During the 1976-1977 drought Colorado's government assumed a lead role in coordinating federal, state, and local government response and promoted statewide public conservation practices. Conclusions from that effort include:

- the diversity, complexity, and ambiguity of drought impacts blurred identification of alternative actions available to decision makers;
- a systematic definition of problem areas and potential solutions was essential to effective government response, so under and overreactions could be minimized;

- both physical and social impact data were needed;
- knowledge of the location, kind, and degree of water shortage provides better identification of impacts;
- timely and accurate data on impact development were crucial to effective response;
- impact identification provides the framework for governmental and public adjustments;
- integration of response by private, public, and governmental entities was needed;
- as the drought intensifies, the maintenance of established channels of responsibility, with emphasis on water conservation and planning, becomes increasingly important;
- as impact problems and local needs become more serious, better management and integration of effort also intensifies; and
- should drought intensify to the point where impacts exceed the State's response capabilities, an effective state program will help facilitate a request for federal assistance.

Governor Lamm took action in February 1981 to deal with potential drought situations. His memorandum of February 5 required the accomplishment of the following tasks:

1. Develop and activate a data collection and assessment system which will identify the potential impacts of a drought and track their occurrence and intensity. At some point, this assessment process may result in a recommendation that a drought emergency be proclaimed.
2. Develop a drought emergency response plan which would be activated by a drought emergency decision. This task includes cataloguing existing state and federal response and relief programs and authorities, and developing recommendations to meet additional needs.

The initial Colorado Drought Response Plan was completed in 1981, and revised in 1986, 1990, 2001, and 2002. In 1981, it was one of three state drought plans in the nation. Since that time, the Plan has been widely distributed and received interest both nationally and internationally and has served as a model for other states. Mitigation was first introduced into the Plan's 2001 update and since that time the Plan has been both a mitigation and response plan. Mitigation includes actions that could be taken pre-drought that would lessen impacts when a drought occurs. It also includes "incident" mitigation, which are short-term actions taken during a drought meant to reduce disasters losses or impacts. The mitigation component was further expanded in 2007 with the development of a companion document "Updated Information Provided in Support of the 2002 Colorado Drought Mitigation and Response Plan." This was developed to align the Plan's mitigation element with the standard state mitigation planning requirements of the DMA, thus making it consistent with the SHMP and placing it on the same update cycle as that plan (required every five years). The SHMP update of 2018 was done in accordance with FEMA standard and enhanced plan requirements.

The Colorado Drought Mitigation and Response Plan was developed to provide an effective and systematic means for the State of Colorado to reduce the impacts of water shortages over the short or long term. The Plan outlines a mechanism for coordinated drought monitoring, impact assessment, response to emergency drought problems, and mitigation of long-term drought impacts. The Plan does not create a new government entity to deal with drought, but provides a

means for coordinating the efforts of public and private entities that would be called upon to deal with drought impacts.

There are four components of the Plan: monitoring, assessment, response, and mitigation. monitoring is ongoing and accomplished by regular meetings of the Water Availability Task Force (WATF). This task force is comprised of Colorado's water supply specialists from state, local, and federal governments, as well as experts in climatology and weather forecasting. This task force monitors snowpack, precipitation, reservoir storage, and streamflow and provides a forum for synthesizing and interpreting water availability information. When the WATF determines that drought conditions are reaching significant levels the Governor is notified and activation of the Plan is recommended. When the Plan is activated, the first step is impact assessment. Assessment begins with activation of the relevant Impact Task Forces (ITFs). These task forces convene to determine impacts within specific sectors which effect the environment and economy. The original Impact Task Forces included Municipal Water, Wildfire Protection, Agricultural Industry, Tourism, Wildlife, Economic Impacts, Energy Loss, and Health. These task forces have been activated as needed during times of drought, notably in 1989-1990, 1994, 1996, 2002, 2011 and 2018. The number and nature of the ITFs have changed over the years; the 2018 ITFs are listed and described in Annex A.

2010 Revision Planning Process

In 2010 the Plan underwent a significant revision and overhaul as part of the five-year State Plan update cycle. The major objectives that revision included:

- Updating the Plan to meet DMA 2000 and EMAP planning standards
- Merging the 2002 Response and Mitigation Plan with the 2007 companion document
- Developing a comprehensive drought hazard vulnerability assessment
- Revising and modernizing the response elements of the Plan
- Developing additional tools and resources to support local drought planning efforts
- Modernizing and evaluating the indices used for drought monitoring in the State

A significant change in the 2010 document was that the response elements can be accessed in one location, Annex A Drought Response Plan. This was done so that these elements could be referenced individually when a drought occurs. The Plan outline mirrors that of the FEMA standard mitigation plan update review crosswalk for consistency with DMA 2000 planning requirements.

2013 Update Planning Process

In 2013 the Plan was updated as part of the three-year State Plan update cycle required at that time. The objectives of the update included:

- Reconvening and updating the DMRPC to provide input to the 2013 planning process
- Meeting DMA 2000 standard state plan update requirements and EMAP planning standards
- Review, revisit, and update all sections of the Plan, highlighting changes since 2010, notably progress in mitigation actions in Chapter 4.
- Update the Vulnerability Assessment in Annex B with recently available information
- Update the hazard profile to capture the 2013 assessment of Colorado's unique climatology, including a discussion of the 2011-2013 drought
- Update the Response Plan in Annex A to reflect current procedures and lessons learned from response to the 2011-2013 drought.
- Update changes in coordination and plan maintenance procedures.

2018 Update Planning Process

In 2018 the Plan was updated as part of the five-year state plan update cycle, as required by FEMA. The objectives of the update included:

- Reconvening and updating the DMRPC to provide input to the 2018 planning process
- Meeting DMA 2000 standard and enhanced state plan update requirements and EMAP planning standards
- Review, revisit, and update all sections of the Plan, highlighting changes since 2013, notably progress in mitigation actions in Chapter 4.
- Update the Vulnerability Assessment in Annex B with recently available information
- Update changes in coordination and plan maintenance procedures.

Similar to the 2010 and 2013 revision process, the committee followed FEMA's four phase planning process and participated in three major planning meetings between November and April 2018, which are summarized in Table 1.

Table 1 Key Planning Meetings of the 2018 Update Process

Meeting	Date	Purpose
1. Kickoff	11/28/2018	Review Disaster Mitigation Act planning requirements, scope of work, and schedule Review role of DMRPC Introduce methodology to record progress of mitigation actions from 2013 Discuss data collection needs Discuss stakeholder involvement Discuss coordination with other State Plan update efforts
2. Risk Assessment & Capability Assessment	02/22/2018	Present and discuss updated risk and vulnerability assessment Discuss improvements to response Plan elements Introduce methodology for updating goals and objectives
3. Mitigation Strategy	04/05/2018	Revisit and revise goals Review and approve state mitigation criteria for evaluation and prioritization Revisit status and priority of existing mitigation actions and develop new mitigation actions

Sign in sheets and summaries of these meetings are included in a Planning Process Reference Notebook on file with the CWCB.

Several other meetings took place to foster coordination and raise awareness of the planning effort. Significant events are noted here:

- Discussion on Plan update progress at monthly WATF meetings January-August 2018.
- Several members of the DMRPC also participated in the 2018 Colorado Hazard Mitigation Plan Update meetings (February 13, April 10 and May 22).

2.1.2 Involvement in Planning Process

Drought Mitigation and Response Planning Committee

The development, implementation, and maintenance of the Drought Plan are the responsibility of the DMRPC under the leadership of the CWCB. The DMRPC is made up of representatives of the principal state agencies and organizations with authorities, responsibilities, or expertise related to drought and hazard mitigation. The committee was formed during the 2010 revision process based on membership of the existing WATF and ITFs. Specific membership is discussed in Appendix A Drought Mitigation and Response Planning Committee.

During the 2018 update process, several individuals participated on the DMRPC and provided information and assistance to promote the development of the document. Appendix A identifies those that were involved or contacted for input in the update of this Plan.

The DMRPC consists of the following agencies/entities:

State

- Colorado State University – Colorado Climate Center
- Colorado State University – Water Resources Institute
- Colorado State University – Colorado State Forest Service
- Colorado School of Mines – Colorado Geological Survey
- Department of Agriculture
- Department of Corrections
- Department of Local Affairs – Division of Local Government
- Department of Public Safety –
 - Division of Homeland Security & Emergency Management - Office of Emergency Management
 - Division of Fire Prevention and Control
- Department of Local Affairs – Division of Local Government
- Department of Military and Veterans Affairs
- Department of Natural Resources – Colorado Water Conservation Board (**lead agency**)
- Department of Natural Resources – Colorado Parks and Wildlife
- Department of Natural Resources – Division of Water Resources
- Department of Natural Resources – State Land Board
- Department of Natural Resources – State Engineer’s Office
- Department of Public Health and Environment
- Department of Regulatory Affairs – Public Utilities Commission
- Colorado Energy Office
- Governor’s Office of State Planning and Budgeting
- Governor’s Office of Economic Development and International Trade – Tourism Office
- University of Colorado at Boulder

Federal

- U.S. Bureau of Reclamation
- U.S. Department of Agriculture - Natural Resources Conservation Service
- National Oceanic and Atmospheric Administration – National Integrated Drought Information System (NIDIS)
- U.S. Geological Survey

Local

- City of Aurora
- City of Thornton
- Northern Colorado Water Conservancy District
- Denver Water
- Colorado Springs Utilities

Other

- National Drought Mitigation Center – University of Nebraska
- National Center for Atmospheric Research
- The Nature Conservancy
- University Corporation for Atmospheric Research
- Western Water Assessment

The DMRPC members were involved in the planning process through:

- Attending and participating in DMRPC meetings
- Providing available data requested
- Reviewing and commenting on Plan drafts and obtain agency buy-in for relevant sections
- Assist with public input/stakeholder process

2.1.3 Agency Involvement in Plan Preparation Process

During the update to the Drought Mitigation Plan, several agencies provided input and technical expertise. Several of the agencies listed previously provided data and information to support the Plan’s vulnerability assessment. Documentation of their involvement in the 2018 update process is included in Appendix A and in the Planning Process Reference Notebook on file with the CWCB. Agencies were provided a data collection worksheet designed to capture information to update the Plan. The worksheet was designed to collect agency input on changes in capabilities and funding sources since 2013. This worksheet also solicited input on the status of existing mitigation actions outlined in the 2013 Plan to determine which items had been completed, deleted, deferred, or were ongoing. DMRPC members filled out these questionnaires and worksheets, and the information directly contributed to the preparation of this Plan. During 2018 specific agencies and organizations with relevant data were contacted through email and phone to provide updated information.

Federal agencies play a key partnership role in drought monitoring and mitigation in Colorado. The NRCS modernized the Surface Water Supply Index (SWSI) for Colorado as part of the 2013 planning effort and developed a summary of this effort that is included in the 2013 Annex D Drought Monitoring Indices. Parallel to this effort the Colorado Climate Center analyzed the validity of the Colorado Modified Palmer Drought Index as a drought indicator and prepared input for Annex D as part of the 2010 revision.

2.1.4 Description of Plan Review and Analysis

During the 2018 update, the DMRPC updated each of the sections of the previously approved plan to include new information and improve organization and formatting of the Plan’s contents. The DMRPC analyzed each section using FEMA’s state plan update guidance to ensure that the Plan met requirements. Table 2 briefly summarizes how each section of the Plan was reviewed and analyzed to capture changes that occurred since the previous plan was approved. More detailed

documentation on revision methodology and process is provided at the beginning of each Plan section.

Additionally, the DMRPC reviewed and provided comment on the draft revised Plan. The document was shared electronically through a web-based collaboration site. Comments were solicited during a two-week period in June.

2.1.5 Indication of Section Revisions

As part of the 2018 update, every section was updated with new or revised information. Table 2 shows which sections of the Drought Mitigation Plan were revised with highlights of what is new.

Table 2 Highlights of Changes in the 2018 Update

Plan Element	Highlights of Update
Prerequisite Adoption by the State	<ul style="list-style-type: none"> Language revised for 2018 2018 approval by CWC Board
Planning Process Documentation of the Planning Process Coordination Among Agencies Program Integration	<ul style="list-style-type: none"> Extensive planning effort documented Multi-agency outreach and coordination and changes in coordination captured Coordination with the 2018 update of the Colorado State Hazard Mitigation Plan
Risk Assessment Identifying Drought Hazards Profiling Drought Hazards Assessing Vulnerability by Jurisdiction Assessing Vulnerability of State Facilities Estimating Potential Losses by Jurisdiction	<ul style="list-style-type: none"> Incorporated 2011-2013 drought info. Revised with latest climate science and incorporation of paleo hydrology analysis Detailed Vulnerability Assessment report in Annex B updated where available data permitted to assess drought vulnerability by various impact sectors; combined vulnerability table and map. Includes EMAP consequence analysis updated to latest standards Refer to Annex B summary of changes
Mitigation Strategy Hazard Mitigation Goals State Capability Assessment Local Capability Assessment Mitigation Actions Funding Sources	<ul style="list-style-type: none"> Goals reassessed and revised to reflect 2018 priorities Mitigation Action table updated with status and progress Actions revised and prioritized New actions developed Comprehensive capability assessment review Funding sources revision
Coordination of Local Mitigation Planning Local Funding and Technical Assistance Local Plan Integration Prioritizing Local Assistance	<ul style="list-style-type: none"> Information revised with changes and assistance provided in past three years
Plan Maintenance Process Monitoring, Evaluating, and Updating the Plan Monitoring Progress of Mitigation Activities	<ul style="list-style-type: none"> Process more clearly defined and revised to reflect 2018 process

Plan Element	Highlights of Update
Drought Response Plan Annex	<ul style="list-style-type: none"> • Minor edits to reflect updated agency names and Impact Task Force representatives • Minor updates to the declaration procedures

2.2 Coordination among Agencies

2.2.1 Involvement of Federal and State Agencies

Federal and state agencies were integrally involved in the development of the information provided in the revision to this Plan and the umbrella SHMP. The agencies are identified in the previous sections with specific contacts identified in Appendix A. Both federal and state agencies were represented on the DMRPC and participated in meetings previously listed. As indicated, these meetings served as a means to identify federal and state requirements, assign roles and responsibilities to obtain pertinent information, provide for the exchange or transmission of the information, and specifically provide insight and data pertinent to the risk assessment and mitigation strategies. In addition, the DMRPC provided a mechanism for federal and state agencies to review the draft Plan and provide comments that were incorporated into the final document.

2.2.2 Involvement of Interested Groups

During the 2018 planning update process other groups and organizations were identified that may have an interest in the Plan or could participate as stakeholders in the process. Stakeholders could participate in various ways, either by contributing input at meetings, being aware of planning activities through an email group, providing information to support the effort, or reviewing and commenting on the draft Plan. The following groups in the list that follows were identified as interested groups. Specific contacts were identified with each group to solicit input on the draft Plan. Those that provided feedback or comments are noted with an asterisk. Many of these agencies provided feedback that improved the accuracy and content of the final draft. Others may be considered for additional involvement or outreach in the future.

Other Federal Agencies

- U.S. Geological Survey (USGS)
- National Oceanic and Atmospheric Association (NOAA)
- National Renewable Energy Laboratory
- USDA – Farm Service Agency (FSA)
- USDA – Risk Management Agency (RMA)
- USDA – U.S. Forest Service (USFS)
- USDA – Natural Resource Conservation Service (NRCS)*
- FEMA

- US Army Corps of Engineers (USACE)
- US Department of the Interior (USDOI) – Bureau of Land Management (BLM)
- USDOI – National Park Service (NPS)
- USDOI – Fish and Wildlife Service (FWS)
- USDOI – Bureau of Indian Affairs (BIA)
- USDOI – Bureau of Reclamation (USBR)

Other Agricultural Organizations

- Co Farm Bureau Federation
- Co Cattlemen’s Association*

Wildland Fire/Forest Health

- Colorado Fire Chiefs Association
- Front Range Fuels Treatment Partnership
- Colorado Bark Beetle Cooperative
- Northern Front Range Mountain Pine Beetle Working group
- Culebra Coalition (southern Front Range)

Other Local and State Government

- Colorado Geological Survey*
- Colorado Parks and Wildlife*
- Colorado Department of Corrections*
- Colorado Municipal League
- Colorado Counties Inc.
- Colorado Emergency Management Association
- Western Governors’ Association*
- Dept. of Labor and Employment

Utility Providers

- Xcel Energy
- Tri-State Energy
- Northern Colorado Water Conservation District
- Colorado River Water Conservation District
- Colorado Watershed Assembly
- Colorado Springs Utilities
- Denver Water
- Aurora Water

Recreation/Tourism

- Chambers of Commerce
- Colorado Ski Country USA

Conservation Organizations

- Colorado Wildlife Federation
- Colorado Audubon Society
- Colorado Trout Unlimited
- Defenders of Wildlife*
- Ducks Unlimited
- Playa Lakes Joint Venture
- Pheasants Forever
- The Nature Conservancy
- Western Resource Advocates*

Other Organizations

- National Drought Mitigation Center (NDMC)*
- Water Commissioners
- Western Water Assessment*
- Colorado Renewable Energy Society
- Associated General Contractors of Colorado
- Colorado Watershed Assembly
- University of Colorado Boulder

Public Review

Before finalizing the 2018 update the draft Plan was made available to the public for review. The Public Review Draft of the Plan was posted on the CWCB website for a 30-day comment period between July 24 - August 24, 2018. A notice was distributed through a CWCB email group that included the Water Availability Task Force. Some minor final state agency feedback was received but no public comments.

2.2.3 Changes in Coordination

Changes in coordination have occurred over the evolution of the Drought Plan. This Plan was originally developed and maintained by the Office of Emergency Management (formerly the Division of Emergency Management). The Plan's lead agency became the DNR-CWCB in 2002 and has continued to be since then.

As a result of the comprehensive analysis done by CWCB through the Statewide Water Supply Initiative (SWSI) following the 2002-2003 drought, as well as work completed by the Interbasin

Compact Committee (IBCC) and the Basin Roundtables (BRTs) it became clear that the State's current water trajectory is neither desirable nor sustainable. In May 2013 Governor Hickenlooper issued Executive Order D 2013-5, which directed CWCB to prepare a water plan for Colorado. The Water Plan is a framework to guide future decision making and to address water challenges with a collaborative, balanced, and solutions-oriented approach. The goals of the plan are to meet the water supply gap, defending Colorado's compact entitlements, improving regulatory processes and exploring financial incentives – all while honoring Colorado's water value and ensuring the state's water resources are protected and available for generation to come. Colorado's Water Plan was completed in 2015. The efforts put forth in the Water Plan will help support many of the mitigation actions previously identified in the Drought Plan.

Colorado has been on the forefront of statewide resiliency planning since the 2013 flood disaster and has developed its own Resiliency Framework to achieve cross-sector resilience planning. The Framework outlines guiding principles and tools for community stakeholders and calls for a collective commitment to partnership and action. The Framework provides guiding principles around resiliency for the state. It defines the structure through which the state will support local agencies and community groups as they identify and implement their own resiliency actions. Risks and vulnerabilities are analyzed, and specific strategies are identified that will strengthen the state's capacity to adapt and support local communities on their path toward resiliency. Information from the Framework was used to inform the 2018 Drought Mitigation Plan update. For example, the prioritization criteria developed for the Framework has been adopted and incorporated into the update of this plan as well as plan updates under the SHMP umbrella.

The Colorado Climate Plan which was initially completed in 2015 and updated in 2018, provides statewide policy recommendations and actions to mitigate greenhouse gas emissions and to increase Colorado's level of preparedness. The water section of the Climate Plan builds on the policies and strategy recommendations that are put forth in the state Water Plan. Some of the strategies and policy recommendations as they relate to this Plan include the following, "promote and encourage water efficiency and/or conservation at the local and state agency level, support water sharing agreements where feasible and cost effective, and promote and encourage drought preparedness through comprehensive drought planning and mitigation implementation."

2.3 Program Integration

2.3.1 Integration of Mitigation Planning with other State Planning Efforts

This Plan has been an integral part of the Colorado Hazard Mitigation Plan since 2007. The State Hazard Mitigation Plan was updated simultaneously as the update for this Plan and is directly integrated in to the State Plan in several ways, including planning process, risk assessment, capabilities, and actions, and is formally included as a supporting document to the State Plan. Portions of information included in drought hazard profile in the SHMP are taken directly from this plan update, contributing to the profile of the drought hazard in Colorado and analysis of the nature of impacts and probability of drought occurrence. Other plans that this Plan revises,

complements, and integrates portions of include the CWCB's 2004 and 2007 Drought and Water Supply Assessments (DWSA). Annex A of this plan also complements and works in concert with the State Emergency Operations Plan.

The State of Colorado is committed to the multi-agency mitigation strategy outlined in this Plan. Two goals listed in this Plan in Section 4.1 are related to this:

- Coordinate and provide technical assistance for state, local and watershed planning efforts
- Continue to develop intergovernmental and interagency stakeholder coordination

Section 4.4 Mitigation Actions provides additional detail on actions designed to improve coordination and integration efforts. Details on related planning programs and initiatives are also discussed in Section 4.2 State Capability Assessment.

The following statewide planning efforts have included collaboration through the incorporation of the findings and recommendations from one plan to another:

- Colorado River Water Availability Study (Phase I and II)
- Colorado Inter Basin Compact Committee planning efforts
- Basin Needs Decision Support System
- Statewide Water Supply Initiative (various reports)
- Colorado Energy Assurance Emergency Plan
- Colorado Forest Resource Assessment Plan
- Local multi-hazard mitigation plans
- Local drought management plans
- Local water conservation plans
- Colorado State Water Plan
- Colorado Climate Plan
- Colorado Hazard Mitigation Plan (2018 Update)

Specific action items related to future integration are noted in Section 4.4. This Plan is a related component of the Colorado River Water Availability Study phases and other water supply planning initiatives being spearheaded by the CWCB.

2.3.2 Integration of Mitigation Planning with FEMA Mitigation Programs and Initiatives

Mitigation planning associated with this document has strived to include the integration of other FEMA mitigation programs and initiatives. The mitigation component of the Plan conforms to the standard State Hazard Mitigation planning requirements of the Disaster Mitigation Act of 2000 based on the FEMA Bluebook Multi-Hazard Mitigation Planning Guidance (2004, revised in 2008) and 2015 FEMA State Mitigation Plan Review Guide. FEMA does not have specific programs aimed at mitigating drought disasters. DHSEM is the primary state coordinating agency

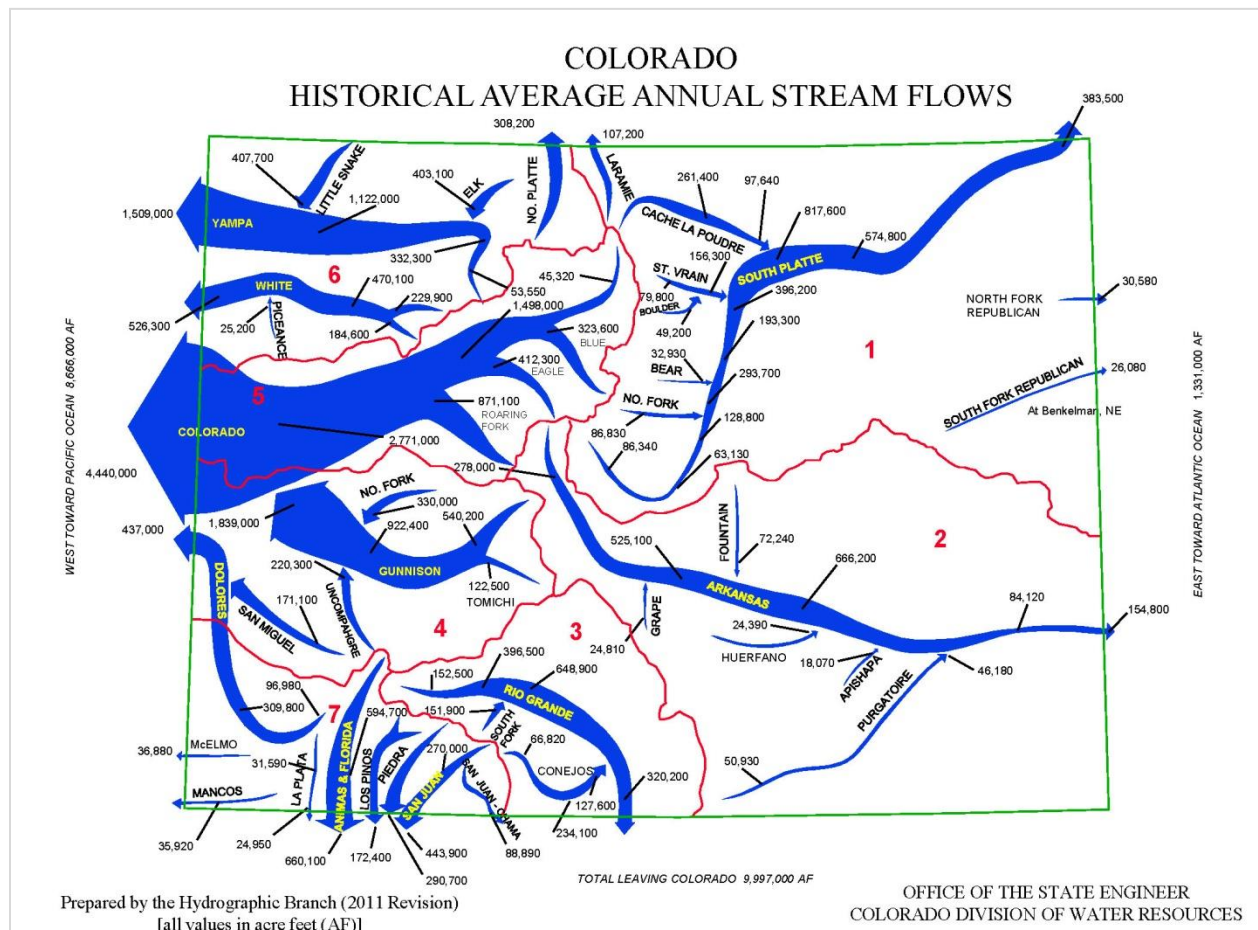
for all local emergency operation plans and hazard mitigation plans. The division has the primary responsibility of working with local governments in developing, reviewing, and updating local hazard mitigation plans. Refer to the 2018 Colorado SHMP for further description of the integration of FEMA mitigation programs and initiatives in Colorado.

3 RISK ASSESSMENT

3.1 Identifying the Drought Hazard

Colorado gets new water supplies from only one source: precipitation, in the form of rain, hail, or snow. Colorado gets all of its water from precipitation because there are no major rivers that flow into Colorado (McKee et al., 1999). There are several major river basins originating in the Colorado Rockies, which flow out of the State (see Figure 1), providing water to much of the southwestern United States, and contributing to the Missouri and Mississippi rivers as well. Thus, Colorado earns its title as “the Mother of Rivers.” The water flowing out of the state fluctuates during wet and dry years, as depicted in Figure 2, which is excerpted from the Colorado Water Plan.

Figure 1 Colorado Historic Average Annual Streamflow (acre-feet)



Source: Office of the State Engineer – Colorado Division of Water Resources

Figure 2 Colorado Summary of Observed Wet and Dry Surface Water Hydrology



Source: Colorado Water Plan 2015

Although the source of Colorado's water supplies is precipitation, it is difficult to use directly in that form. Instead, water is often stored in one of five forms of usable water:

- snowpack (SN), used directly for recreation, although it also serves as a large storage of water supplies;
- streamflow (ST), used for recreation, habitat, irrigation and municipal water supplies, as well as meeting interstate compact obligations;
- reservoir water (RW), used similarly to streamflow;

- soil moisture (SM), used by natural vegetation and agriculture; and
- groundwater (GW) used for irrigation and municipal water supplies.

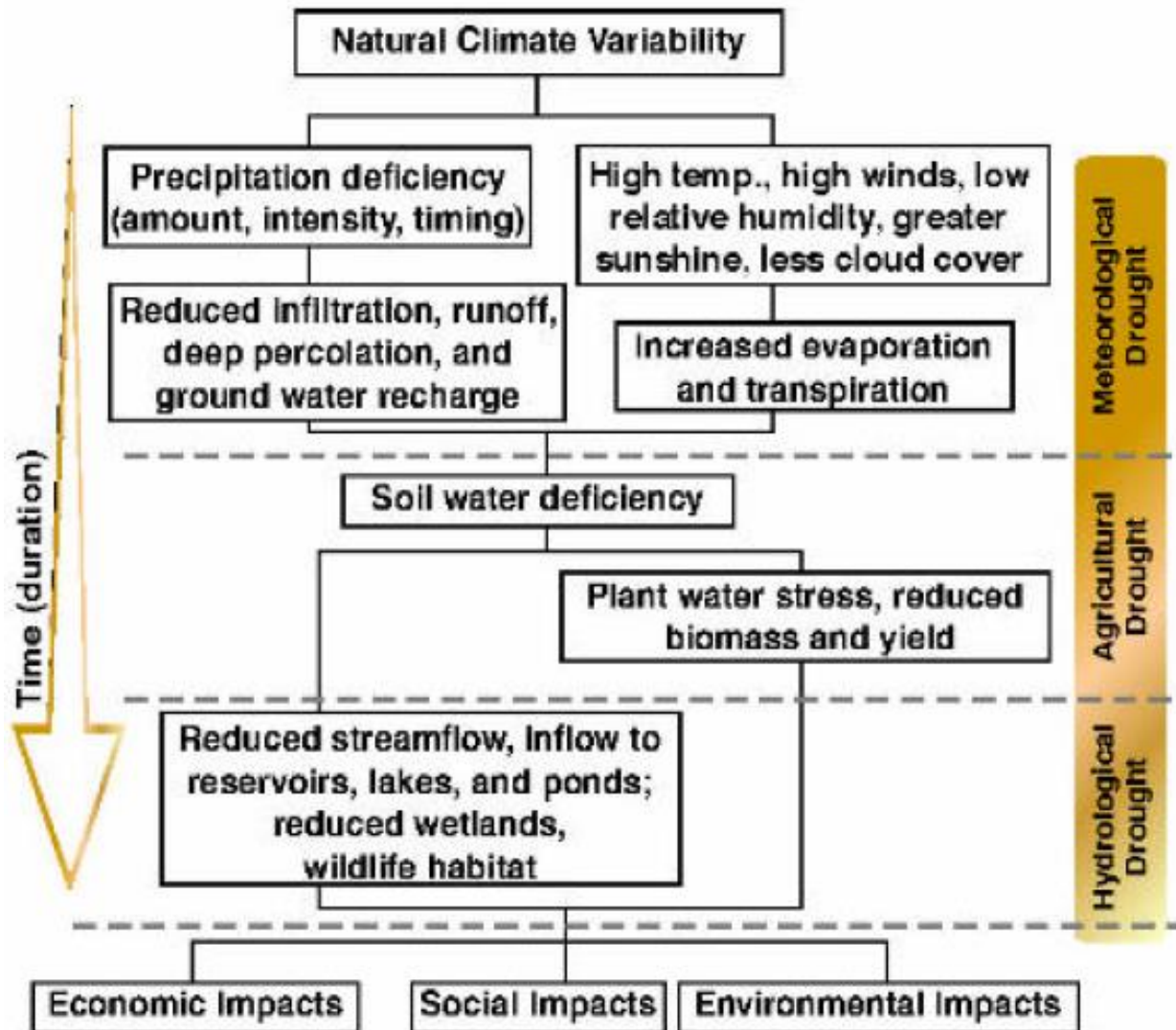
The amount of time it takes for precipitation to turn into a usable form of water can vary greatly. Precipitation can add to soil moisture or snowpack almost immediately. However, there can be delays of several days, weeks, or months before precipitation adds to the water levels in streams, reservoirs, or groundwater aquifers. During those periods, some precipitation is lost to evaporation as well as wind and dust-on-snow enhancing sublimation. Therefore, in warmer months with less precipitation such as summer, brief rains that fall will add little or no water to the usable water supply.

Drought is a complex and a gradual phenomenon in Colorado. Although droughts can be characterized as emergencies, they differ from other emergency events in that most natural disasters, such as floods or forest fires, occur relatively rapidly and afford little time for preparing for disaster response. Droughts typically occur slowly, over a multi-year period, and it is often not obvious or easy to quantify when a drought begins and ends. Drought can often be defined regionally based on its effects:

- **Meteorological** drought is usually defined by a period of below average precipitation.
- **Agricultural** drought occurs when there is an inadequate water supply to meet the needs of the state's crops and other agricultural operations such as livestock.
- **Hydrological** drought is defined as deficiencies in surface and subsurface water supplies. It is generally measured as streamflow, snowpack, and as lake, reservoir, and groundwater levels.
- **Socioeconomic** drought occurs when a drought impacts health, well-being, and quality of life, or when a drought starts to have an adverse economic impact on a region.

Figure 3 relates these definitions to drought duration and potential impacts.

Figure 3 Causes and Impacts of Drought



Source: National Drought Mitigation Center

3.2 Drought Hazard Profile

Drought is a natural part of the Colorado climate, due to the state's semiarid conditions. Because natural variations in climate and precipitation, it is rare for all of Colorado to be deficient in moisture at the same time. However, single season droughts over some portion of the State are quite common; these are sometimes referred to as flash droughts. According to NOAA flash drought refers to relatively short periods of warm surface temperature and anomalously low and rapid decreasing soil moisture that can usually be classified into two categories: heat wave and precipitation deficit flash droughts. Hydrologic conditions constituting a drought for water users in one location may not constitute a drought for water users elsewhere, or for water users that have

a different water supply. Individual water suppliers may use different criteria, such as rainfall/runoff, amount of water in storage, or expected supply from a water wholesaler, to define their water supply conditions. The drought issue is further compounded by water rights specific to a state or region. Water is a commodity possessed under a variety of legal doctrines. (See the Water Rights discussion in Section 3.2.5, and Chapter 4 of the Drought Vulnerability Assessment Technical Information document).

Drought impacts are wide-reaching and may come in different forms, such as economic, environmental, and/or societal. The most significant impacts associated with drought in Colorado are those related to water intensive activities such as agriculture, wildfire protection, municipal usage, commerce, tourism, recreation, and wildlife preservation. A reduction of electric power generation and water quality deterioration are also potential effects. Drought conditions can also cause soil to compact, decreasing its ability to absorb water, making an area more susceptible to flash flooding and erosion. A drought may also increase the speed at which dead and fallen trees dry out and become more potent fuel sources for wildfires. Drought can make trees more susceptible to insect infestations, causing more extensive damage to trees and increasing wildfire risk, at least temporarily. Trees in urban forests can also become susceptible to insects and mortality due to lack of water. An ongoing drought which severely inhibits natural plant growth cycles may impact critical wildlife habitats. Drought impacts increase with the length of a drought, as carry-over supplies in reservoirs are depleted and water levels in groundwater basins decline.

Impacts from drought can also be exacerbated due to the effects of dust settling on snow, which causes increased solar energy absorption. As a result, snowmelt takes place earlier in the season and runoff magnitudes increase. Research has shown that dust deposition has increased throughout the western United States since 1992, with the largest increases in western Colorado (Brahney et al., 2013). Rigorous sampling and analyses of dust by the Colorado Dust-on-Snow program (CODOS) and USGS show that most dust being deposited to the Colorado mountain snowpack is originating from source areas located outside of Colorado, scattered throughout the greater Colorado Plateau. Drought conditions in those dust source areas can increase the availability of dust for wind transport and, thereby, increase the dust-on-snow hazard in Colorado, even when the Colorado mountains are not experiencing drought conditions. In addition to earlier snowmelt due to dust-on-snow, runoff yields can be reduced, in some years, due to increased evapotranspiration by plants. This is caused by the plant community becoming active sooner than normal as a result of earlier snowmelt and loss of snow cover (Painter et al., 2010).

The impacts related to early runoff pose problems for many important sectors in Colorado including agriculture, recreation, tourism, and municipal water supplies. If runoff happens in a shorter timeframe, sometimes months early, it could mean a shorter season for the rafting industry and less water available for irrigation diversions in the summer. Reservoirs may also be filled to capacity during these constrained runoff periods, causing spills to be necessary. Ideally, to avoid releases of water downstream, water is captured over a longer timeframe with gradual melting of snowpack.

Alternatively, dust produced from the hardening and drying of bare soil can also be exposed as vegetative cover decreases due to extended periods of drought. The Eastern Plains of Colorado, where much of the agricultural economy exists, can suffer from dust storms originating from topsoil that is easily airborne. Entire crops can be damaged in one storm, affecting the livelihood of the farmers and ranchers.

3.2.1 Location of Drought Hazards in Colorado

No portion of the State of Colorado is immune from drought conditions. The effects of drought vary based on where in the state it occurs, when it happens, and how long the drought persists. For example, a drought in the plains of the state can greatly affect agricultural crops. A long-term drought is not needed to affect agricultural yields though. Droughts of just a few weeks during critical periods of plant development can have disastrous effects on agriculture production. Droughts that occur in the mountainous regions of the state during winter months may have great effects on the ski and tourism industry. However, drought in one area of the state may also impact other regions. Lack of winter snowfall in the mountains can eventually lead to agricultural impacts on the eastern plains due to decreased streamflows. Reduced reservoir storage from decreased runoff in the mountains leads to municipal and industrial water shortages on the Front Range. Droughts that occur in populated areas may not have direct affects to the residents, but may increase the threat of wildfire in the wildland/urban interface areas. In summary, drought is one of the few hazards with the potential to directly and indirectly impact the entire population of the State, be it from water restrictions, higher water and food prices, reduced air or water quality, or restricted access to recreational areas (McKee and Doesken, 1999).

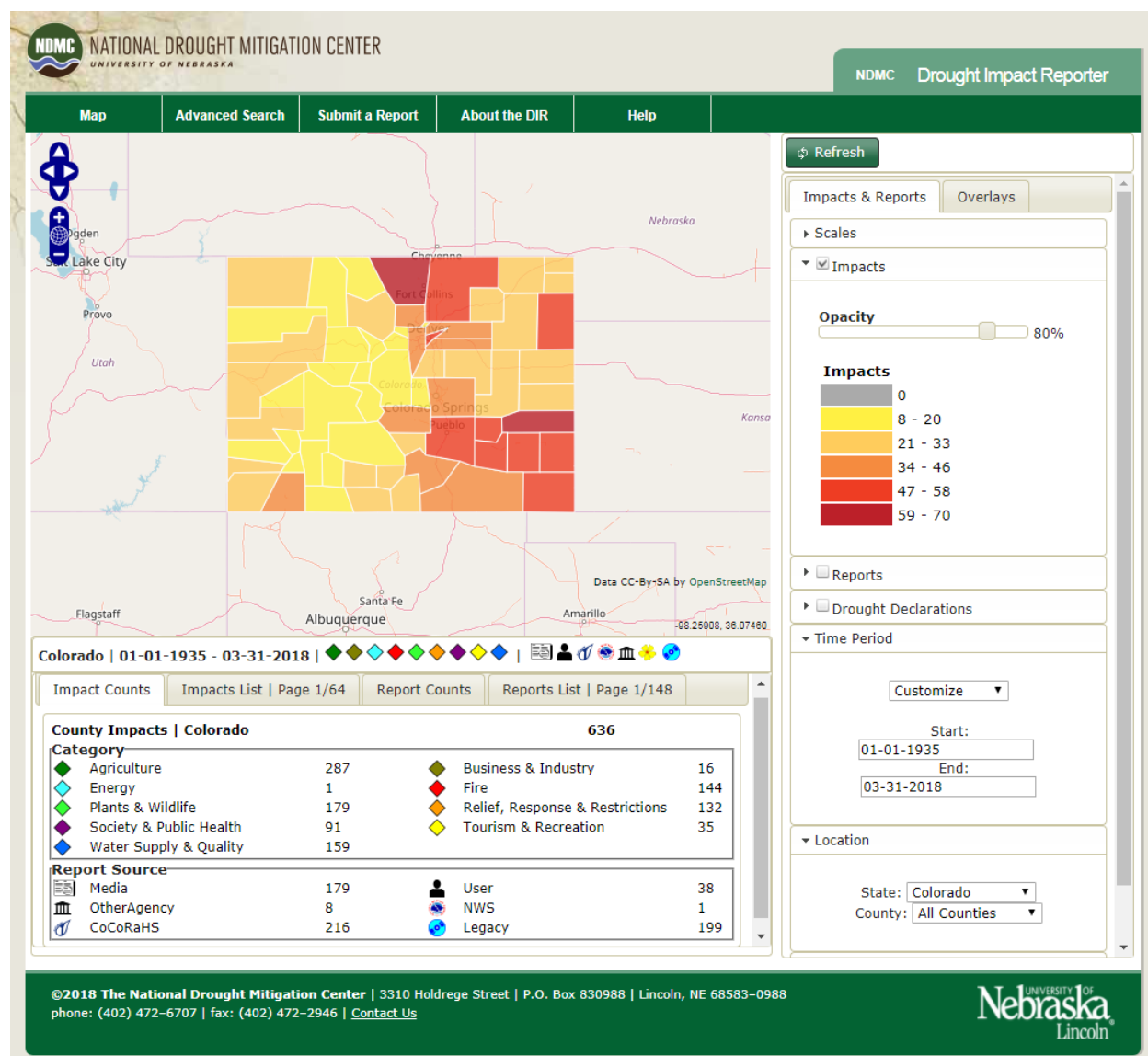
Tracking drought impacts can be difficult. The Drought Impact Reporter (Reporter) from the NDMC is a useful reference tool that compiles reported drought impacts nationwide. The Reporter, launched in 2005 and updated in 2011, is the first comprehensive database in the U.S. for drought impacts. Prior to the release of the Drought Impact Reporter, information on drought impacts were collected through rain gauges and media outreach. The Reporter helps to tell the whole story of drought by allowing individuals impacted by drought to add information, including pictures, to the database. The database also serves as an archive of drought impacts, helping planners and policy makers in prioritizing funding during future drought events. Figure 4 shows reported total drought impacts for all Colorado counties since the previous Plan update was approved in 2013 in the following impact categories:

- Agriculture
- Business & Industry
- Energy
- Fire
- Plants & Wildlife
- Relief, Response & Restrictions
- Society & Public Health
- Tourism & Recreation

- Water Supply & Quality

Figure 4 shows total drought impacts for all Colorado counties from January of 1935 to March of 2018, for the same impact categories. Based on reports to the NDMC, all counties recorded some impact from drought, and most counties recorded moderate to major amounts of impacts, illustrating that drought affects all regions of the state in all impact categories at one time or another. The data represented is skewed, with the majority of these impacts from records within the past 15 years. Since 1935, Colorado counties have reported 636 total drought impacts, with most of them being tied to the agricultural sector.

Figure 4 Total Drought Impacts for Colorado since 1935



Source: NDMC, <http://droughtreporter.unl.edu/map/>

3.2.2 Monitoring Drought in Colorado

Because drought can be defined differently, based on the cause (lack of supply) and the effect (adverse impacts to water users), several methods have evolved to measure and assess drought. Severity, the most commonly used term for measuring drought, is a combination of the magnitude and duration of the drought. In order to assess the severity of a drought event it is necessary to monitor “normal” or average conditions as well as conditions during drought events. Individual indicators of drought conditions can be used in addition to indices that combine multiple indicators to give a more comprehensive set of information. Both traditional maps and graphs of precipitation, snowpack, and streamflow patterns and compilations provide valuable information for drought monitoring. Instrumental data are used extensively for monitoring precipitation, snowpack, streamflow, and reservoir levels, some of which are summarized below:

- Precipitation is measured daily at several hundred locations across Colorado. National Weather Service (NWS) stations have collected data for 100 years or more, and are used extensively by the Colorado Climate Center (CCC) at Colorado State University (CSU) for drought research.
- Snowpack data, critical for predicting runoff and surface water supplies, are collected at higher elevations by the NRCS at Snow Telemetry Network (SNOTEL) sites. A few of these sites date back more than 65 years. Precipitation and snowpack data have been analyzed to determine the patterns of wet and dry periods and their hydroclimatic impacts in Colorado over the last 100 years. Monitoring this data is very important to predict near-future drought potential.
- Streamflow is the net result of precipitation, snowmelt, evapotranspiration, infiltration, and groundwater recharge, as well as man-made influences such as irrigation diversions and reservoir storage and releases. The combination of streamflow readings and reservoir levels provides the best direct indication of available surface water supplies in each of Colorado’s river basins.
- Dust and its impacts are being monitored by the CODOS program of the Center for Snow and Avalanche Studies (CSAS), based in Silverton, Colorado. CSAS's Senator Beck Basin Study Area at Red Mountain Pass is the primary sentry site for dust-on-snow events in Colorado, where rigorous monitoring began in 2002/2003. Ten additional locations throughout the Colorado mountains are also being monitored each spring by CODOS (CODOS, <http://www.codos.org/#codos>).

These climate observation networks provide important data necessary to analyze recent and historic droughts and relate water availability to observed impacts. Years of experience, along with common sense, have shown that drought impacts are directly related to the following drought characteristics:

- Magnitude – how large the water deficits are in comparison with historic averages
- Duration – how long the drought lasts
- Areal Extent – what area is impacted by the drought

A variety of drought indices are used to track precipitation and water supply, as well as classify droughts that have occurred in the past. These indices help simplify and synthesize complex data to provide actionable information for planners and decision makers. Paleoclimatic techniques, such as measurement of tree rings, ice cores, pollens, and ancient lake levels, are also employed to study drought patterns and frequencies over the past several centuries. The following is a discussion of indices or index blends are most commonly used in Colorado and used to activate the Response Plan in Annex A.

The **Surface Water Supply Index (SWSI)** was originally developed in Colorado in 1981 by the Soil Conservation Service (now the NRCS) and the Colorado Division of Water Resources (DWR). The purpose of the index was to describe drought severity where water availability is driven by winter snow accumulation and subsequent melt, typical in the Western US. The SWSI is comprised of four inputs: snowpack, streamflow, precipitation, and reservoir storage. During the winter months (December to May) the index uses snowpack, water year precipitation and reservoir storage. In summer and fall, (June to November) the index switches to streamflow, previous month's precipitation and reservoir storage. The index is computed by determining each variable's non-exceedance probability (the probability that subsequent sums of that component will not be greater than the current sum), then multiplying by a subjective weighting factor. The Index currently uses the following inputs depending on the time of year:

- For January-June: $SWSI = \text{Streamflow Forecast} + \text{Reservoir Storage}$
- For July-September: $SWSI = \text{Reservoir Storage} + \text{Previous Month's Streamflow}$
- For October-December: $SWSI = \text{Reservoir Storage}$

The variables are summed and converted to an index of +4.16 (abundant supplies) to -4.16 (extreme drought). The +4.16 to -4.16 range was used to mimic the Palmer Drought Index. The SWSI is calculated independently for each basin due to differences in climate and reservoir capacities. One of the advantages to the SWSI is that it is simple to calculate and gives a representative measurement of surface water supplies across the state. It has been modified and applied in other western states as well.

The **Standardized Precipitation Index (SPI)**, also developed in Colorado, is fairly simple to compute but is often a robust index for describing drought patterns. The SPI values are based on the probability, calculated from the long-term precipitation record for a given location, of recording a given amount of precipitation over the stated time period, and these probabilities are standardized so that a value of zero always indicates the median precipitation amount. The SPI can be computed for different time scales, can provide early warning of drought and help assess drought severity, and is less complex than the Colorado Modified Palmer Drought Index, or CMPDI (which was discontinued in 2016 in favor of other indices). The SPI identifies a beginning and end for each drought, as well as an intensity level for each month in which the drought occurs. Table 3 shows the values for the SPI index. The challenge of utilizing SPI objectively is understanding the appropriate time scale and vulnerability for various known and potential impacts.

Table 3 SPI Index

SPI Values	Description
2.0 +	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

Source: NOAA National Climatic Data Center

The **Crop Moisture Index** was developed from the Palmer Index, and was designed to evaluate short-term moisture conditions across major crop producing regions. It uses the average temperature and total precipitation for each week and compares the calculated index with the previous week. This is a better index to measure rapidly changing conditions and for comparing different locations. However, the gross scale of the climate divisions (only five for Colorado) makes it a less useful index for Colorado statewide.

In addition to the indices noted above, the **U.S. Drought Portal**, which is a product of the National Integrated Drought Information System (NIDIS), is also used in Colorado.

The U.S. Drought Portal is part of an interactive system to:

- Provide early warning about emerging and anticipated droughts
- Assimilate and quality control data about droughts and models
- Provide information about risk and impact of droughts to different agencies and stakeholders
- Provide information about past droughts for comparison and to understand present conditions
- Explain how to plan for and manage the impacts of droughts
- Provide a forum for different stakeholders to discuss drought-related issues

A major component of this portal is the **U.S. Drought Monitor**. The Drought Monitor concept was developed jointly by the NOAA's Climate Prediction Center, the NDMC, and the USDA's Joint Agricultural Weather Facility in the late 1990s as a process that synthesizes multiple indices, outlooks and local impacts into an assessment that best represents current drought conditions. The final outcome of each Drought Monitor is a consensus of federal, state, and academic scientists who are intimately familiar with the conditions in their respective regions.

Upper Colorado River Basin NIDIS Project

A pilot effort to develop a drought monitor type of product specific to the Upper Colorado River Basin (UCRB) began in 2009. This effort included:

- Interviews with water providers and users to influence the design
- UCRB Community on the Drought Portal
- Web based snow model charting tool
- UCRB Weekly Climate, Water and Drought Assessment webinar series
- Monitoring gaps assessment
- Spatial analysis of water demand
- Reconciling estimates of 21st century flows
- Low flow impacts database
- Linkage of climate and river modeling
- Develop and test drought early warning activities

Results of this project (which started as a pilot study) and lessons learned were implemented into the development of the NIDIS Intermountain West Drought Early Warning System project, to be applied in other major river basins in Colorado. The specific pilot project has since morphed into the “Upper Colorado Drought Early Warning System,” and two Drought Early Warning System (DEWS) regions now exist for Colorado. Current activities of the DEWS regions include weekly monitoring; drought assessment webinars; and weekly climate, water and drought assessments for the respective basins. After a local consensus is reached for each assessment, monitoring information is sent to the U.S. Drought Monitor along with recommendations.

Drought Monitoring Indicators 2018 Review

During the 2018 update of this Plan an effort was made to do a literature review of the current state of the art drought indicators or evolving technologies that could be used to supplement the tried and true indexes. The findings of this effort are included in Annex D Drought Monitoring Indices. While the USDM, SWSI, PDSI, and SPI indices represent the most widely applied drought tracking index tools, there are numerous other drought indices that have provided added benefit to the state’s ongoing drought monitoring practices as well as several newer indices that may soon provide further enhancements to drought monitoring in Colorado. A literature review of recent publications provided the framework for a brief overview of the indices commonly applied within the state and regional drought monitoring community. Each index summary includes a breakdown of documented applications as well as some of the most relevant strengths and weaknesses of the indices in their current state. By providing this information in an organized and detailed manner, future updates to the Plan may continue to evaluate the list of indices and focus efforts on linking local drought impact response/mitigation to the most appropriate drought indices and index values.

The annex also presents a synopsis of the 2012-2013 drought conditions in southeastern Colorado through a series of timeline plots. This high-level case study evaluation is intended to help illustrate the drought progression and decision-making processes performed via the Plan. The analysis also provides a simplified proof of concept example of a post-event evaluation that can be generated for future Plan updates to further refine indices and threshold values for improved localized monitoring.

3.2.3 Drought Indicators Modernization

The SWSI has been used, along with the SPI and Drought Monitor, as the basis for making decisions for the activation and deactivation of the Drought Response Plan (Annex A). While the use of the word “triggers” has been used in the past, the index values have been more appropriately used as guidelines that need to be evaluated with the professional judgment of the Water Availability Task Force (WATF) before activation of the Response Plan (Annex A). It had long been recognized that the SWSI methods were in need of modernization. A significant effort has been made in recent years to modernize the SWSI and other indices for Colorado. One example of how analysis of drought index effectiveness has translated into action is the discontinuation of the CMPDI, as it was deemed not useful at a local level based on how it performed indicating the severity of past droughts. The findings of these and related index study efforts are included in Annex D Drought Monitoring Indices.

3.2.4 Drought History in Colorado

Since the late 1800s, Colorado has experienced widespread, severe drought many times. The most dramatic occurred in the 1930s and 1950s when many states, Colorado included, were affected for several years at a time. Table 4 shows seven multi-year droughts experienced in Colorado since 1893, based on McKee et al. 1999. The 2002 and 2011-2013 droughts occurred after the study was published, but the table has been modified and updated to reflect Colorado’s most recent and intense droughts based on input from the Colorado Climate Center (CCC). During the writing of this 2018 Plan Update, parts of Colorado was experiencing extreme and exceptional drought. The impacts of the 2018 drought on the state included in the next plan update. Following this section is a history of drought declarations. Details on the more significant droughts, particularly the droughts of 2002 and 2011-2013, conclude the discussion of the State’s drought history.

Table 4 Historical Dry and Wet Periods in Colorado

Date	Dry	Wet	Duration (years)
1893-1905	X		12
1905-1931		X	26
1931-1941	X		10
1941-1951		X	10
1951-1957	X		6
1957-1959		X	2
1963-1965	X		2
1965-1975		X	10
1975-1978	X		3
1979-1999*		X	20
2000-2006*	X		6
2007-2010*		X	3
2011-2013*	X		2

Source: McKee, et al. 1999

*modified for 2018 Plan Update based on input from the CCC

USDA Disaster Declarations for Colorado

Past USDA Secretarial Disaster Declarations needed to be requested by a governor's authorized representative or by an Indian Tribal Council leader. Damages and losses prompting disaster designation should have been due to a natural disaster and a minimum of 30 % production loss in at least one crop in the county must have occurred. The Secretarial Disaster Declaration is widely used and makes low-interest loans and other emergency assistance available for those affected, e.g., to farmers and ranchers in the case of agricultural disasters due to drought. Under a new streamlined process by the Farm Services Agency (FSA), a nearly automatic USDA Disaster Declaration can be made if any portion of a county has experienced eight consecutive weeks of severe drought (D2) according to the U.S. Drought Monitor (Congressional Research Service, 2013), provided it occurs during the growing season. Table 5 lists the disaster declarations related to drought for Colorado from 2003 through May 2018. The calendar year is listed, along with the type of hazard, the declaration number, and the primary affected counties. As can be seen in the table below, numerous drought declarations took place from 2011 through 2013. In early July of 2012, 62 of the State's 64 counties were included in a Secretarial disaster designation due to drought. Farmers were then eligible to apply for FSA emergency loans for the next eight months. As of May 2018, 43 of Colorado's 64 counties were included in a Fast Track Secretarial disaster designation due to drought.

Table 5 USDA Secretarial Disasters 2003-2017

Year	Type	Declaration Number and Affected Counties
2003	Drought	S1797 Baca, Bent, Elbert, Kiowa, Lincoln, Prowers
2003	Drought, Insects	S1843 Alamosa, Archuleta, Chaffee, Conejos, Costilla, Crowley, Custer, Dolores, Fremont, Garfield, Hinsdale, Huerfano, La Plata, Lake, Las Animas, Mesa, Mineral, Moffat, Montezuma, Otero, Pueblo, Rio Blanco, Rio Grande, Routt, Saguache
2003	Drought	S1890 Cheyenne, Phillips
2004	Drought, Freeze, Hail	S1947 Baca, Chaffee, Cheyenne, Custer, Eagle, Fremont, Garfield, Grand, Jackson, Kiowa, Kit Carson, Lake, Lincoln, Phillips, Pitkin, Prowers, Pueblo, Routt, Summit, Yuma
2004	Drought	S2009 Moffat
2005	Drought	S2031 Huerfano, Las Animas, Rio Blanco
2005	Drought, Freezing Temperatures	S2160 Delta, Kit Carson
2005	Drought, Wind, Heavy Rain, Hail	S2188 Crowley, El Paso, Lincoln, Otero, Park, Phillips, Pueblo, Teller, Washington, Yuma
2005	Drought, Crop Diseases, Insect Infestation	S2217 Logan
2005-2006	Drought, Crop Diseases, Insect Infestation	S2287 Huerfano, Kiowa, Las Animas, Sedgwick
2005-2006	Drought, Fire, High Winds, Heat	S2327 Adams, Alamosa, Baca, Broomfield, Chaffee, Cheyenne, Conejos, Costilla, Custer, Denver, Dolores, Douglas, Elbert, Fremont, Hinsdale, Huerfano, Kit Carson, Lake, Las Animas, Mineral, Montezuma, Morgan, Prowers, Pueblo, Rio Grande, Saguache, San Miguel, Weld
2006	Heat, High Winds, Insect pests, Late Freeze, Drought	S2329 Arapahoe, Archuleta, Bent, Boulder, Crowley, Delta, El Paso, Gunnison, Jefferson, Kiowa, La Plata, Montrose, Ouray, Park, Phillips, Teller, Washington
2006	Heat, High Winds, Drought	S2351 Eagle, Garfield, Larimer, Logan, Otero, Pitkin, Rio Blanco, Yuma
2006	Drought	S2382 Jackson, Lincoln, Mesa, Moffat
2006	Drought	S2480 Sedgwick
2007	N/A	N/A
2008	Drought	S2750 Adams, Arapahoe, Baca, Bent, Cheyenne, Crowley, Douglas, El Paso, Elbert, Huerfano, Kiowa, Kit Carson, Las Animas, Lincoln, Logan, Otero, Park, Prowers, Pueblo, Teller, Washington, Weld
2008	Drought	S2802 Fremont
2009	Drought	S2970 Dolores, Mesa, Montezuma, Montrose, San Miguel
2010	Drought, High Winds	S2996 Costilla, Las Animas
2011	Drought	S3080 Baca S3125 Baca, Bent, Crowley, El Paso, Kiowa, Las Animas, Lincoln, Otero, Prowers, Pueblo S3131 Archuleta, Baca, Conejos, Costilla, Las Animas S3133 Alamosa, Baca, Bent, Chaffee, Cheyenne, Costilla, Crowley, Custer, El Paso, Fremont, Gunnison, Huerfano, Kiowa, Lake, Las Animas, Lincoln, Otero, Park, Pitkin, Prowers, Pueblo, Saguache, Teller S3144 Alamosa, Archuleta, Chaffee, Conejos, Costilla, Custer, Fremont, Gunnison, Hinsdale, Huerfano, Las Animas, Mineral, Rio Grande, Saguache

Year	Type	Declaration Number and Affected Counties
	Drought, Wildfires, High Winds Drought, Fire/Wildfire, Heat/Excessive Heat, Rain, Flooding, Tornadoes, Lightning, High Winds, Hail, Blizzard, Freeze Drought, Excessive Heat/Rain, Flooding	S3149 Montezuma S3172 Arapahoe, Douglas, El Paso, Elbert, Jefferson, Lincoln, Park, Teller S3117 Baca, Cheyenne, Kiowa, Kit Carson, Prowers S3139 Baca S3157 Cheyenne, Kit Carson
2012	Drought Drought, Wind/High Winds, Heat/Excessive Heat Drought, Wind/High Winds, Fire/Wildfire, Heat/Excessive Heat, Insects	S3229 Arapahoe, Cheyenne, Crowley, Elbert, El Paso, Kiowa, Kit Carson, Lincoln, Pueblo, Washington S3260 Adams, Alamosa, Arapahoe, Archuleta, Baca, Bent, Boulder, Broomfield, Chaffee, Cheyenne, Clear Creek, Conejos, Costilla, Crowley, Custer, Delta, Denver, Dolores, Douglas, Eagle, Elbert, El Paso, Fremont, Garfield, Gilpin, Grand, Gunnison, Hinsdale, Huerfano, Jackson, Jefferson, Kiowa, Kit Carson, Lake, La Plata, Larimer, Las Animas, Lincoln, Logan, Mesa, Mineral, Moffat, Montezuma, Montrose, Morgan, Otero, Ouray, Park, Phillips, Pitkin, Prowers, Pueblo, Rio Blanco, Rio Grande, Routt, Saguache, San Juan, San Miguel, Sedgwick, Summit, Teller, Washington, Weld, Yuma S3267 Montezuma S3269 Delta, Gunnison, Mesa, Montrose S3276 Baca, Cheyenne, Kiowa, Kit Carson, Prowers, Yuma S3281 Yuma S3282 Archuleta, Baca, Conejos, Costilla, La Plata, Las Animas, Montezuma S3284 Baca S3289 Dolores, Garfield, Mesa, Moffat, Montezuma, Montrose, Rio Blanco, San Miguel S3290 Jackson, Larimer, Moffat, Routt, Weld S3315 Logan, Phillips, Sedgwick, Weld, Yuma S3319 Jackson, Larimer
2013	Drought, Wind/High Winds, Fire/Wildfire, Heat/Excessive Heat, Insects Drought, Heat/Excessive Heat, Insects	S3455 Montezuma S3456 Adams, Arapahoe, Baca, Bent, Boulder, Broomfield, Chaffee, Cheyenne, Clear Creek, Costilla, Crowley, Custer, Denver, Douglas, Eagle, Elbert, El Paso, Fremont, Gunnison, Huerfano, Jefferson, Kiowa, Kit Carson, Lake, Larimer, Las Animas, Lincoln, Logan, Morgan, Otero, Park, Phillips, Pitkin, Prowers, Pueblo, Saguache, Sedgwick, Teller, Washington, Weld, Yuma S3459 Baca, Cheyenne, Kiowa, Kit Carson, Prowers, Yuma S3461 Archuleta, Baca, Conejos, Costilla, La Plata, Las Animas, Montezuma S3463 Baca S3466 Dolores, Garfield, Mesa, Moffat, Montezuma, Montrose, Rio Blanco, San Miguel S3505 Phillips, Sedgwick, Weld, Yuma S3508 Larimer, Moffat, Routt, Weld S3518 Alamosa, Conejos, Costilla, Huerfano, Las Animas S3539 Archuleta, Dolores, Gunnison, Hinsdale, La Plata, Mineral, Montezuma, Montrose, Ouray, Saguache, San Juan, San Miguel S3545 Conejos, Hinsdale, La Plata, Mineral, Rio Grande, Saguache S3548 Adams, Alamosa, Arapahoe, Archuleta, Boulder, Broomfield, Chaffee, Clear Creek, Conejos, Costilla, Custer, Delta, Denver, Douglas, Eagle, Fremont, Garfield, Gilpin, Grand, Gunnison, Hinsdale, Huerfano, Jackson, Jefferson, Larimer, mesa, Mineral, Moffat, Montrose, Ouray, Park, Pitkin, Rio Blanco, Rio Grande, Routt, Saguache, San Miguel, Teller S3550 Moffat S3575 Eagle, Garfield, Grand, Lake, Pitkin, Routt, Summit

Year	Type	Declaration Number and Affected Counties
		S3583 Delta, Garfield, Gunnison, Mesa, Montrose, Ouray, Pitkin, San Miguel S3641 Baca, Cheyenne, Kiowa, Kit Carson, Prowers, Yuma
2014	Drought, Wind/High Winds, Fire/Wildfire, Heat/Excessive Heat, Insects	S3627 Arapahoe, Baca, Bent, Cheyenne, Costilla, Crowley, Custer, Douglas, Elbert, El Paso, Fremont, Huerfano, Kiowa, Kit Carson, Las Animas, Lincoln, Logan, Otero, Phillips, Prowers, Pueblo, Sedgwick, Teller, Washington, Yuma S3629 Baca, Cheyenne, Kiowa, Kit Carson, Prowers, Yuma S3630 Baca, Costilla, Las Animas S3632 Baca S3634 Dolores, Mesa, Montezuma, Montrose, San Miguel S3645 Archuleta, Conejos, Costilla S3651 Montezuma S3653 Archuleta, La Plata, Montezuma S3669 Phillips, Sedgwick, Yuma S3698 Yuma S3703 Sedgwick S3714 Garfield, Moffat, Rio Blanco S3715 Archuleta, Conejos, Dolores, Hinsdale, La Plata, Mineral, Montezuma, Rio Grande, San Juan, San Miguel
2015	Drought, Wind/High Winds, Fire/Wildfire, Insects	S3783 Montezuma S3785 Arapahoe, Baca, Bent, Cheyenne, Costilla, Crowley, Elbert, El Paso, Huerfano, Kiowa, Kit Carson, Las Animas, Lincoln, Otero, Prowers, Pueblo, Washington S3787 Baca, Cheyenne, Kiowa, Kit Carson, Prowers, Yuma S3788 Archuleta, Baca, Costilla, La Plata, Las Animas, Montezuma S3790 Baca S3792 Dolores, Mesa, Montezuma, Montrose, San Miguel S3802 Archuleta, Conejos S3826 Garfield, Moffat, Rio Blanco S3925 Delta, Gunnison, Mesa, Montrose
2016	N/A	N/A
2017	Drought	S4145 Adams, Boulder, Broomfield, Weld, Arapahoe, Baca, Bent, Cheyenne, Crowley, Douglas, Elbert, El Paso, Kiowa, Kit Carson, Larimer, Las Animas, Lincoln, Logan, Morgan, Prowers, Pueblo, Washington S4148 Baca, Prowers S4152 Baca
2018	Drought	S4279 Montezuma S4380 Baca, Bent, Las Animas, Prowers S4285 Costilla, Las Animas S4289 Baca, Bent, Costilla, Huerfano, Las Animas, Otero, Pueblo S4290 Baca, Prowers S4291 Baca, Las Animas S4293 Alamosa, Baca, Bent, Costilla, Custer, Fremont, Huerfano, Kiowa, Las Animas, Otero, Prowers, Pueblo, Saguache S4300 Archuleta, Conejos, Costilla, La Plata, Montezuma S4304 Bent, Crowley, Delta, Garfield, Gunnison, Kiowa, Las Animas, Mesa, Montrose, Otero, Pitkin, Pueblo S4308 Dolores, Mesa, Montezuma, Montrose, San Miguel S4309 Delta, Gunnison, Mesa, Montrose, Ouray, San Miguel S4313 Arapahoe, Bent, Cheyenne, Crowley, Custer, Elbert, El Paso, Fremont, Huerfano, Kiowa, Kit Carson, Las Animas, Lincoln, Otero, Prowers, Pueblo, Washington S4315 Cheyenne, Kiowa, Kit Carson, Prowers S4318 Garfield, Mesa, Montrose S4320 Alamosa, Archuleta, Chaffee, Conejos, Costilla, Custer, Dolores, Fremont, Gunnison, Hinsdale, Huerfano, La Plata, Las Animas, Mineral,

Year	Type	Declaration Number and Affected Counties
		Montezuma, Montrose, Ouray, Rio Grande, Saguache, San Juan, San Miguel S4326 Chaffee, Custer, El Paso, Fremont, Gunnison, Lake, Park, Pitkin, Pueblo, Saguache, Teller S4329 Alamosa, Archuleta, Chaffee, Conejos, Costilla, Delta, Gunnison, Hinsdale, Huerfano, La Plata, Mesa, Mineral, Montrose, Ouray, Pitkin, Rio Grande, Saguache, San Juan S4331 Crowley, Douglas, Elbert, El Paso, Fremont, Lincoln, Pueblo, Teller S4334 Arapahoe, Douglas, Elbert, El Paso, Lincoln S4336 Eagle, Garfield, Mesa, Pitkin, Rio Blanco, Routt S4338 Garfield, Moffat, Rio Blanco S4345 Garfield, Moffat, Rio Blanco

Source: USDA – Colorado Farm Services Agency

Governor’s Drought Emergency Declarations for Colorado

In addition to USDA Drought Declarations, the following list shows a timeline for Governor Drought Emergency Declarations and Executive Orders, from 1951 to 2018. These differ from USDA declarations because they can provide emergency assistance beyond that targeted for agricultural purposes alone.

- 8/3/1951 – Governor Dan Thornton declared a drought emergency in La Plata, Dolores, Montezuma, Rio Grande, Archuleta, Conejos, Alamosa, Saguache, Costilla, and Mineral counties due to a shortage of feed for livestock.
- 8/22/1952 – Governor Dan Thornton declared a drought emergency for Elbert, Douglas, Kit Carson, El Paso, and Cheyenne counties due to a shortage of feed for livestock.
- 2/10/1977 – Governor Richard Lamm issued a “Conserve Water! Month” proclamation. The Proclamation stated the snowpack was 30% of normal, and that the eastern plains had not received adequate precipitation for the second straight year. The intention of the proclamation was to encourage water conservation in order to lessen the impact of drought.
- 3/31/1977 – Governor Richard Lamm issued a “Conserve Water Year” proclamation, essentially extending the above proclamation out for the entire year. .
- 7/20/1977 – Governor Richard Lamm issued a proclamation for the formation of the Drought Council.
- 2/16/1978 – Governor Richard Lamm issued a proclamation to retain the Drought Council until the end of the drought.
- 8/1/1994 - In response to extremely arid conditions, Governor Roy Romer activated several Impact Task Forces to assess impacts.
- 7/29/1996 - Governor Roy Romer issued an Executive Order (D000996) proclaiming a Drought Disaster Emergency Declaration. Fifteen counties were included in a request for USDA assistance. The Directive activated the Water Availability, Agriculture, Wildfire, Tourism, Municipal Water, and Review and Reporting Impact Task Forces.
- 2002 – Governor Bill Owens activated eight Impact Task Forces during the 2002 drought. (Colorado received a statewide Presidential Disaster Declaration for the wildfires)

- 2011 – Governor John Hickenlooper activated the Drought Mitigation and Response Plan and the Agricultural Impact Task Force due to drought conditions in southeast Colorado.
- 2012 - Governor John Hickenlooper requested and received a Presidential Disaster Declaration due to severe wildfires associated with ongoing drought conditions. The Governor also expanded activation of the Drought Mitigation and Response Plan from the southeast to statewide.
- 14/5/2013 - Governor John Hickenlooper activated the Municipal Water Impact Task Force in response to growing water availability concerns due to ongoing and expanded drought conditions since 2011.
- 7/19/2017 – Governor John Hickenlooper declared a disaster emergency due to the statewide fire risk arising from very hot and dry conditions which began in June.
- 5/2018 – Initiated by a Governor request, USDA fast tracked disaster designations for 43 of the 64 counties in Colorado as primary natural disaster areas due to losses and damages by the recent drought.

Major Droughts

The following is a summary of information on major droughts that have affected Colorado.

The 1930's Drought – The Dust Bowl drought severely affected much of the United States during the 1930s. Figure 5 illustrates the extent of the Dust Bowl as defined by the Natural Resources Conservation Service.

Figure 5 Extent of the Dust Bowl



Source: Public Broadcasting System American Experience "Surviving the Dust Bowl"
<http://www.pbs.org/kenburns/dustbowl/interactive/homestead/>

The drought came in three waves, 1934, 1936, and 1939-1940, but some regions of the High Plains experienced drought conditions for as many as eight consecutive years. The soil, depleted of moisture, was lifted by the wind into great clouds of dust and sand which were so thick they concealed the sun for several days at a time. They were referred to as “black blizzards.” The period itself is known as the dust bowl. The “black blizzards” were caused by sustained drought conditions compounded by years of land management practices that left topsoil susceptible to the forces of the wind.

The agricultural and economic damage devastated residents of the Great Plains. The Dust Bowl drought worsened the already severe economic crisis that many Great Plains farmers faced. In the early 1930s, many farmers were trying to recover from economic losses suffered during the Great Depression. To compensate for these losses, they began to increase their crop yields. High production drove prices down, forcing farmers to keep increasing their production to pay for both their equipment and their land. When the drought hit, farmers could no longer produce enough crops to pay off loans or even pay for essential needs. Even with federal emergency aid, many Great Plains farmers could not withstand the economic impacts of the drought. Many farmers were forced off of their land. One in ten farms changed possession at the peak of the drought. The agricultural and economic damage devastated residents of the Great Plains.

Many factors contributed to the severe impact of this drought and in its aftermath a better understanding of the interactions between the natural elements (e.g., climate, plants, and soil) and human-related elements (e.g., agricultural practices, economics, and social conditions) of the Great Plains developed. As a result, farmers adopted new cultivation methods to help control soil erosion in dry land ecosystems; consequently, subsequent droughts in the region have not had the same impact.

The 1950s Drought – Fueled by post-war economic stability and technological advancement, the 1950s represented a time of growth and prosperity for some Americans. But while much of the country celebrated a resurgence of well-being, many residents of the Great Plains and southwestern United States were suffering. During the 1950s, the Great Plains and the southwestern U.S. withstood a five-year drought, and in three of these years, drought conditions stretched coast to coast. The 1950s drought was characterized by both decreased rainfall and excessively high temperatures. The first effects of the drought were felt in the southwestern U.S. in 1950 and by 1953 conditions had spread to Oklahoma, Kansas, and Nebraska. By 1954, the drought encompassed a ten-state area reaching from the mid-west to the Great Plains, and southward into New Mexico. The area from the Texas panhandle to central and eastern Colorado, western Kansas, and central Nebraska experienced severe drought conditions. The drought maintained a stronghold in the Great Plains, reaching a peak in 1956. The drought subsided in most areas with the spring rains of 1957. A disaster of this magnitude can create severe social and economic repercussions, as was the case in the southern Great Plains region. The drought devastated the region's agriculture, with crop yields in some areas decreased as much as 50%. Excessive temperatures and minimal rainfall scorched grasslands typically used for grazing. With grass scarce, hay prices rose, forcing some ranchers to feed their cattle a mixture of prickly pear cactus and molasses. By the time the

drought subsided in 1957, many counties across the region were declared federal drought disaster areas (NCDC, 2003).

The 1977 Drought – During 1976 and 1977, the state experienced record-low streamflows at two-thirds of the major stream gages, records that held until the 2002 drought. In addition, the Colorado ski industry estimated revenue losses at \$78.6 million; agriculture producers had to incur higher crop production costs due to short water supplies; and numerous municipalities were forced to impose water use restrictions on their customers. The state’s agriculture producers and municipalities received over \$110 million in federal drought aid as a result of the 1976-1977 drought.

1980-1981 Drought – Although short lived, beginning in the fall of 1980 and lasting until the summer of 1981, this drought generated costly impacts to the ski industry and initiated a huge investment in snow making equipment; it motivated the writing of the “Colorado Drought Response Plan” and the formation of the “Water Availability Task Force” described in Section 2.1.1.

1994 Drought – On August 1, 1994, in response to extremely arid conditions, the Governor activated, by memorandum, several Task Forces to assess impacts: Agriculture (blowing soils), Wildlife, Wildfire, Commerce/Tourism, and Review and Reporting. Significant impacts reported included an increase in wildfires statewide, loss to the winter wheat crops, difficulties with livestock feeding, and impacts to the State’s fisheries.

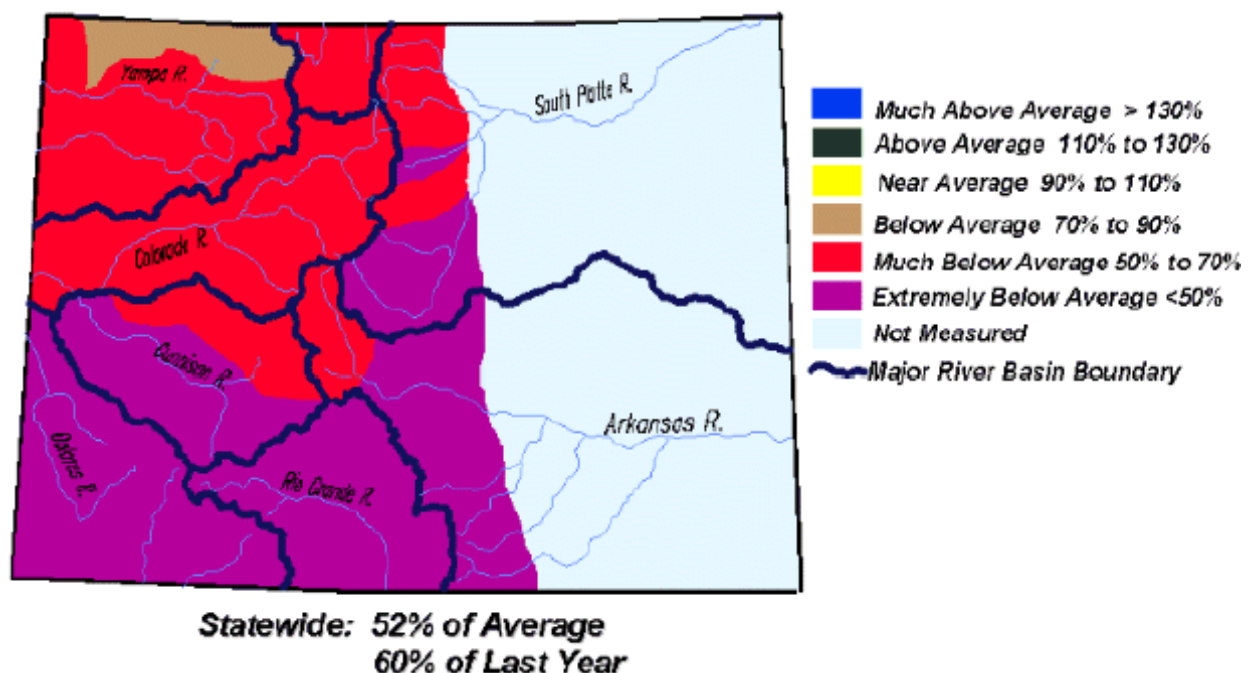
1996 Drought – On July 29, 1996, the Governor issued an Executive Order (D000996) proclaiming a Drought Disaster Emergency Declaration. Fifteen counties were included in a request for USDA assistance. The directive activated the Water Availability, Agriculture, Wildfire, Tourism, Municipal Water, and Review and Reporting Task Forces to monitor the situation, and evaluate impacts to potable water supplies in the southwest and northwest portions of the state. The State Drought Review and Reporting Task Force provided a Drought Status Report to the Governor’s Office. The situation called for continued monitoring by the WATF until fall and winter precipitation alleviated further concerns.

2002 Drought – On a statewide basis, 2002 was the most intense single year of drought in Colorado’s history (Pielke and Doesken, 2003). This was an extremely dry year embedded in a longer dry period (2000-2006), similar to 1934 being an extremely dry year within a period of longer drought (1931-1939). Holders of senior water rights dated 1865 and 1881 placed calls on the South Platte River—the most senior calls placed on the river in over a generation. In the southern part of the state, the Rio Grande nearly ceased to flow (Hall, 2002). The magnitude of this drought cannot be overstated. These conditions were rated “exceptional” by the U.S. Drought Monitor and were the most severe drought experienced in the region since the Dust Bowl (Tronstad and Feuz, 2002). Indeed, based on studies of tree rings and archaeological evidence from aboriginal cultures, the 2002 drought was arguably the most severe in the recorded history of the state (Pielke and Doesken, 2003).

The drought of 2002 had its roots in the autumn of 1999. After a very wet spring and a soggy August, precipitation patterns reversed and the fall of 1999 was very dry across most of Colorado. The winter of 1999-2000 followed with below average snowfall and above average temperatures, dryness continued into spring and early summer over northeast Colorado and the South Platte watershed and drought conditions quickly emerged. A persistently hot summer with evapotranspiration rates higher than average deteriorated conditions. The 2001 water year, although less extreme, continued to trend on the dry side.

October 2001 weather patterns appeared more favorable as a variety of storm systems crossed the region. However, the storms resulted in little moisture and when the month was over precipitation totaled again less than 50% of average over the majority of the state. November and December brought some snow accumulation but snow water content remained below average; and January's above average snowfall came down in the Front Range urban corridor and the southeastern plains, contributing very little to overall water supplies. February and March, despite cooler temperatures and numerous storm systems, did not see the copious wet snows that Colorado spring snowstorms typically produce. By the end of March 2002, the statewide snow water equivalent was a mere 52% of average and portions of Colorado's mountains were even further below average (see Figure 6).

Figure 6 April 1, 2002 snowpack for the State of Colorado



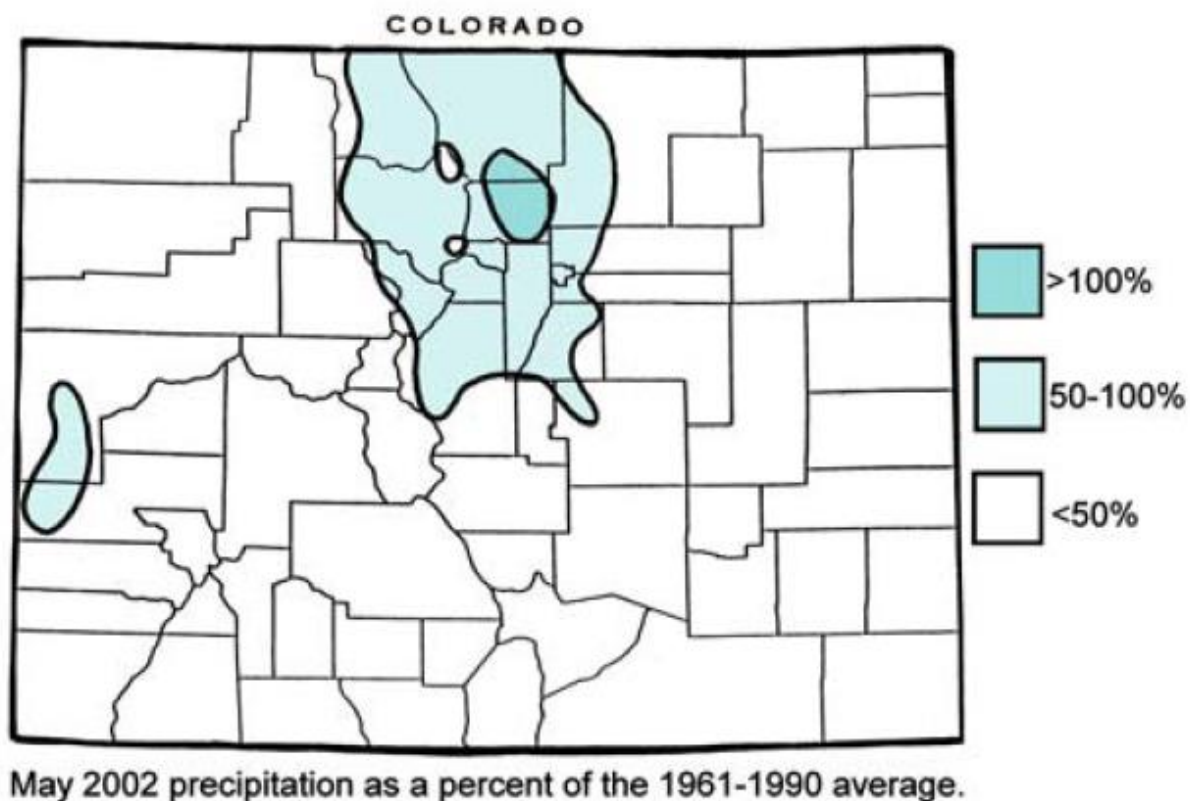
Source: National Resources Conservation Service

The spring storms that sometimes dump heavy and widespread precipitation were nonexistent in April and temperatures soared to record highs. In the mountains snow melted or evaporated at an alarming rate. Relative humidity on several afternoons fell to below 10%. Fire danger, which

typically stays low to moderate through early June, was already high by mid-April, and the first severe forest fire of the season ignited near Bailey on April 23 (Snaking Fire).

May was even drier (see Figure 7). At a time of year when Colorado's rivers and streams are normally churning with snowmelt runoff, there were only mere glimpses of snowmelt flows. Irrigation water demand was high, and it was soon obvious that supplies would not last through the growing season. Municipalities began to face the possibility that available water supplies might not be sufficient to meet typical summertime demand. Many areas implemented strict water conservation restrictions. Other forest fires erupted and each new blaze seemed to spread faster than the one before.

Figure 7 May 2002 Precipitation as a Percent of 1960-1991 Average

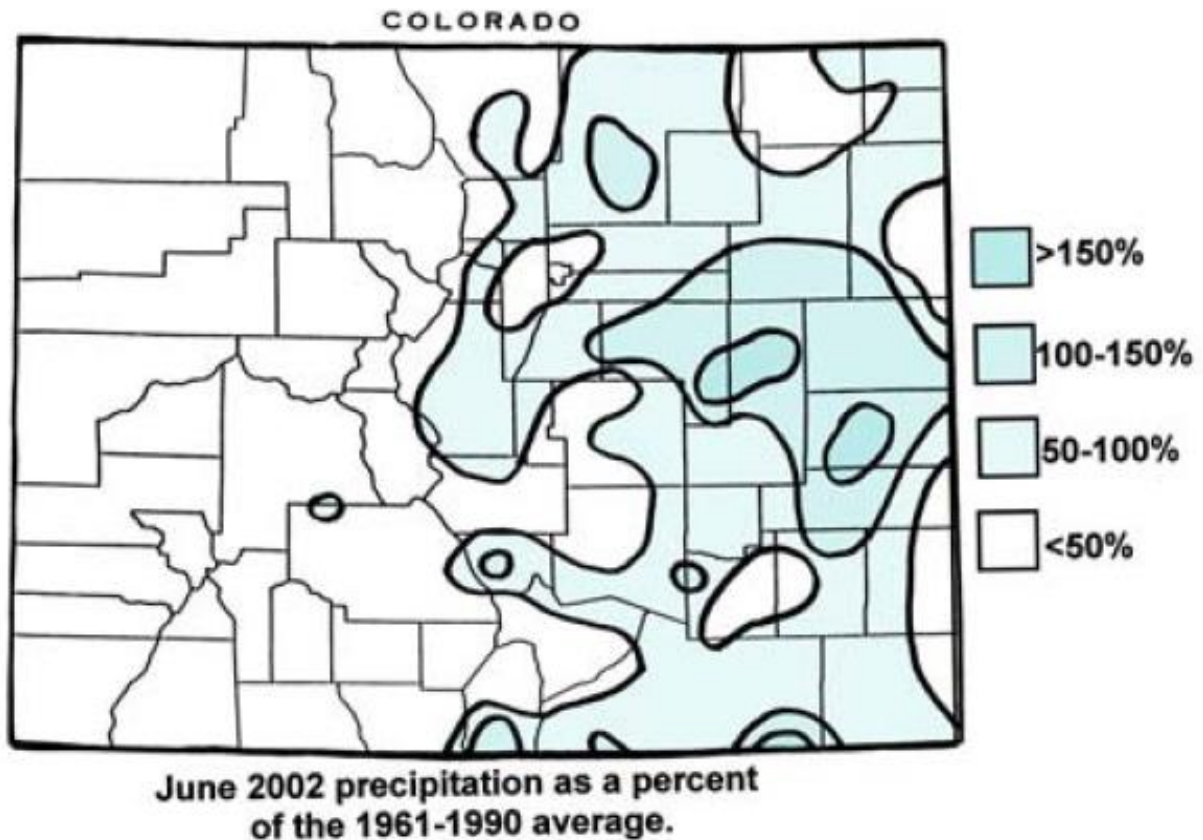


Source: *The Drought of 2002 in Colorado*. Nolan Doesken and Roger Pielke, Sr.

June arrived accompanied by relentless summer heat, temperatures routinely climbed above 90 degrees Fahrenheit at lower elevations east and west of the mountains. Vegetation that normally grows lush and tall with spring moisture barely greened up. Relative humidity often dropped to less than 10%, and bans on outside burning were enforced statewide. Little or no precipitation fell for the entire month over western Colorado (see Figure 8). Winter wheat crop conditions continued rapid deterioration, and ranchers quickly sold or relocated their herds in response to the poor range conditions and high cost of feed. The most severe fires of the season erupted in June, including the

Hayman fire southwest of Denver which quickly grew to be the largest documented forest fire in Colorado (217 mi²) on record.

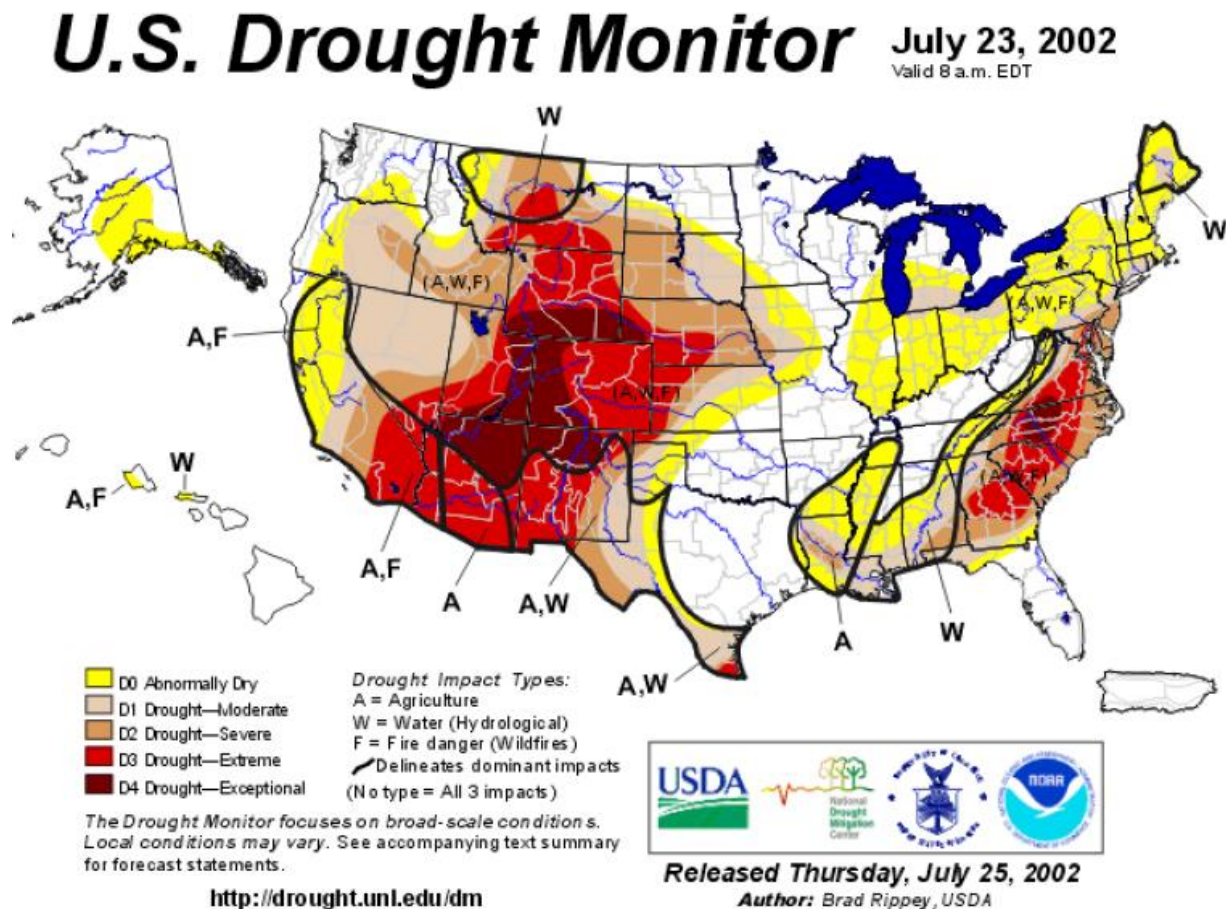
Figure 8 June 2002 Precipitation as a Percent of the 1961-1990 Average



Source: *The Drought of 2002 in Colorado*. Nolan Doesken and Roger Pielke, Sr.

July brought a few changes. Below average precipitation persisted statewide and temperatures were above average for the fourth consecutive month. By late July, the entire state of Colorado was in a serious drought. (See Figure 9)

Figure 9 2002 Drought – Drought Monitor from July 23, 2002



Source: National Drought Monitor

The first several days of August brought some hope for a respite but the monsoon moisture surge was brief. By mid-August, 100°F+ temperatures led media reports to liken conditions to the great Dust Bowl of the 1930s. As the month neared its end, a subtle change in weather patterns brought a round of spring-like thunderstorms loaded with hail and high winds to portions of eastern Colorado. Humid and stormy weather continued into September and for the first time since August 2001, the majority of Colorado received above average rainfall.

Fortunately for Colorado, drought conditions continued to slowly recede during the end of 2002 and into 2003. The March 18, 2003 blizzard that hammered the Colorado Front Range with as much as 87 inches of snow significantly relieved many of the lingering effects of the drought. Some areas of the state, however, continued to experience moderate to severe drought conditions, but these droughts did not affect the state as a whole. The 2007 Drought Update reported that during calendar year 2006, at least some portions of the state also experienced severe drought conditions (D2 drought intensity) between March and December, while additional parts of the state experienced extreme drought conditions (D3 drought intensity) between May and September.

In the 2007 DWSA, many (64% of respondents) felt the drought had passed, and that the state had “fully recovered” from the 2002 drought. Since 2003 both drought conditions the state water situation has improved, but it has taken nearly eight years to recover from the 2002 drought. Discussion in the April 2010 WATF meeting suggested that the state’s water situation was the best it had been since the late 1990s, with near average snowpack and reservoir storage in most basins in the state.

Historical Perspective of the 2002 Drought

The year 2002 is considered the driest single year in recorded Colorado history. Statewide snowpack was at or near all-time lows. Water year 2002 precipitation was extremely low when compared to 1961-1990 normal precipitation levels. There have been individual years in Colorado that have been drier at individual points or portions of the State – 1894, 1934, 1939, 1954 and 1966 are some examples. However, what made 2002 so unusual was that the entire State was dry at the same time. By all accounts, soil moisture was nearly depleted in the upper one-meter of the soil profile over broad areas of Colorado by late August 2002. 2002 was clearly the driest year in over 100 years of record based on streamflow. Reservoirs dropped to extremely low levels. The excess of the late 1990s helped Colorado survive the drought of 2002, but very little useable water remained even with strict enforced water restrictions. For a more detailed historical impact of the 2002 drought, see *The Drought of 2002 in Colorado*, authored by Nolan Doesken and Roger Pielke, Sr. and referenced many times in this Plan.

2002 Drought and the Impact Task Forces

All eight impact task forces (ITFs) at the time were activated by the Governor during the 2002 drought. One outcome was the 2003 Drought Impact and Mitigation Report. It identified impacts from the drought, as well as actions or mitigation measures that already had been, or would be taken to address the impacts of an ongoing drought. The report also identified state and federal agencies and entities that are associated with actions and mitigation measures, as well as implementation statuses and related costs of those actions and mitigation measures. Each of the ITFs provided a summary table listing these actions and activities, also summarized in Appendix B.

2011-2013 Drought

Even though 2011 was very wet across northern Colorado, the extreme drought during this time in Texas, New Mexico and Oklahoma was also felt in the Rio Grande and Arkansas Basins in Colorado. This trend continued in those Basins as 2012 began, but also increased in breadth across the rest of Colorado. Based on the U.S. Drought Monitor, approximately 50% of Colorado was already under drought conditions at the beginning of 2012. Minimal snow accumulation further exacerbated the already dry conditions as below average snowfalls and above average temperatures occurred in February and March. The above average temperatures continued into April and May, causing early runoff as the thin snowpack quickly melted. The entire State was under drought conditions by the end of May 2012, causing concern as it included the regions where

80% of the State's water supply originates. Streamflows measured only slightly better compared to the extreme drought years of 1934, 1954, 1977 and 2002 (Ryan and Doesken, 2013).

Agriculture was highly impacted. Soil moisture was low on the plains during the spring planting season and temperatures were high, giving crops little chance to establish and survive the summer. This was compounded by less water availability for summer irrigation diversions due to low snowpack and runoff. June was very hot, consistently over 100°F, especially in the eastern plains of the state. These temperatures rivaled those observed during the historic drought years of 1934 and 1954, with many other areas setting high temperature records. A majority of pasture and rangeland areas were classified as “poor” or “very poor” by August of 2012. Hay was hard to come by due to production decreasing to 10% to 50% of average and limited supplies from neighboring states also impacted by drought. This caused prices to drastically increase, necessitating trucking hay in from northern Montana and Idaho, and even as far away as the Carolinas. Crop prices also increased in 2012. For example, corn prices increased 43% over two years as nearby corn-producing regions in other states also struggled with drought. High commodity prices helped some producers through the drought as they were able to sell fewer commodities and still bring in enough to cover their costs. Still other producers were not able to take advantage of the high prices because they lacked the product to sell.

The multi-year drought in 2011-2013 also deteriorated vegetative cover across the state's Eastern Plains. The exposed soil, combined with heavy winds, created dust storms similar to those of the devastating 1930's Dust Bowl. Some farmers lost entire crops with one storm, causing immense financial strain and emotional hardship. In early June 2013, many areas on the Eastern Plains normally inhabited by crops or cattle were barren. Many ranchers sold their herds because grasses had gone dormant (or had even died) and hay was expensive and in short supply. Even the smallest wind can create dust storms in Southeastern Colorado where the soil has become very thin after repeated dry years. Recovering from these conditions will take time, but many farms are implementing updated farming practices to help mitigate the effects of drought. These techniques include no-till farming and allowing crop residue to remain after harvest to help anchor the soil (Denver Post, 2013).

Dust can have other impacts that exacerbate drought conditions. The dust-on-snow phenomenon has been increasingly evident in recent years, particularly in the spring of 2013. The snowpack that the State relies on for water supplies, agriculture, recreation, habitat, and for many other economic sectors melts out even faster due to the presence of dust that settles on the snow. This dust is borne from wind and often from storms that originate in Arizona, New Mexico and Utah. The absorption of heat from the dust-laden sun hastens snowmelt, causing rapid loss of snowpack instead of the slow melt over a longer period of time that is desired for capture in storage reservoirs. Dust-covered snow can absorb 70% more solar energy compared to the 5 to 20% that is absorbed with clean snow (Durango Herald, 2013). Snowpack may already be thin from little snowfall in the preceding winter, further compounding the issue. Dust events that occurred repeatedly in April 2013 were followed by large snow events in the San Juan Mountains, Steamboat Springs, Summit County, Vail and Aspen, thus layering the dust throughout the snowpack. Runoff greatly increases

when the dust layers converge as melt occurs. Faster melting of snowpack decreases the likelihood that the water can effectively be captured in storage reservoirs for use in the summer when it is needed the most. This also affects late-season base flows in streams, a problem for irrigators who rely on this water for diversions (Denver Post, 2013b).

Drought conditions and a period of extremely hot temperatures in June 2012 also contributed to very dry forests, contributing to the conditions that led to the High Park fire in northern Colorado and the Waldo Canyon fire near Colorado Springs, two of Colorado's most destructive. These wildfires prompted a Presidential Disaster Declaration to be declared the end of June 2012 to provide federal disaster assistance to supplement state and local recovery efforts. Insurance claims totaled more than more than \$453.7 million for the Waldo Canyon fire (Associated Press, 2013). This does not include the costs to fight the fire. Wildfires continued to burn throughout the State in 2012 until the last fire, the Fern Lake Fire in Rocky Mountain National Park finally extinguished in January 2013, a testament to how dry the forests were coupled with a low snowpack at the end of the year. Dry conditions on the Eastern Plains also contributed to an extended grass fire season. Typically, these fires occur in the spring, but in 2012 they were experienced well into the summer. Approximately 45,000 acres were scorched in a matter of days, destroying 23 structures, including 5 homes, as a result of the Last Chance Fire.

At the time, the Waldo Canyon Fire in Colorado Springs was the most destructive fire in Colorado history in terms of structures lost, burning approximately 346 total homes (The Gazette, 2012). However, the Black Forest Fire, also near Colorado Springs, surpassed it a year later when a record-setting 498 homes were destroyed and 28 damaged in June 2013 (El Paso County Sheriff's Office, 2013).

Other impacts seen during the 2011-2013 drought were decreased rafting numbers in 2012 due to low streamflows and wildfire conditions, making some river reaches inaccessible. Colorado's ski industry, another important economic driver for the state, experienced an 11.9% decrease in visits for the 2011-2012 season as compared to the five-year average. Many ski resorts closed early in 2012 because of minimal March snowfall and high temperatures. Both of these industries have developed marketing and operations strategies in recent years to mitigate economic impacts due to drought. In the agriculture sector, the Arkansas Basin lost approximately 1,300 jobs and \$105 million in economic activity (Gunter et al., 2012).

Reservoir levels in many portions of the State helped abate some of the drought impacts seen in 2011-2013. Had they not been at levels sufficient for carryover storage into 2012 due to record breaking high snowpack in 2011 in many river basins, many of the impacts discussed above may have been worse. However, since May 2012, reservoir storage has dropped below average in most basins. Some relief was brought to northern Colorado from late spring storms that boosted snowpack in 2013, but reservoirs in the region remain below normal.

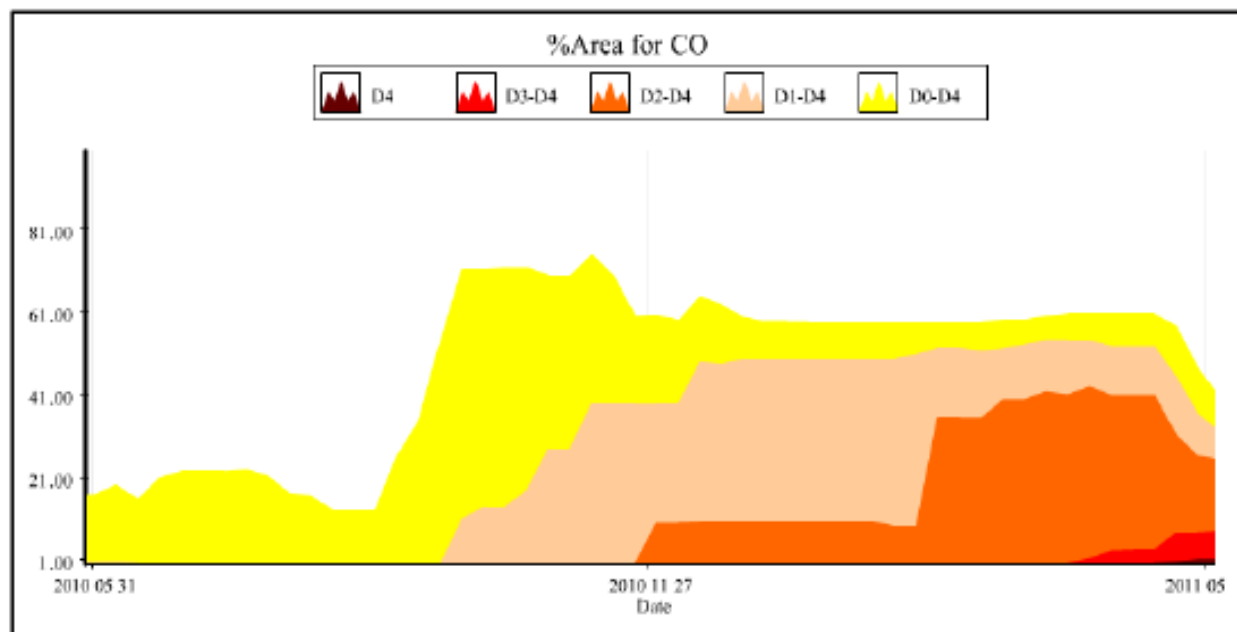
Figure 10 through 13 present time series graphs in year intervals beginning in May 2010 as a visual representation of the development of the 2011-2013 drought. Figure 10 highlights the drought

cycle from before the exceptional drought conditions began in late 2011, all the way to the ending period of the drought in 2015. These figures illustrate what percentage of the State was affected by drought according to the following intensities:

- D0: Abnormally Dry
- D1: Drought – Moderate
- D2: Drought – Severe
- D3: Drought – Extreme
- D4: Drought – Exceptional

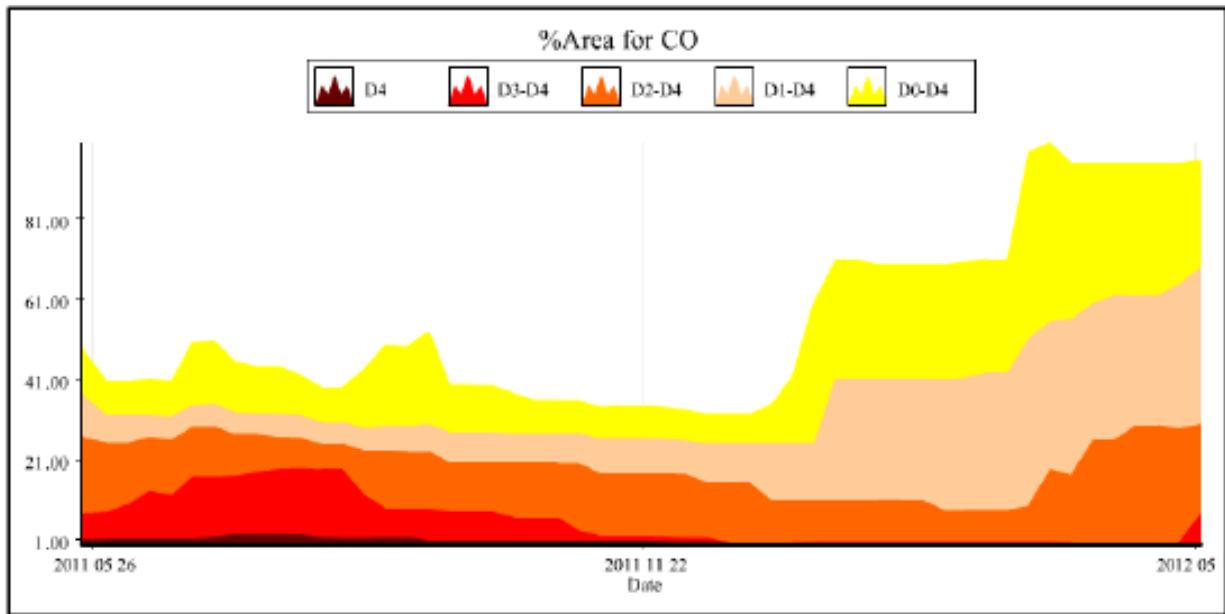
Beginning in May 2010, the majority of the state was not experiencing drought, though some regions were classified D0. By fall of 2010, some moderate drought conditions began, which elevated in intensity throughout the end of 2010 and into the beginning of 2011. However, the wet conditions during the spring and summer of 2011 suppressed the severity of drought conditions in northern Colorado. By early 2012 drought conditions began to expand and strengthen in intensity. The whole state was, at a minimum, under a severe drought by the summer of 2012. These conditions persisted until around October of 2013, when exceptional drought conditions ceased slightly throughout Colorado. The last remnant of drought (when the D0 category ceased to be prevalent from the entire State) was seen to last until summer of 2015, though the most severe drought conditions ended in late 2014.

Figure 10 Drought Time Series: May 2010-May 2011



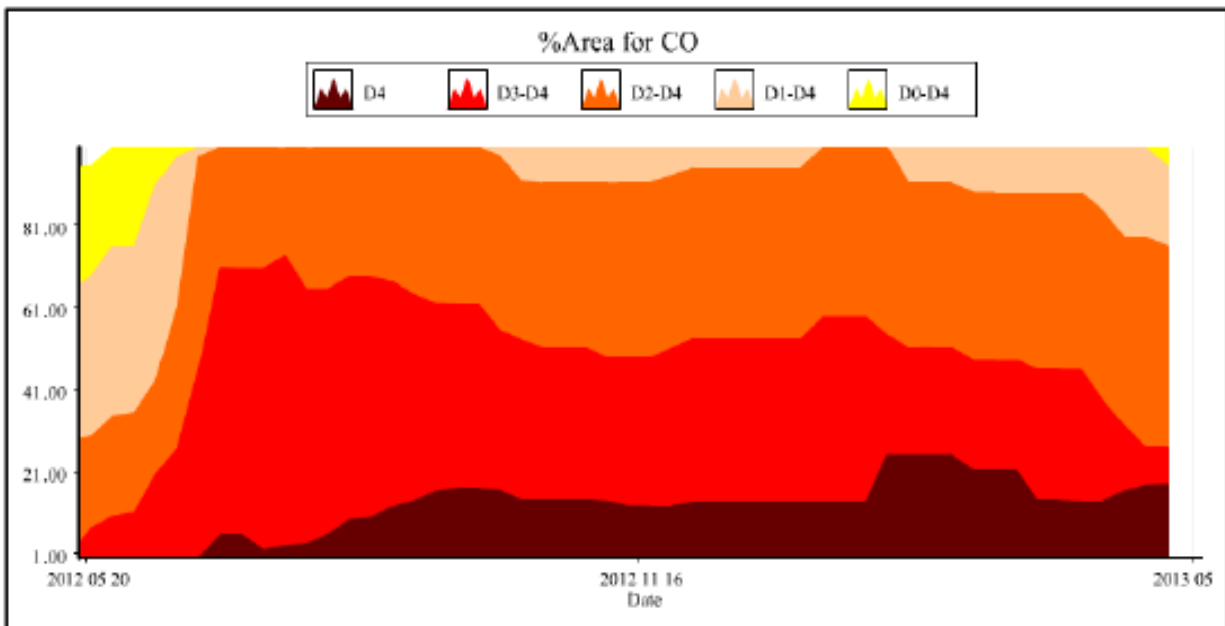
Source: NIDIS U.S. Drought Portal

Figure 11 Drought Time Series: May 2011-May 2012



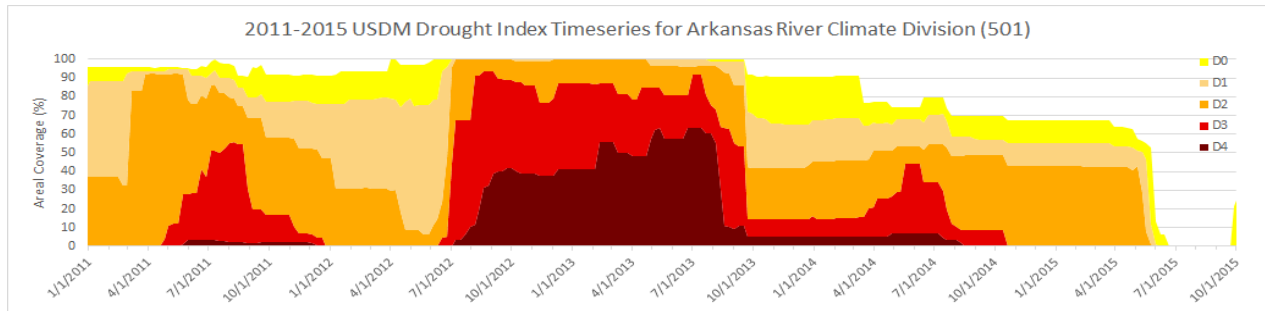
Source: NIDIS U.S. Drought Portal

Figure 12 Drought Time Series: May 2012-May 2013



Source: NIDIS U.S. Drought Portal

Figure 13 Drought Time Series with ‘before’ and ‘after’ drought conditions: January 2011-October 2015



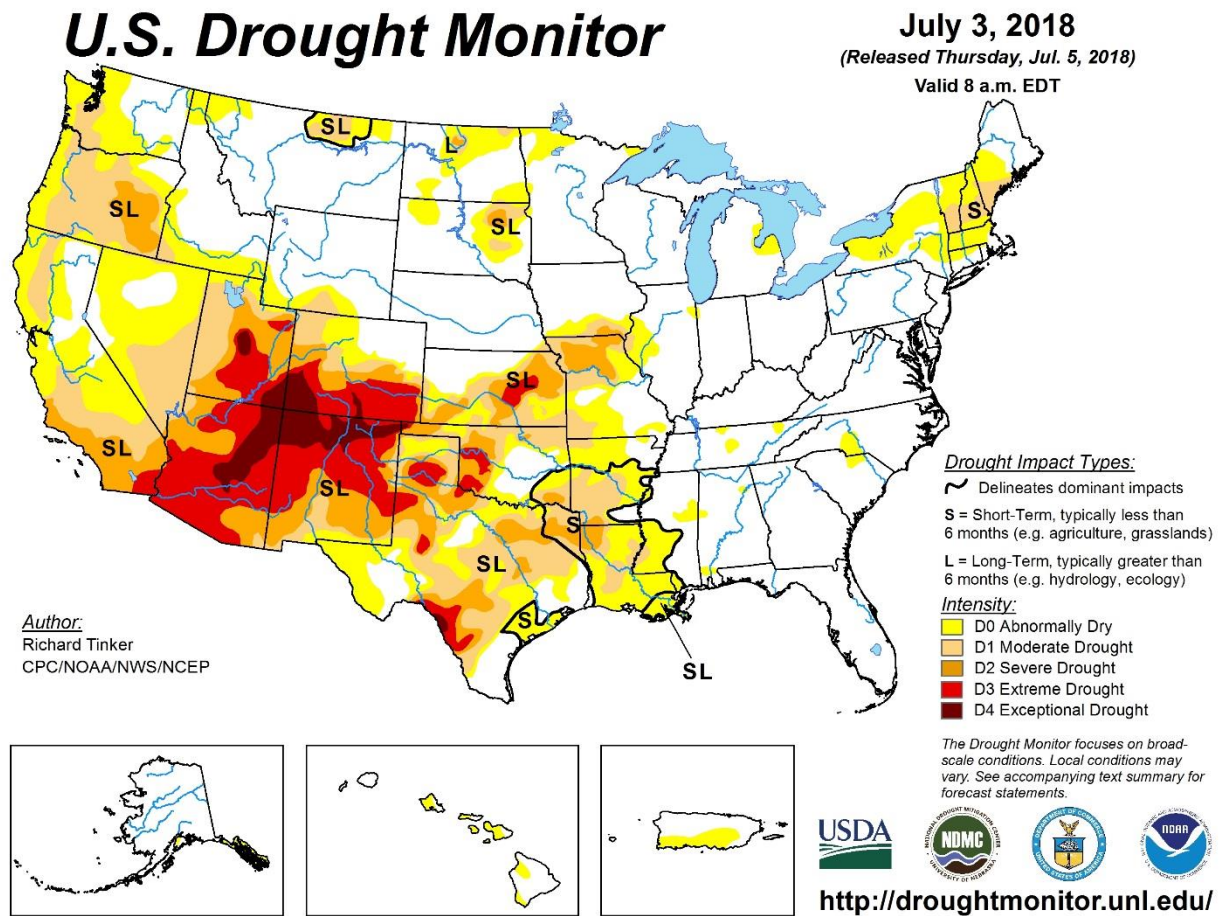
2011-2013 Drought and the Impact Task Forces - The Agricultural Impact Task Force met for much of 2011 and 2012 following activation by the Governor in 2011, bringing together Farm Service Agency personnel and state water managers to report failed and prevented planting acreages, updates on CRP (Conservation Reserve Program) grazing availability as well as emergency loan status and disaster declarations status by county.

Governor John Hickenlooper activated the Municipal Water Task Force (MWTF) in May 2013, as a response to growing water availability concerns. The MWTF assessed 2013 drought impacts on municipal water supply and public health impacts, and made recommendations for response actions.

2018 Drought

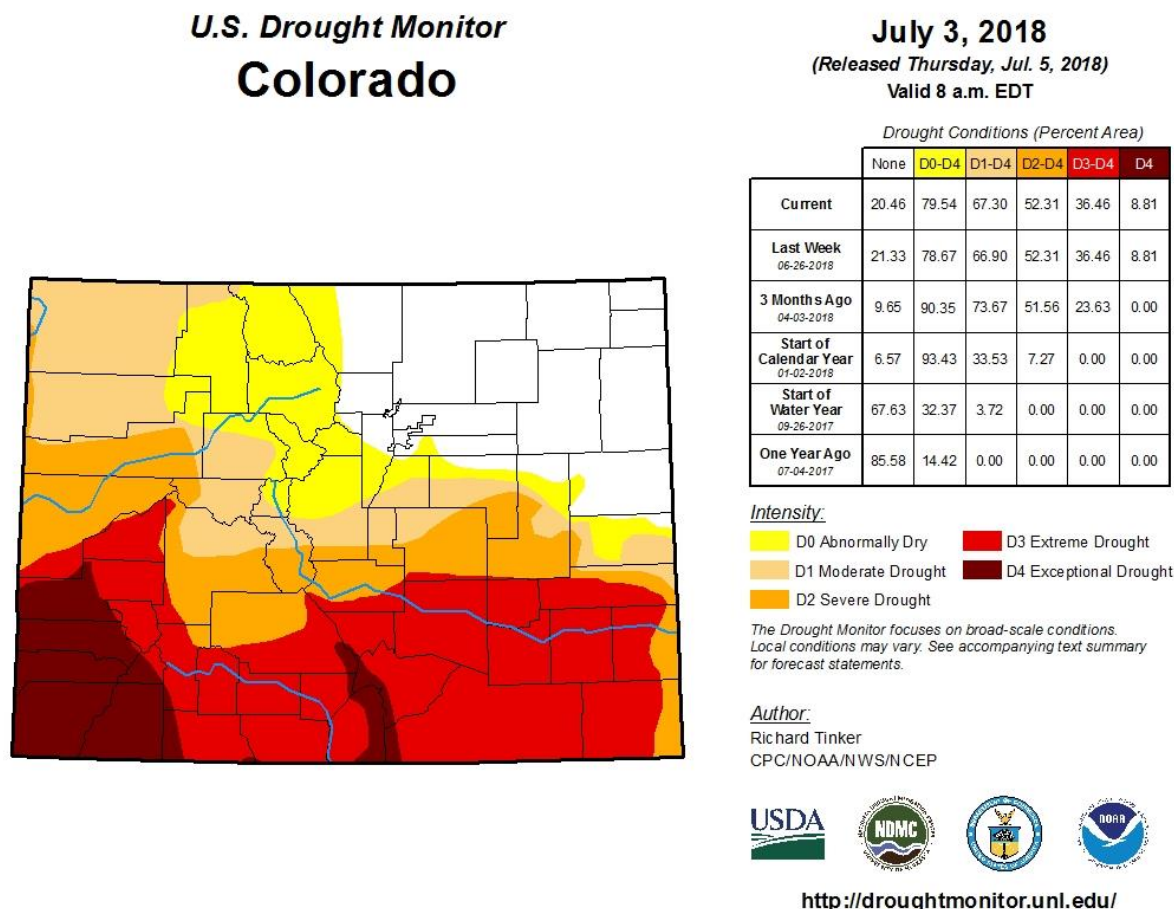
When this Plan was updated in late 2017-2018, drought emerged over the winter and persisted into the summer. A snapshot of the drought conditions as of July 2018 nationwide and specific to Colorado can be found in the following figures. The figures indicate the dry conditions that are evident throughout much of the south-central and western United States. As indicated below, the four corners region of the country (Arizona, New Mexico, Utah and Colorado) are experiencing extreme and exceptional drought. In addition to moderate and severe drought impacting Kansas, northern Texas, and western Oklahoma. Some areas of the west coast of the U.S. and the northeast are also experiencing moderate and severe droughts, such as in Vermont, Washington, California and Oregon. The majority of drought conditions are classified as short-term, however, typically lasting less than 6 months.

Figure 14 July 2018 U.S. Drought Conditions



Source: United States Drought Monitor

Figure 15 July 2018 Colorado Drought Conditions



Source: United States Drought Monitor

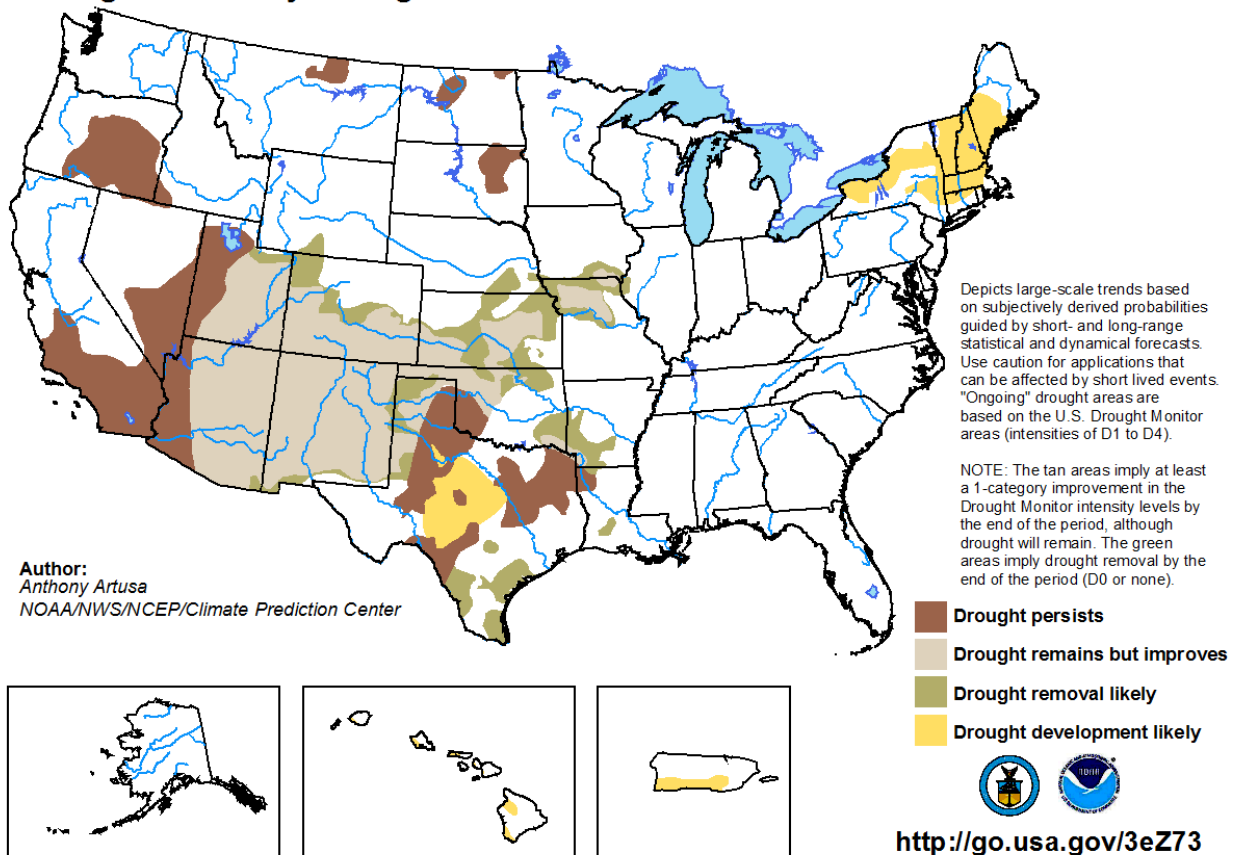
Figure 15 displays the conditions in Colorado as of July 3, 2018. The southern region of the state is increasingly susceptible to drought, which is indicated by the yellow, beige, and orange shading, while most of the state exhibits signs of drought. The southern edge is particularly affected by extreme drought, with the southwestern corner being under exceptional drought conditions (dark umber shading). The central region is mostly under moderate and severe drought, with parts of the central-north, northwest, and central-east under abnormally dry conditions. Finally, the top central and northeastern parts are mostly unaffected, in stark contrast to the southern half of the state.

The U.S. Seasonal Drought Outlook developed by NOAA synthesizes long-term forecasts to generalize drought tendencies across the nation. A sample of this product is shown in the figure below, which shows that persistent drought is likely to continue in the northern high plains region while a portion of the central and southwestern U.S., including a very small area in southeastern Colorado near Kansas and Oklahoma, may show some improvement in drought conditions.

Figure 16 Seasonal Drought Outlook June 21 - September 30, 2018

U.S. Seasonal Drought Outlook
Drought Tendency During the Valid Period

Valid for June 21 - September 30, 2018
Released June 21, 2018



Source: NOAA Climate Prediction Center

The USDA designated several counties in Colorado as primary natural disaster areas due to losses and damages from drought taking place in April and May of 2018. The counties include: Alamosa, Archuleta, Conejos, Gunnison, Hinsdale, Mineral, and Rio Grande. Farmers and ranchers in the following contiguous counties also qualified for natural disaster assistance: Chaffee, Costilla, Delta, Huerfano, La Plata, Mesa, Montrose, Ouray, Pitkin, Saguache, and San Juan. San Juan's declaration was initiated by a Governor's request due to being outside of the growing season for that county. The CWCB reported exceptional drought conditions in April, via their monthly drought update report, and the declaration was officially approved May 25th. The Colorado Drought Response Plan was once again activated in response to the drought conditions.

The four corners region suffered persistent precipitation deficits, which are expected to continue. While strong reservoir storage tempers conditions somewhat, the agricultural sector is seeing loss of winter wheat and early fires have already been reported. The Mesa Verde area in the southwest is seeing its lowest year-to-date water accumulation in its 95 year record.

Probability of Future Droughts

Historical analysis of precipitation shows that drought is a frequent occurrence in Colorado (McKee et al., 1999). Short duration drought, as defined by the three-month Standardized Precipitation Index (SPI), occurs somewhere in Colorado in nearly nine out of every ten years (McKee et al., 2000). However, severe and widespread multiyear droughts are much less common.

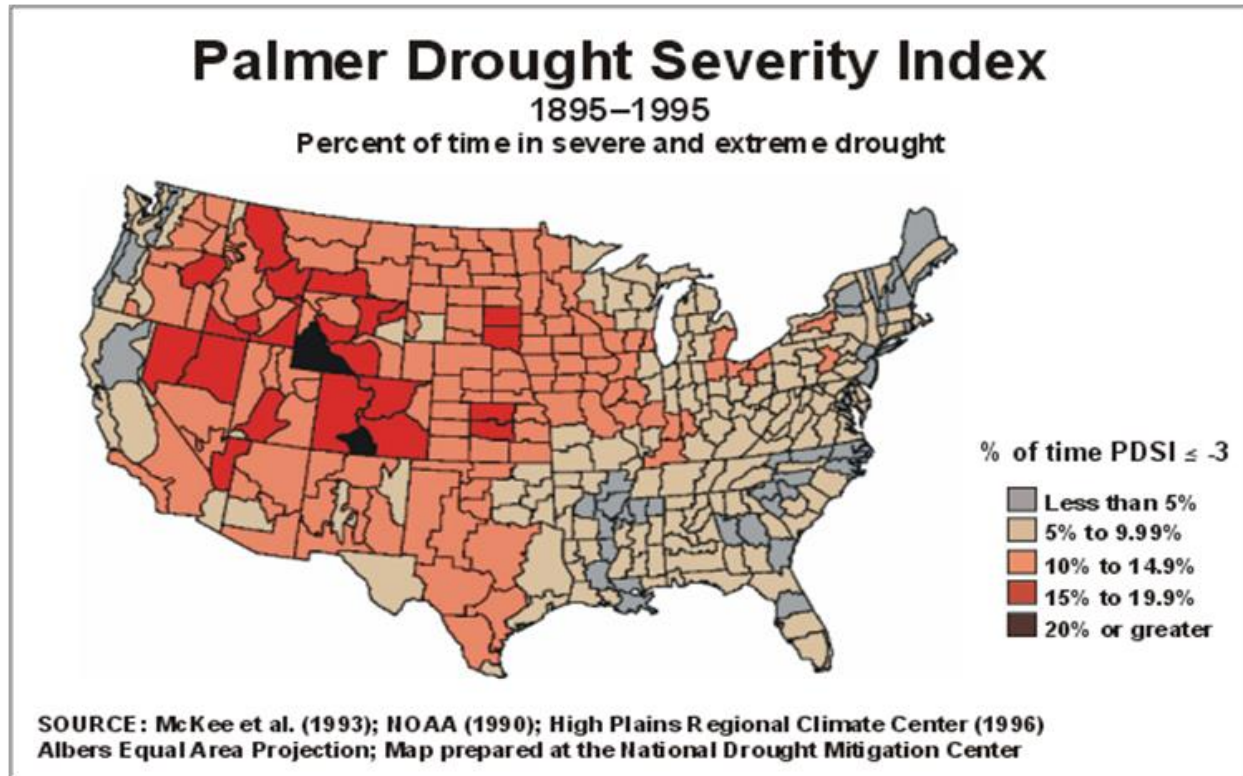
Up until the publishing of the *2004 Drought Water Supply Assessment* (DWSA), there had been six recorded drought incidents which impacted the State of Colorado since 1893, during a span of 111 years (from 1893 to 2004). As such, the SPI derived probability of a drought occurring in any given year is 32.4%. Table 6 under Section 3.2.4 summarizes the major multi-year drought and wet periods in Colorado history.

NOAA projects short term future probability of drought by releasing U.S. Seasonal Drought Outlook maps that forecast anticipated drought conditions three months out. The April 19 through July 2018 Outlook map was shown as Figure 7, under section 1.2.2. According to NOAA, in the short term, drought is expected to persist or intensify throughout most of Colorado's southwest. The southeast of the state is expected to see some drought remain but improving slightly, and small sections of the central-east might see actual drought removal conditions.

Figure 17, from the NDMC, illustrates that most of Colorado experienced severe or extreme drought between 15% and 19.9% of the time over a 100-year period (from 1895 to 1995).

Climate change could increase the frequency of drought in Colorado in the future. For a more thorough discussion on climate change as it relates to the probability of future droughts and its effects on the state economy, resources, and population, please review Annex C Climate Change Implications. However, a short section on this topic is included under Section 3.2.5 below.

Figure 17 United States: Percent of Time in Drought, 1895–1995



3.2.5 Other Drought Implications in Colorado

Climate Change

The hydrology and water resources, and hence the economy of Colorado, is extremely sensitive to climate. Climate change researchers around the world have recognized mountain systems as sensitive bellwethers of regional change. The interannual variability of the snow resource, the impacts of rapidly emerging factors such as dust-on-snow, and the possibility that climate change could cause substantial long-term reductions in Colorado's seasonal snow cover, highlight the vulnerability of the state's mountain snowpack and the economies that depend on the predictable storage and release of the water supply from snowmelt.

Multifaceted stress on water supply such as irrigation and municipal demands, mandated biological flows, coupled with climate variability and overall change, are increasing the importance of supply forecasting to both water managers and business markets. While the scientific understanding of climate change is ever evolving and entails many complexities when linking it with future trends in drought, in general, climate change is projected to increase the frequency of drought events in Colorado. As a result of increasing temperatures, water yields will generally decrease. Warmer temperatures will likely result in precipitation occurring as rain rather than snow, decreased high-elevation snowpack volume, an earlier spring melt of the decreased snowpack, more intense and

damaging precipitation events (e.g., flash floods), and increased evapotranspiration (WWA, 2011, CWCB 2008, CWCB 2010, Knowles et al., 2006, Mote 2006, Saunders 2005, Udall 2007). Consequently, runoff will start earlier and end earlier. Reservoirs will fill earlier, and what cannot be stored in the spring and early summer will be spilled when agricultural demands are not as great as they are later in the summer. Decreased runoff in the summer will result in additional reservoir drawdown, and many studies agree that higher temperatures and lower precipitation during summer months will further increase agricultural demands, thus causing even more stress on reservoir storage even when annual total precipitation is projected to increase (CWCB, 2008; CWCB, 2012).

The International Panel on Climate Change (IPCC) indicated that predicted changes in mean flow or flow variability could cause physical infrastructure to be inadequate for intended purposes, or increase the risk of failure of the water resource system under extremes of drought (IPCC, 2007 and 2014). While such risks may be somewhat buffered in large water systems by robustness and resilience in the design of the system, smaller systems may be extremely vulnerable under climate scenarios beyond those considered in their design. To illustrate the evolving understanding of climate change science, several documents by the Congressional Research Service such as the IPCC's Fourth and Fifth Assessment reports indicated that large uncertainties still exist in terms of trends about drought on a global scale. Nevertheless, these reports highlight why and how early mitigation actions targeted to climate change impacts can improve aspects of citizens' everyday lives, enhance well-being and livelihoods, improve environmental amenities, and much more (IPCC 2007; CRS, 2013). Colorado has been paying increased attention to climate change projections from the IPCC, particularly with the latest IPCC report released in 2014.

The State has also been involved regionally and nationally in policy-making decisions to reduce vulnerabilities due to climate impacts to the various sectors that drive Colorado's economy. The Colorado Climate Action Plan that was developed in 2007 and updated in 2015 identifies the need to investigate vulnerabilities of the State's water supplies to climate change and to plan for severe drought (as well as other risks) resulting from climate change. More recently, the Colorado Climate Plan, updated in 2018, introduces additional policies and strategies for the State, designed to mitigate and adapt to a changing climate. This Plan particularly provides recommendations about water issues, public health, greenhouse gas emissions, transportation, tourism, ecosystems, agriculture, and the partnerships and efforts behind supporting federal, regional, and local entities and agencies become more resilient and adaptable.

The State has also held conferences to bring water providers, planners, managers, and government officials together to assess drought risk, impacts, and preparedness in Colorado, and to consider the improvements that will be needed for management under different conditions such as climate change. The Governor's Conference on Managing Drought and Climate Risk was held in October 2008 and included attendees from state, federal and local agencies. The September 2012 CWCB Statewide Drought Conference program focused on building a drought resilient economy through innovation which included discussions on climate variability. In February of 2018, the Colorado Communities Symposium took place, where Governor John Hickenlooper and many elected

officials and community business leaders participated in visioning workshops and educational programs tied to climate preparedness and clean energy development. These forums are important to bring stakeholders together to discuss adaptive strategies, incorporate variability into decision making, and understand the complexities and challenges associated with the constantly evolving nature of climate science.

Annex C contains a more detailed analysis of possible implications of climate change for drought in Colorado. Assessments from the Colorado River Water Availability Study (CRWAS) phases were sponsored by the CWCB, to investigate water availability on the Colorado River under a range of climate change scenarios. CRWAS analyzed drought duration intensity and the likelihood for a range of possible future conditions. Refer to Annex C for the findings of this analysis, as the document was updated in 2018 with information from the CRWAS Phase II findings.

Water Rights

Under the Colorado system of prior appropriation, also known as “first in time, first in right,” claims with earlier adjudication dates and earlier appropriation dates have senior rights while claims with more recent adjudication dates and appropriation dates have junior rights. During droughts, senior water rights take precedence over junior rights. Water use will be reduced or cut off for junior rights, protecting senior rights. Colorado’s water supply fluctuates continually. During times of drought, when water is scarce, the prior appropriation doctrine has profound implications for water management. The topic of drought and Colorado Water Rights, including background details on the Colorado Water Trust and State Water Plan from 2015, is discussed in more detail in chapter 4 of the Annex B Drought Vulnerability Assessment Technical Information. Below is a general discussion on the system of prior appropriation, a summary of river administration during the 2002 drought, and recommendations for future studies. While some information is available on river administration based on the 2011-2013 drought, including aspects about leasing instream flow rights and utilizing reaches to protect assets, more time and collaborations would be necessary to acquire and process data that captures the extent of the impacts of the 2011-2013 drought on water rights. Future endeavors should address in more detail some of these water rights complexities, however, to highlight issues behind water appropriation and administration during and after times of water scarcity.

3.3 Assessing Vulnerability by Jurisdiction

The Plan’s risk assessment includes an overview and analysis of the State’s vulnerability based on estimates provided in both the local and state risk assessments. The plan must also identify those jurisdictions that are most threatened and most vulnerable to loss and damage due to drought. The following section follows the FEMA requirements and explains the process used to analyze information from the local risk assessments, as well as a requirement on how the Plan reflects changes in development in hazard prone areas.

According to FEMA’s risk assessment guidance, vulnerability is defined as being open to damage or attack, and risk is defined as the possibility of loss or injury. For this assessment, the vulnerability of a county is approximated by looking at previous impacts due to drought and identifying existing conditions, or “metrics,” that would cause a county to be more or less impacted during future droughts. These metrics are determined on a sector-by-sector basis. In an attempt to expand upon previous vulnerability assessments for the State of Colorado, the scope has been widened to include six private economic sectors and one public sector in total. The private sectors are as follows: Agriculture, Energy, Environment, Municipal and Industrial (M&I), Recreation and Tourism, and Socioeconomic. The public sector is State Assets. State assets that are considered at-risk from drought are as follows: state-owned or operated buildings, critical infrastructure, state lands, instream flows, and fish hatcheries. Only those facilities that are state-owned or operated are specifically addressed in the state assets section of the Plan, but the impacts and vulnerabilities identified for these facilities would apply to similar privately-owned facilities and lands as well. While Agriculture, Energy, Environment, Municipal and Industrial (M&I), Recreation and Tourism, and the Socioeconomic sectors are discussed in this section (3.3), facilities related and infrastructure related to the State Assets sector are described under section 3.4 instead, given their slightly different nature in affecting the economic sphere in Colorado.

In addition to the FEMA requirements, the Emergency Management Accreditation Program, or EMAP risk assessment standards, require a consequence-based analysis. Table 6 outlines the detrimental impacts that drought can have on various subject areas as designated by EMAP.

Table 6 EMAP Consequence/Impact Analysis: Drought

EMAP Risk Assessment Subject Area	Detrimental Impacts
Health and Safety of the Public	Water supply disruptions may adversely affect people. Reduced water quantity and quality could impact delivery of potable water, particularly in rural areas. Reduced air quality associated with blowing dust could have detrimental impacts. Mental health issues may be associated with loss of farm income and heavily impacted lifestyles in agricultural areas. See the Socioeconomic Sector analysis for a detailed impact discussion.
Health and Safety of Personnel Responding to the Incident	Nature of hazard expected to have minor impacts to properly equipped and trained personnel, though dust storms may require special equipment.
Continuity of Operations Including Delivery of Services	Slow onset and nature of drought makes it unlikely to have an impact on continuity of operations. Nature of hazard not expected to impact delivery of government services, except for moderate impact on water utilities. In extreme cases, municipal water delivery may be interrupted. Ability to deliver recreational services may be impacted at the local level. Food supply and delivery could be disrupted, with an associated increase in food prices.

EMAP Risk Assessment Subject Area	Detrimental Impacts
Property, Facilities, and Infrastructure	<p>Buildings: Nature of hazard expected to have minimal impact. Landscaping can be damaged or lost in events of severe municipal water restrictions or water rights out of priority. Increased risk of wildfire can threaten catastrophic loss of buildings.</p> <p>Critical infrastructure (e.g., dams, transmountain ditches, irrigation ditches): Infrastructure can be damaged by excessively dry expansive soil as it contracts. Dams and ditches can experience structural damage due to decreased pore water pressure, damage caused by high sediment loads when pulling water from the bottom of reservoirs, and damage caused by debris flows and flooding following wildfires.</p> <p>State lands: Environmental quality of land can be impacted by overgrazing during drought conditions.</p> <p>See the State Assets Sector analysis for a detailed impact discussion.</p>
The Environment	<p>May cause disruptions in wildlife habitat, resulting in an increasing interface with people, and reduction in numbers of animals. Land quality can be negatively impacted by overgrazing during drought. Water quality can become degraded to the point of causing localized fish kills. See the Environment Sector analysis for a detailed impact discussion. Low streamflows will have negative impacts on riparian habitats and aquatic species.</p>
Economic Condition	<p>Local economy and finances dependent on abundant water supply or precipitation (e.g., snow at ski areas) adversely affected for duration of drought.</p> <p>Agricultural economies adversely affected if drought results in widespread loss of crops or yield reductions.</p> <p>Increased expenses possible among M&I providers.</p> <p>See sector analyses for Recreation and Tourism, Agriculture, State Assets, Energy, M&I, and Socioeconomic.</p>
Regulatory and Contractual Obligations	<p>Water trading between municipalities expected to occur on a voluntary rather than obligatory basis. Drought reservations or instream flows may be invoked to allow a reduction in bypass requirements and an interruption to agricultural leases (see the M&I Sector analysis). Interstate compact obligations could become stressed if long term or severe decreases in availability occurs.</p> <p>Recreational in-channel diversions and instream flow rights are subject to water rights priority system and may become out-of-priority in a drought (see Recreation and Tourism and State Assets analyses).</p>
Public confidence in the jurisdiction's governance	<p>Ability to respond and recover may be questioned and challenged if planning, response, and recovery efforts are not timely and effective.</p> <p>State must balance <i>over</i> and <i>under</i> responses to the drought hazard.</p>

In the sections that follow, the process used to analyze information from previous work is explained, the methodology for assessing vulnerability by county is discussed, and the results of the vulnerability assessment, presented in the chapters of Annex B, are presented.

3.3.1 Vulnerability Based on Local and State Risk Assessment

State and local hazard mitigation plans were reviewed to assess vulnerability of the private economy sectors of Recreation and Tourism, M&I, Socioeconomic, Environment, Energy, and Agriculture sectors, on a jurisdictional level. Information was updated accordingly to reflect hazard mitigation plans that have been finalized since the previous update to this Plan was

completed in 2013. During that 2013 Plan update, an extensive literature review was conducted to collect previously-reported impacts to drought and adaptive capacities that had been developed by sectors and the State. Interviews were conducted with individuals knowledgeable about a particular sector or asset. The information was analyzed and incorporated into a spreadsheet to evaluate vulnerability in a quantitative as well as qualitative way. To the extent available, new reports and data available since the 2013 update were reviewed and incorporated into revised vulnerability analyses during this 2018 update.

The six private economy and one public economy sectors, listed in Figure 18, were divided into sub-sectors to facilitate analysis in cases when a sector is sufficiently diverse to warrant separate consideration (e.g., Recreation and Tourism).

Figure 18 Sectors and Sub-Sectors Analyzed in the Drought Vulnerability Assessment

M&I		Socioeconomic		Environment	
Recreation		Energy		Agriculture	
<ul style="list-style-type: none"> • Rafting • Boating • Golf • Hunting, Camping, Fishing • Wildlife Viewing • Skiing 		<ul style="list-style-type: none"> • Mining • Power 		<ul style="list-style-type: none"> • Green Industry • Livestock • Crops 	
				State Assets	
				<ul style="list-style-type: none"> • State-owned and operated buildings and structures • Land Board Revenue • State Land-Based Recreation • Aquatic Species and Habitat • Protected State Areas 	

As shown in Figure 19, the private sectors of Agriculture, Energy, and Recreation & Tourism were divided into sub-sectors while Environment, M&I, and Socioeconomic were not. The public sector of State Assets was also broken into sub-sectors, but its sub-sectors are described in more detail under Section 3.4.

From the literature review, previous drought impact reports (including local and state hazard mitigation plans), and interviews with agency directors, program employees, industry

representatives, and academics who are continually involved in drought-related issues¹, impacts of drought to the sub-sectors and departments were identified and listed for analysis. Similarly, adaptive capacities were identified as they can mitigate the impacts to the sub-sectors. The existence of adaptive capacities helps offset the impacts and reduce overall vulnerability and risk.

Using the list of impacts and adaptive capacities, data relating to the impacts that could be used to quantify the vulnerability of each sector were identified. An example of a vulnerability (impact) metric for Energy is the total water withdrawals used in the power generation sector. For Agriculture, an identified impact was crop loss due to drought; crop indemnity data is available by county specifically for drought, so these data were used as a metric for agriculture. The data for all the sectors were aggregated at a county level to satisfy the jurisdictional requirements of the FEMA regulation, while also introducing localized details and perspectives.

To determine the overall impact a sector or sub-sector has within a county, data were collected to assess the spatial density of the sub-sector in question (in one or more ways). This enabled a presentation of sub-sector relative densities throughout the State. For example, Colorado State Parks were mapped and correlated to one or more counties where they are located. In this way, only counties that contain state parks can be vulnerable to drought impacting state parks (in terms of visitation revenue, for instance), or for agriculture, only counties that have grazing cattle can be vulnerable to grazing losses during a drought.

For each sector and/or sub-sector, spatial inventory data were used to determine its proportionality within the county. For example, a county with a high number of high-value state buildings and state-owned dams, but a low acreage of land managed by the State Land Board, would have its vulnerability rated proportionally higher for state-owned buildings and dams. Refer to Annex B (Drought Vulnerability Assessment Technical Information) for further discussion of the vulnerability assessment methodology.

3.3.2 Jurisdictions Most Threatened and Most Vulnerable to Damage or Loss

While these other approaches are examples of tools addressing vulnerability, risks, and impacts of drought to the State of Colorado, the vulnerability assessment and methodology incorporated in this Plan differs by highlighting vulnerability and adaptive capacities, impact metrics, spatial

¹ Including individuals from the Colorado Department of Agriculture (CDA), Colorado State University (CSU), U.S. Department of Agriculture (USDA), National Oceanic and Atmospheric Administration (NOAA), water division engineers, National Resources Conservation Service (NRCS), GreenCO, water commissioners, The Nature Conservancy (TNC), NatureServe, Audubon Society, Department of Local Affairs (DOLA), Colorado Energy Office (CEO), National Renewable Energy Laboratory (NREL), Tri-State Energy, Xcel Energy, Colorado Geological Survey (CGS), Division of Reclamation and Mining Safety (DRMS), Western Resource Advocates (WRA), Golf Course Superintendents Association of America (GCSAA), U.S. Geological Survey (USGS), Colorado River Outfitters Association (CROA), National Ski Areas Association (NSAA), Office of Economic Development and International Trade (OEDIT), State Office of Risk Management, State Land Board, fish hatchery managers, Colorado Park and Wildlife (CPW), Colorado Department of Public Health and Environment (CDPHE), and others.

densities, and of course the localized perspectives of each sector based on interviews, professional interactions, and other such information and data. In addition, both private and public economic sectors are taken into account, more holistically approaching the issue of drought at local and statewide scales. In the section below, drought vulnerabilities are summarized based on the methodology described herein (in the Plan), by county and sector.

Drought Vulnerability by County Summary

By researching previous impacts to various sectors and by talking to people in the industries/agencies of concern, a methodology to “rank” vulnerability in a quantitative way was developed. This ranking process is described in discussions specific to each sector in Annex B, and results were updated in 2018. In many cases, vulnerability scores did not change from 2013 due to lack of available quantitative data consistent statewide. Where changes did occur in the county listings, notably in state-owned buildings and infrastructure and state-owned recreational activities, this was due to incorporation of improved data. The summaries of the rankings are provided in Table 7 below, excluding the M&I sector because that sector did not follow the standard methodology and instead calculated vulnerabilities and adaptive capacities based on the seven major river basins across the state (and not counties). Figure 19 displays the cumulative vulnerability assessment scores for all the sectors (except the M&I sector), in map form.

Table 7 Vulnerability Ranks by County and Sector (excluding M&I), 2018 Update

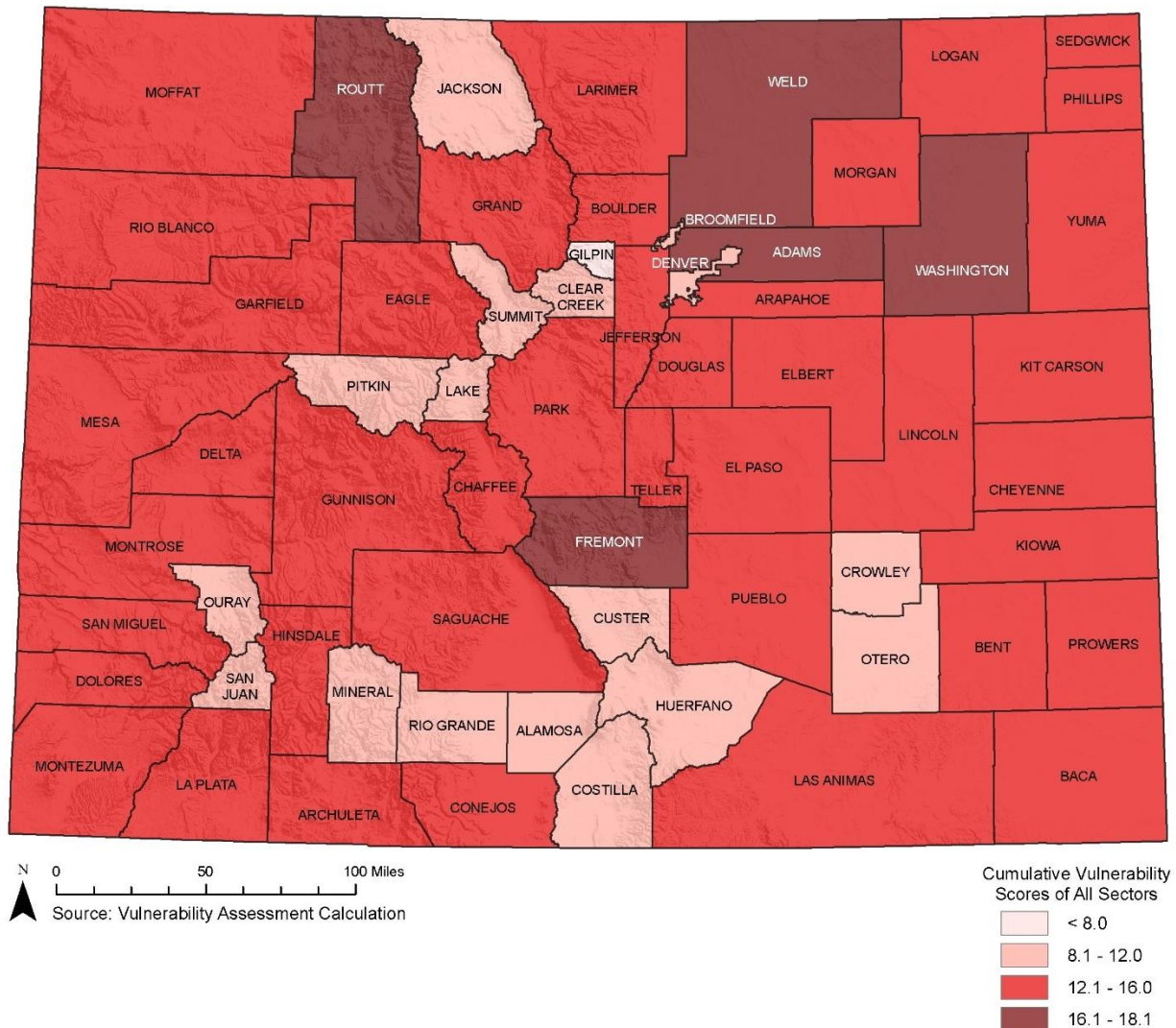
County	Recreation	Energy	Agriculture	State Assets	Socioeconomic	Environment	Average Overall Vulnerability (not including M&I Sector)	Cumulative Vulnerability Assessment Scores (not including M&I Sector)	Number of Sectors with Vulnerability Scores of 3.0 and above
Adams	2.29	3.00	3.54	2.92	2.80	2.50	2.84	17.05	2
Alamosa	1.17	0.55	1.85	1.98	2.80	1.27	1.60	9.62	0
Arapahoe	2.35	1.00	2.96	2.31	2.60	1.90	2.19	13.12	0
Archuleta	2.75	1.75	2.17	2.84	3.20	1.94	2.44	14.65	1
Baca	2.14	1.48	4.00	2.82	2.20	1.83	2.41	14.47	1
Bent	1.91	0.40	3.38	2.70	2.00	1.94	2.06	12.33	1
Boulder	2.15	3.00	2.05	1.50	1.80	2.08	2.10	12.58	1
Broomfield	1.94	0.00	2.06	1.35	2.40	1.67	1.57	9.42	0
Chaffee	2.55	1.75	1.92	2.14	2.80	2.03	2.20	13.19	0
Cheyenne	1.75	3.25	3.32	2.92	2.20	1.67	2.52	15.11	2
Clear Creek	2.12	1.00	1.00	1.98	2.80	1.36	1.71	10.26	0
Conejos	2.20	1.47	2.66	2.08	2.40	1.67	2.08	12.48	0
Costilla	1.50	1.00	2.19	1.67	2.80	0.97	1.69	10.13	0
Crowley	1.00	0.00	2.43	2.85	2.00	2.17	1.74	10.45	0
Custer	1.60	0.00	2.13	1.57	3.00	1.53	1.64	9.83	1
Delta	2.46	2.75	1.88	2.84	2.40	2.54	2.48	14.87	0
Denver	1.44	2.00	0.75	1.53	2.60	2.00	1.72	10.32	0

County	Recreation	Energy	Agriculture	State Assets	Socioeconomic	Environment	Average Overall Vulnerability (not including M&I Sector)	Cumulative Vulnerability Assessment Scores (not including M&I Sector)	Number of Sectors with Vulnerability Scores of 3.0 and above
Dolores	1.65	1.75	3.13	1.97	2.20	1.59	2.05	12.29	1
Douglas	2.46	1.00	2.17	1.97	2.40	2.03	2.00	12.03	0
Eagle	2.94	1.50	2.00	2.10	3.00	2.08	2.27	13.62	1
El Paso	2.44	0.94	2.40	2.14	2.60	2.54	2.18	13.06	0
Elbert	1.33	1.75	3.25	2.95	3.00	1.83	2.35	14.11	2
Fremont	3.48	3.75	2.17	2.43	1.80	2.54	2.69	16.17	2
Garfield	3.04	2.00	2.25	2.97	2.60	2.86	2.62	15.72	1
Gilpin	1.33	0.00	0.00	1.74	2.60	1.52	1.20	7.19	0
Grand	2.98	1.38	2.00	2.11	3.00	2.42	2.31	13.89	1
Gunnison	2.54	2.71	1.46	2.56	2.60	1.74	2.27	13.61	0
Hinsdale	1.96	1.00	2.25	2.19	3.20	1.52	2.02	12.12	1
Huerfano	2.09	0.75	2.25	3.00	1.60	2.12	1.97	11.81	1
Jackson	1.58	0.00	2.50	1.80	2.00	1.45	1.55	9.33	0
Jefferson	2.48	1.00	2.42	2.59	2.00	2.27	2.13	12.76	0
Kiowa	1.00	1.75	3.58	3.23	2.60	2.00	2.36	14.16	2
Kit Carson	2.00	1.10	3.78	3.67	2.40	1.83	2.46	14.78	2
La Plata	2.57	2.69	2.20	1.78	2.80	2.03	2.34	14.07	0
Lake	1.44	2.13	2.25	1.95	1.60	1.45	1.80	10.82	0
Larimer	3.08	1.54	2.74	2.43	2.60	3.33	2.62	15.72	2
Las Animas	2.57	1.99	3.42	2.80	1.40	2.78	2.49	14.96	1
Lincoln	1.43	0.82	4.00	3.23	2.40	2.00	2.31	13.88	2
Logan	2.36	1.62	3.41	2.93	2.20	2.67	2.53	15.19	1
Mesa	3.02	2.13	1.85	3.57	1.80	2.86	2.54	15.23	2
Mineral	2.03	0.00	1.00	1.38	2.80	1.25	1.41	8.46	0
Moffat	3.08	3.88	2.40	1.91	1.60	2.58	2.57	15.45	2
Montezuma	2.43	1.45	2.13	2.77	3.00	1.82	2.27	13.6	1
Montrose	2.64	2.20	1.28	3.53	2.80	2.22	2.45	14.67	1
Morgan	2.90	2.15	2.81	2.81	2.80	2.33	2.63	15.8	0
Otero	1.79	0.40	3.04	3.14	1.00	2.17	1.92	11.54	2
Ouray	2.13	1.00	1.75	2.75	2.20	1.59	1.90	11.42	0
Park	2.83	1.00	2.00	2.07	2.60	2.17	2.11	12.67	0
Phillips	1.60	1.75	2.71	3.60	1.80	1.33	2.13	12.79	1
Pitkin	2.26	1.00	1.63	1.43	3.60	1.11	1.84	11.03	1
Prowers	1.50	1.45	3.25	3.00	2.00	1.67	2.14	12.87	2
Pueblo	3.08	1.60	3.20	3.09	2.00	2.38	2.56	15.35	3
Rio Blanco	2.73	2.80	1.70	2.40	2.00	2.32	2.32	13.95	0
Rio Grande	2.62	0.00	2.04	2.67	2.20	1.88	1.90	11.41	0

County	Recreation	Energy	Agriculture	State Assets	Socioeconomic	Environment	Average Overall Vulnerability (not including M&I Sector)	Cumulative Vulnerability Assessment Scores (not including M&I Sector)	Number of Sectors with Vulnerability Scores of 3.0 and above
Routt	3.28	3.50	2.75	2.19	4.00	2.32	3.01	18.04	3
Saguache	2.57	0.85	2.13	2.30	2.80	2.12	2.13	12.77	0
San Juan	2.25	0.00	1.00	1.63	2.60	0.87	1.39	8.35	0
San Miguel	2.47	1.00	2.13	2.37	3.40	2.06	2.24	13.43	1
Sedgwick	1.00	0.70	2.83	3.68	2.60	1.50	2.05	12.31	1
Summit	2.16	1.00	2.13	1.30	3.40	1.67	1.94	11.66	1
Teller	1.92	2.50	2.50	2.59	2.80	1.59	2.32	13.9	0
Washington	2.13	3.25	3.13	3.43	2.40	2.50	2.81	16.84	3
Weld	2.96	2.32	2.81	2.50	3.00	3.50	2.85	17.09	2
Yuma	1.58	2.50	3.53	2.36	3.00	1.11	2.35	14.08	2

Source: Vulnerability assessment calculation

Figure 19 Vulnerability Assessment Cumulative Scores for all Sectors (except M&I)



The following conclusions were reached in terms of least adaptable and/or most vulnerable jurisdictions to damage associated with drought, for the State Assets sector:

- Vulnerability to state-owned buildings and critical infrastructure was found to be highest in these counties: Archuleta, Eagle, Mesa, Rio Blanco, Routt, Baca, Conejos, Kit Carson, Larimer, Park, Saguache, and San Miguel. This is because these counties contain state-owned buildings and/or dams (as determined from data provided by the Colorado Risk Management Office and the National Inventory of Dams). These counties either have proportionally more dams (since dams are more likely to be impacted by drought than buildings, this would make a county relatively more vulnerable), and/or there is a moderate to high wildfire threat as determined by the Colorado State Forest Service (CSFS) Wildfire Threat data, which poses a risk to state-owned buildings. These results are displayed in Figure 22.

- Vulnerability to State Land Board lands and revenues in Figure 23 was found to be high in quite a few counties. In general, counties on the eastern plains were found to have the highest vulnerability to drought as it impacts state lands because these counties received the highest agricultural lease discounts in the 2002 drought. Several counties in the west/southwest also have high vulnerability scores for the same reason. In 2002, the State Land Board issued across-the-board agriculture lease discounts, something they do not intend to do in future droughts as it did not have the desired effect of encouraging ranchers and farmers to adjust their grazing/farming practices to reflect the lower carrying capacity of the drought-stressed land. Because of this, in future droughts, State Land Board lease revenue will vary based on how many discounts are offered to individuals in each county (personal communication with State Land Board, 2010). While the spatial density metric (acres) was updated with the latest data as were total Land Board-owned surfaces in acres, this Lease Discounts vulnerability metric could not be updated for the 2011-2013 drought as the program was discontinued after the 2002 drought.
- Vulnerability to state-operated recreational activity and parks (CPW) in Figure 24 was found to be highest in Chaffee, Routt, Archuleta, Eagle, Mesa, Garfield, Huerfano, Las Animas, Montezuma, Weld, Park, Delta, Gunnison, Jefferson, Logan, Morgan, and Pueblo counties. This is because these counties contain state parks with relatively high annual visitation numbers, the state parks are water-based (which tend to attract more visitors and are more vulnerable to drought), and/or are in an area of moderate to high wildfire risk based on CSFS Wildfire Threat data.
- Vulnerability to aquatic habitat and species as shown in Figure 25 (consisting of instream flows and state-owned or operated fish hatcheries) was found to be highest in these counties: Mesa, Pueblo, Arapahoe, Ouray, Teller, El Paso, Montrose, Fremont, Alamosa, Garfield, Huerfano, Delta, Jefferson, Larimer, Gilpin, San Miguel, and Clear Creek. This is because these counties contain state-owned or operated hatcheries and/or many instream flows (as determined from data obtained from CPW and the CWCB), and they could have relatively junior instream flow rights.

Jurisdictional vulnerability to drought for the six private (i.e., not state-owned) sectors is discussed in detail in Annex B. General results by sector are as follows:

- Vulnerability to agriculture activities was higher in counties with significant proportions of dryland crops compared to total farmed acreage, and in counties with high numbers of grazing cattle and livestock feed program allocations. Aspects about the Green Industry were taken into account as well, to derive overall vulnerability ranks. These counties are found to be most vulnerable (obtaining scores of 3.5 and above, or most vulnerable/least adaptable): Adams, Baca, Kiowa, Kit Carson, Lincoln, and Yuma.

Although the vulnerability analysis for the Energy Sector was performed on a county by county basis to be consistent with the drought vulnerability modeling methodology, it is important to note that energy production is regional, i.e., it is distributed over a grid which covers the entire

western United States. Generally, the energy sector is fairly resilient to drought impacts. This is due to the broad spectrum of drought preparedness utilities and power providers implement, which can range from diverse water rights portfolios to contract supplies from municipalities. In addition, due to a shift in energy production that is moving towards more sustainable and renewable sources, county vulnerabilities are changing from what was previously expected due to reliance on water for cooling processes in mining, for example. The county-level analysis showed that vulnerability was higher in counties with high mining water use (as estimated in a 2010 study from the USGS), and of that water use, counties using a higher percentage of surface water (as opposed to groundwater) are considered more vulnerable to drought. Counties with renewable energy development options (wind and/or solar power) were considered to have higher adaptive capacity, so that drought vulnerability is subsequently reduced. These counties scored highest in vulnerability: Washington, Cheyenne, Routt, Fremont, Boulder, Adams, and Moffat.

- Vulnerability in the Environmental Sector was higher in counties with relatively low protected area status (as determined by stewardship rankings in the 2000 Southwest Regional Gap Analysis Program), a relatively high number of Environmental Protection Agency (EPA) 303(d) Listed Impaired Waters, forests infected by bark beetle (as determined by the USFS aerial surveys), moderate to high ranking in the wildfire threat data, relatively junior instream flow rights, and a relatively high number of high-order streams (as determined by the USGS National Hydrography Dataset flowline attributes). The highest-ranking counties in terms of vulnerability/low adaptability are: El Paso, Delta, Fremont, Moffat, Logan, Las Animas, Garfield, Mesa, Larimer, and Weld counties.
- Vulnerability to the M&I Sector is generalized to water divisions rather than specific counties or water providers. In general, providers will be better insulated from drought impacts if they have senior water rights, if they actively plan and are prepared for drought, and if they have a diverse portfolio. Specific vulnerability rankings were not available for this Sector. Drought and water resources planning information from CWCBS surveys focused on the M&I sector were conducted in 2004, 2007 and 2013 along with supplemental information from various resources that were used to characterize the sector's vulnerability.
- Vulnerability to drought specific to the Recreation and Tourism Sector was higher in counties with little recreational diversity, or a high concentration of water-dependent activities. For example, a county with a strong economic dependence on the skiing industry is more vulnerable to drought impacts than a county with recreational attractions ranging from hiking and camping to rafting and boating. The highest-ranking counties in terms of vulnerability or low adaptability are: Mesa, Garfield, Pueblo, Moffat, Larimer, Routt, and Fremont.
- Vulnerability to drought specific to the Socioeconomic Sector was higher in counties with little economic diversity. Counties that depend upon one main economic sector for the majority of their stability (for example, recreation or agriculture) are more vulnerable to drought conditions. This is because these counties lack other aspects of their economies that would not be impacted by drought to keep the overall economy functioning. In addition, counties with large highly vulnerable or at-risk populations such as the elderly are also more likely to prove

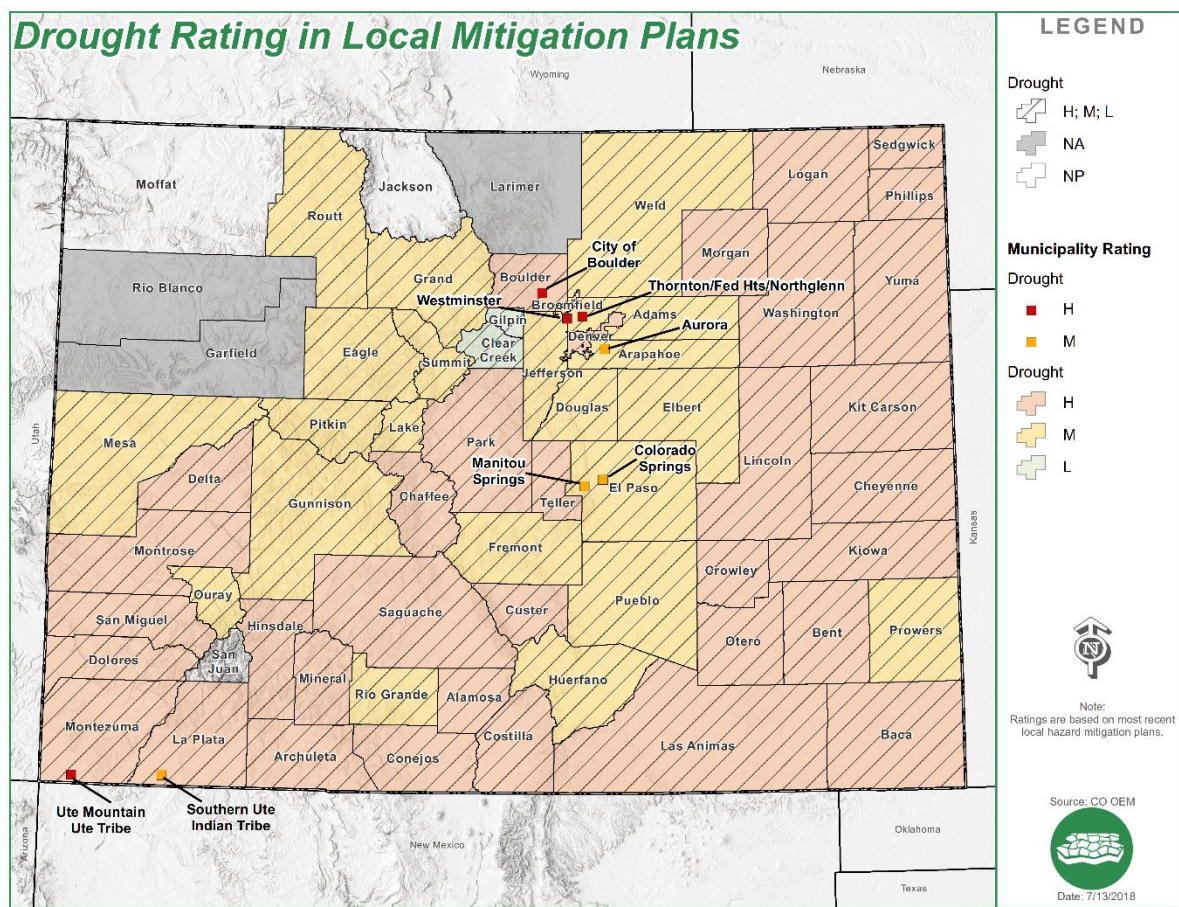
vulnerable in this sector. The highest-ranking counties are: Routt, Pitkin, San Miguel, Summit, Archuleta, Hinsdale, Grand, Weld, Eagle, Montezuma, Custer, Yuma, and Elbert.

In some cases, the counties determined by the vulnerability assessment to have high vulnerability to drought are not as intuitive as others. The limitations and recommendations sections of the Drought Vulnerability Assessment Technical Information report, located in Annex B, include discussion of these instances.

3.3.3 Process Used to Analyze Information from Local Mitigation Plans

As of June 2018, there were three counties (Moffat, Jackson, and San Juan) without Hazard Mitigation Plans, six counties with plans that expired, and 55 counties' plans were approved and active. Figure 20 below highlights how local hazard mitigation plans, including jurisdictional plans (for cities), rate drought in terms of hazard priority. To arrive at these conclusions, the state plans were reviewed to obtain insight as to how individual jurisdictions view their vulnerability to drought.

Figure 20 Ranking of Drought as a Hazard in Local Mitigation Plans in Colorado



The results in Table 10 suggest that counties consider drought a high priority hazard for planning purposes, given the fact they include it in their plans. Not all the plans included a priority ranking, and among those that did the ranking, systems were not uniform. A recommendation for future local planning efforts is to standardize the priority ranking system and drought vulnerability methodology so county-level plans can be easily compared. The statewide methodology presented in this Plan (using risk and vulnerability metrics for the various sectors of the economy) could be adapted and improved upon at the local level for improvement of local hazard mitigation plans. More information on local plan assessment as related to losses is available in Section 3.5.2

3.3.4 Changes in Development Patterns

As part of the Plan revision process, changes in growth and development were examined in the context of drought vulnerability. Changes in growth and development naturally affect loss estimates and vulnerability, and when the population in a hazard area increases, so too does the vulnerability of the people and property unless mitigation measures are taken. When the population of a hazard area decreases, the burden of managing agencies and assuming loss to communal property may exceed the resources of the declining population.

Growth and development are primarily noted in the Socioeconomic and M&I Sector analyses in Annex B, although population growth and decline will cause impacts from drought to manifest with more or less severity across the board. Population growth was factored into socioeconomic vulnerability by designating the fastest growing counties as most vulnerable to drought impacts. Drought can severely challenge a public water supplier through depletion of the raw water supply and greatly increased customer water demand; and any impacts to municipal providers can be exacerbated by increased water demands brought about by a growing population. If a county or city is growing rapidly, the entity may have difficulties securing new sources of water while maintaining a comfortable margin of storage in case of drought. In general, counties experiencing higher growth are also likely to experience increased competition over existing water supplies.

Table 8 summarizes county population and growth rates, and Figure 21 displays the data in map form, illustrated with gray circles to show growth percentages, while shading represents projected growth rates. Projections are from 2010 to 2030. Counties with already large populations and high projected growth include Broomfield and Weld Counties. Other counties with significant growth rates include Elbert and San Miguel. These counties are expected to have correspondingly higher vulnerability to drought as it impacts the M&I and Socioeconomic Sectors (see the M&I and Socioeconomic Sector analyses in Annex B for more discussion). Counties such as Moffat, Jackson, Las Animas, and Kit Carson (among others) are projected to decrease in population anywhere from 0.71% to 0.01%.

Table 8 Projected Growth in Colorado by County, 2010-2030

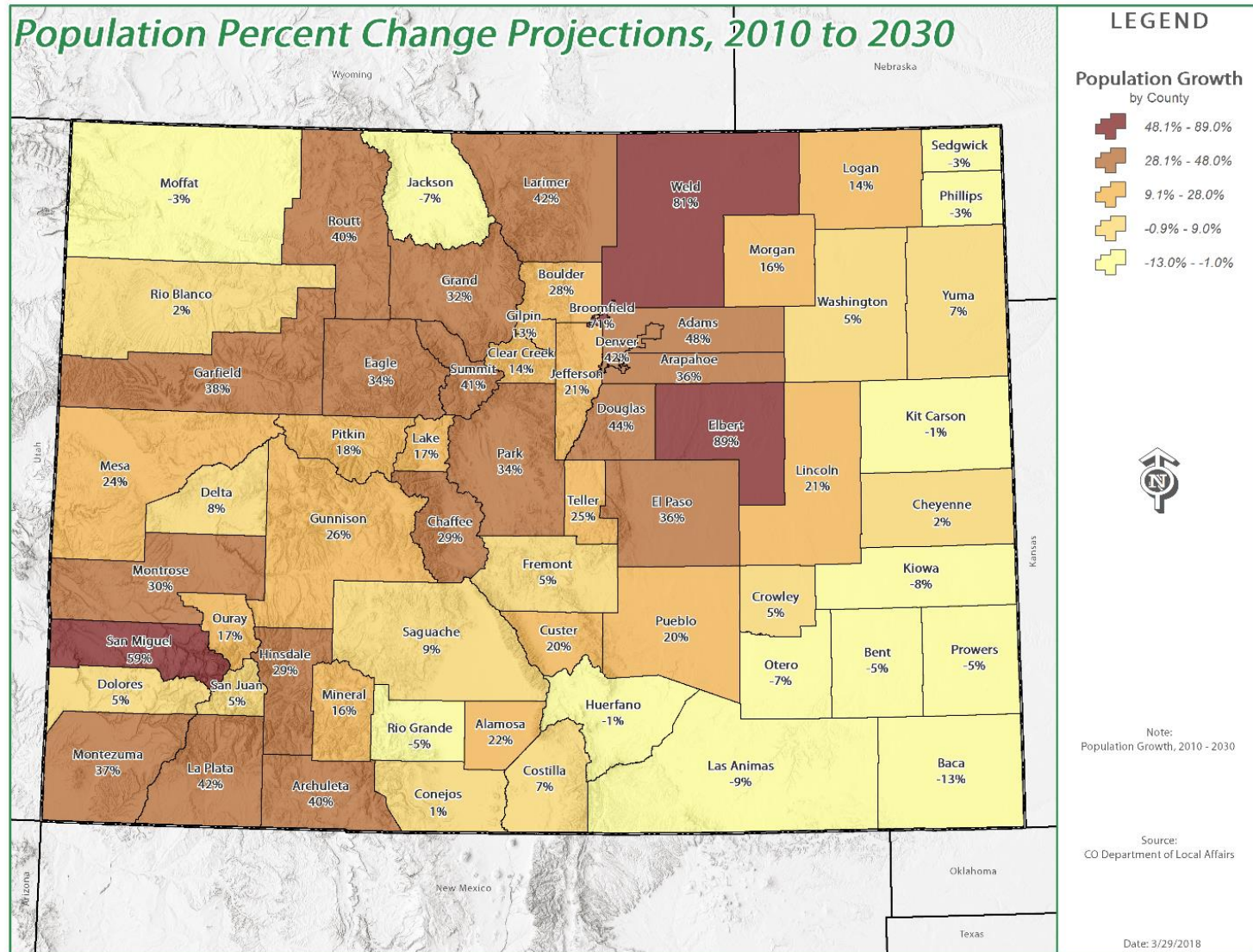
Counties	Census 2010 Population	Projected 2030 Population	Change Percent	Average Annual Percent Change	Growth Rate
COLORADO	5,049,935	6,892,192	20.26%	0.85%	0.01%
Adams	443,709	658,865	48.49%	2.00%	2.00%
Alamosa	15,454	18,894	22.26%	1.01%	1.01%
Arapahoe	574,808	779,283	35.57%	1.53%	1.53%
Archuleta	12,082	16,942	40.22%	1.70%	1.70%
Baca	3,765	3,262	-13.36%	-0.71%	-0.71%
Bent	6,523	6,206	-4.86%	-0.25%	-0.25%
Boulder	295,610	377,107	27.57%	1.22%	1.22%
Broomfield	56,098	96,097	71.30%	2.73%	2.73%
Chaffee	17,835	23,040	29.19%	1.29%	1.29%
Cheyenne	1,811	1,848	2.06%	0.10%	0.10%
Clear Creek	9,083	10,319	13.60%	0.64%	0.64%
Conejos	8,293	8,374	0.97%	0.05%	0.05%
Costilla	3,549	3,795	6.94%	0.34%	0.34%
Crowley	5,850	6,128	4.75%	0.23%	0.23%
Custer	4,248	5,079	19.57%	0.90%	0.90%
Delta	30,897	33,417	8.16%	0.39%	0.39%
Denver	604,875	861,706	42.46%	1.79%	1.79%
Dolores	2,084	2,191	5.15%	0.25%	0.25%
Douglas	287,119	413,162	43.90%	1.84%	1.84%
Eagle	52,064	69,748	33.97%	1.47%	1.47%
El Paso	627,238	855,170	36.34%	1.56%	1.56%
Elbert	23,140	43,695	88.83%	3.23%	3.23%
Fremont	46,856	49,354	5.33%	0.26%	0.26%

Counties	Census 2010 Population	Projected 2030 Population	Change Percent	Average Annual Percent Change	Growth Rate
Garfield	56,153	77,404	37.85%	1.62%	1.62%
Gilpin	5,461	6,178	13.13%	0.62%	0.62%
Grand	14,790	19,487	31.76%	1.39%	1.39%
Gunnison	15,314	19,282	25.91%	1.16%	1.16%
Hinsdale	825	1,067	29.32%	1.29%	1.29%
Huerfano	6,639	6,560	-1.19%	-0.06%	-0.06%
Jackson	1,417	1,316	-7.10%	-0.37%	-0.37%
Jefferson	535,648	647,959	20.97%	0.96%	0.96%
Kiowa	1,410	1,298	-7.98%	-0.41%	-0.41%
Kit Carson	8,259	8,169	-1.09%	-0.05%	-0.05%
La Plata	51,443	73,266	42.42%	1.78%	1.78%
Lake	7,288	8,536	17.12%	0.79%	0.79%
Larimer	300,545	426,293	41.84%	1.76%	1.76%
Las Animas	15,383	13,937	-9.40%	-0.49%	-0.49%
Lincoln	5,502	6,673	21.28%	0.97%	0.97%
Logan	22,291	25,438	14.12%	0.66%	0.66%
Mesa	146,587	181,209	23.62%	1.07%	1.07%
Mineral	728	846	16.22%	0.75%	0.75%
Moffat	13,812	13,389	-3.06%	-0.16%	-0.16%
Montezuma	25,515	35,043	37.34%	1.60%	1.60%
Montrose	41,179	53,355	29.57%	1.30%	1.30%
Morgan	28,213	32,631	15.66%	0.73%	0.73%
Otero	18,875	17,566	-6.94%	-0.36%	-0.36%
Ouray	4,471	5,210	16.54%	0.77%	0.77%
Park	16,277	21,834	34.14%	1.48%	1.48%
Phillips	4,467	4,336	-2.93%	-0.15%	-0.15%

Counties	Census 2010 Population	Projected 2030 Population	Change Percent	Average Annual Percent Change	Growth Rate
Pitkin	17,147	20,218	17.91%	0.83%	0.83%
Prowers	12,527	11,865	-5.28%	-0.27%	-0.27%
Pueblo	159,464	191,163	19.88%	0.91%	0.91%
Rio Blanco	6,634	6,763	1.95%	0.10%	0.10%
Rio Grande	12,018	11,440	-4.81%	-0.25%	-0.25%
Routt	23,451	32,916	40.36%	1.71%	1.71%
Saguache	6,101	6,672	9.35%	0.45%	0.45%
San Juan	713	746	4.62%	0.23%	0.23%
San Miguel	7,393	11,742	58.83%	2.34%	2.34%
Sedgwick	2,403	2,340	-2.64%	-0.13%	-0.13%
Summit	28,078	39,540	40.82%	1.73%	1.73%
Teller	23,402	29,228	24.90%	1.12%	1.12%
Washington	4,851	5,104	5.22%	0.25%	0.25%
Weld	254,240	459,772	80.84%	3.01%	3.01%
Yuma	10,030	10,721	6.89%	0.33%	0.33%

Source: Colorado Department of Local Affairs, March 2018; U.S. Census, 2010

Figure 21 Projected Population Growth by County, 2010-2030



Source: Colorado Hazard Mitigation Plan 2018

3.4 Assessing Vulnerability of State Facilities

Vulnerability to state facilities and other assets from drought varies depending on the asset. For state-owned or operated facilities (e.g., buildings, dams, ditches) the primary vulnerability is to catastrophic loss due to wildfires that can be made more severe by drought conditions. These facilities can be damaged due to prolonged droughts. For example, a building can be in an area with mandatory municipal watering restrictions, and as a consequence landscaping can be damaged or lost, incurring costs to the State. Dams and ditches, which are built to hold water, can become weakened if left dry for extended periods of time. The at-risk critical assets and their impacts are shown in Table 9, revised from the 2018 Updates to the Colorado Drought Mitigation and Response Plan.

Table 9 Critical Assets at Risk to Drought

State Assets at Risk	Key Impacts
State owned or operated buildings	Increased exposure to wildfires, increased wear and tear on building exterior and HVAC systems due to degraded air quality, and water shortages due to out-of-priority rights or restrictions imposed by municipality, landscaping loss.
Critical infrastructure	Decreased water levels in dams can cause structural damage, dry ditches can be damaged by animal holes and general exposure, and increased vegetative growth and high sediment loading resulting from low reservoir levels or wildfire debris can damage structures. Drought causes extensive damages to state rights of way through accumulation of dust and dirt on right of way fences and stormwater diversion utilities.
State Land Board	Decreased forage and crop yields on leased lands, negative impacts to lands if lessees do not appropriately adjust grazing allowances, and decreased mining activity if water is not available for production.
State Parks and CPW	Low reservoir and stream levels can deter visitors and prevent water-based recreation, park closures and campfire restrictions can result from severe wildfires, negative media portrayal is possible, and visitation decline results in lower operating budget. Revenue from licenses, water activities, tourism, park visitation, biological loss – State Forest and park land trees – dead trees, beetle activity, wildfires, impacts to tourism and recreation sectors.
Aquatic habitat	Impacts to flow levels, water quality, habitats, and fish populations, including increased management requirements and protection programs.
Instream flow rights	Junior rights associated with instream flows mean that adequate water flow may not be secured in the expected way, leading to possible economic and biological losses.

These at-risk state assets were reviewed and incorporated into the state assets assessment (the results of which are summarized in Section 3.3.2).

The following sections describe the types of facilities included in this assessment and present an overview of estimated monetary losses, where available.

3.4.1 Types of State Owned/Operated Facilities

For the vulnerability assessment of state assets, the sector was divided into the following sub-sectors: state infrastructure (buildings and dams), Land Board revenue (including state-owned lands), state-based recreation, aquatic species and habitat, and protected areas. Drought vulnerable critical infrastructure includes dams, transmountain ditches, and irrigation ditches. Instream flow rights are non-consumptive “in-channel” or “in-lake” water rights that can only be held by the Colorado Water Conservation Board, and were used as metrics to calculate vulnerable aquatic species and habitat as well as protected state-owned and operated areas. These instream flow rights designate minimum flows between specific points on a stream, or water levels for natural lakes.

The primary agencies responsible for drought-vulnerable state assets are the State Land Board, CWCB, and the CPW. Table 10 lists some key impacts to sub-sectors (based on their associated metrics and features) that were identified during the literature review and interview portion of the vulnerability assessment, in addition to those listed in Table 10.

Table 10 State Assets Key Impacts

State Assets Sub-sector	Key Impacts
State-owned or operated buildings	Increased exposure to wildfires, increased wear and tear on building exterior and HVAC systems due to degraded air quality, and water shortages due to out-of-priority rights or restrictions imposed by municipality, landscaping loss.
Critical infrastructure	Decreased water levels in dams can cause structural damage, dry ditches can be damaged by animal holes and increased vegetative growth and high sediment loading resulting from low reservoir levels. Wildfire debris can damage structures as well. Drought causes extensive damages to state rights of way through accumulation of dust and dirt on right of way fences and stormwater diversion utilities.
State Land Board	Decreased forage and crop yields on leased lands, negative impacts to lands if lessees do not appropriately adjust grazing allowances, and decreased mining activity if water is not available for production or cooling processes.
State Parks	Low reservoir and stream levels can deter visitors and prevent water-based recreation, park closures and campfire restrictions can result from severe wildfires, negative media portrayal is possible, and visitation decline results in lower operating budget. Increased costs of wildlife population management may occur as well, given degradation of habitats and environmental resources.
Aquatic habitat	Impacts to flow levels, water quality, and fish populations which are tied to increased management requirements.
Instream flow rights	Junior rights associated with instream flows mean that adequate water flow may not be maintained, resulting in environmental damages.

3.5 Estimating Potential Losses by Jurisdiction

Many state assets are conservation areas or protected wildlife that cannot be adequately evaluated based on the revenue they generate. Colorado is renowned for its wilderness areas and outdoor recreation activities, and the value of these areas goes far beyond any revenue stream. Still, economic consideration is important because the revenues generated by state assets help to maintain protected areas. The following sections offer discussion on infrastructure values, land values, and revenue streams for the state agencies such as those listed above.

3.5.1 Overview and Analysis of Potential Losses

A list of state-owned buildings and structures was provided by the Colorado Risk Management Office in 2017. This list is fairly comprehensive but may not be a complete inventory of state buildings (e.g., university campuses are not reflected in the list and there are individual counties that maintain their own lists of local assets, which may be more comprehensive than the statewide dataset). Critical infrastructure data (limited to dams for the quantitative analysis) were originally obtained from the Homeland Security Infrastructure Program (HSIP) Freedom database, which in turn used information from the National Inventory of Dams from 2015. Storage and volume data was not available for the 2018 Plan update, and as such was pulled from the previous version of the vulnerability assessment published in 2013. Table 11 summarizes building values and dam storage volumes by county, along with the vulnerability ranking (1 through 4, where 1 is the lowest vulnerability and 4 is the highest vulnerability) for the overall “structures” category. The vulnerability ranking is a weighted average of spatial inventory and vulnerability metrics – the spatial inventory establishes the relative presence of the drought-vulnerable item or sub-sector (in the case of structures, the items are buildings and dams), and the vulnerability metrics establish relative impacts to drought (for structures, the metrics are relative importance of dams over buildings as well as ratings on the wildfire susceptibility index). The result of combining these into a weighted average based on spatial density is the overall vulnerability ranking. See Annex B for a thorough explanation of the vulnerability ranking methodology.

In Table 11, counties that are ranked highly have a considerable amount of storage in state-owned or operated dams, and their buildings may be within a moderate or high wildfire threat area. In addition, building and structure values may quite high, indicating a large number of state-owned and managed structures that may be difficult to manage and maintain given drought conditions. The next step to improving this loss estimate would be to expand the database to include not just dams, but other state-owned water conveyances like ditches and channels. Instead of storage volume, the cost to repair or replace these assets would be another source of information that could be used to estimate potential costs due to drought impacts, as it would more fittingly describe actual impacts to those structures.

Table 11 Building Values, Dam Storage, and Vulnerability to Structures, by County

County	State-owned or Operated Building/Structure Value	State-owned Dam Storage Volume (Acre Feet)	Structures (buildings and dams) Vulnerability Ranking
Adams	\$ 2,161,277,205	0	2
Alamosa	\$ 361,142,477	0	1.7
Arapahoe	\$ 539,093,243	85	2
Archuleta	\$ 12,576,016	2,149	3.3
Baca	\$ 1,559,394	75,241	3
Bent	\$ 116,882,346	0	2
Boulder	\$ 3,184,873,780	0	2
Broomfield	\$ 7,925,505	0	1.7
Chaffee	\$ 135,641,024	0	2
Cheyenne	\$ 712,471	0	2.6
Clear Creek	\$ 117,846,309	0	1.7
Conejos	\$ 6,598,804	14,965	3
Costilla	\$ 4,179,436	0	2
Crowley	\$ 99,475,999	0	1.7
Custer	\$ 1,130,093	0	2
Delta	\$ 39,890,611	1,333	2.3
Denver	\$ 2,631,589,251	0	1.7
Dolores	\$ 4,252,292	0	2.3
Douglas	\$ 41,437,868	0	2.3
Eagle	\$ 22,080,216	576	3.3
El Paso	\$ 664,445,003	0	2
Elbert	\$ 6,135,198	0	1.7
Fremont	\$ 762,885,781	0	2.3
Garfield	\$ 935,656,625	4,826	2.6
Gilpin	\$ 10,009,237	0	1.7
Grand	\$ 12,702,273	220	2
Gunnison	\$ 297,472,631	2,137	2.3
Hinsdale	\$ 1,605,114	12,829	2.4
Huerfano	\$ 35,640,305	2,760	2.6
Jackson	\$ 13,799,847	8,822	2.4
Jefferson	\$ 1,220,747,271	0	2.3
Kiowa	\$ 1,308,651	0	1.7
Kit Carson	\$ 4,146,764	1,360	3
La Plata	\$ 459,565,270	526	2.3

County	State-owned or Operated Building/Structure Value	State-owned Dam Storage Volume (Acre Feet)	Structures (buildings and dams) Vulnerability Ranking
Lake	\$ 2,881,105	0	1.7
Larimer	\$ 2,520,380,928	3,039	3
Las Animas	\$ 152,450,903	0	2.6
Lincoln	\$ 115,435,436	345	2
Logan	\$ 321,168,915	950	2.3
Mesa	\$ 571,483,874	3,580	3.3
Mineral	\$ 30,302,497	3,199	1.7
Moffat	\$ 15,349,887	115	2.6
Montezuma	\$ 26,250,958	0	2.6
Montrose	\$ 19,168,190	0	2.6
Morgan	\$ 67,190,695	0	2.3
Otero	\$ 79,711,659	0	2
Ouray	\$ 8,684,297	0	2
Park	\$ 17,071,984	1,963	3
Phillips	\$ 196,989	106	2.4
Pitkin	\$ 712,334	0	2
Prowers	\$ 73,450,933	0	2
Pueblo	\$ 1,100,717,918	77	2.3
Rio Blanco	\$ 63,910,055	9,038	3.3
Rio Grande	\$ 134,839,207	5,158	2.3
Routt	\$ 19,636,863	29,249	3.3
Saguache	\$ 5,188,187	880	3
San Juan	\$ 4,603,609	131	1.7
San Miguel	\$ 6,959,485	7,081	3
Sedgwick	\$ 1,827,494	63	2.4
Summit	\$ 210,520,143	0	1.7
Teller	\$ 9,932,427	2,066	2.7
Washington	\$ 4,317,255	0	2.3
Weld	\$ 723,621,026	192	2.6
Yuma	\$ 14,101,084	143	2

Source: Risk Management Office, 2017. Dam Storage Volumes from 2013 Plan

The State Assets sub-sector analysis includes a thorough discussion of the ranking process, but in general the factors of vulnerability for structures were “relative importance of storage” and “wildfire threat ranking.” Structure rankings ranged from 1.7 to 3.3, which is a relatively small range. A higher ranking resulted from a high relative importance of water storage and location within the wildfire urban interface.

The State Land Board is another other sub-sector within state assets where a dollar-value for the revenue stream was available. The State Land Board generates revenue by leasing land for agricultural and industrial activities. They also lease mineral and mining rights, and a significant portion of their income is produced by mineral royalties. Table 12 shows the leasing revenue by source for fiscal years 2014-2017. Although agricultural leases account for most of the land leases, they do not generate as much revenue as the mineral, oil, gas, and coal royalties.

Table 12 State Land Board Gross Revenue, FY 2014-2017

Revenue Source	FY 2014	FY 2015	FY 2016	FY 2017
Minerals including oil and gas, coal, copper, gravel, uranium, and other minerals	\$ 155,207,000	\$ 167,152,000	\$ 108,382,000	\$ 95,158,000
Surface including rental payments for grazing, cropland, rights-of-way, recreation, surface use agreements, timber sales, and ecosystem services	\$ 13,367,000	\$ 15,759,000	\$ 18,158,000	\$ 17,243,000
Commercial including rental payments from office buildings, ground leases, communication towers, and renewable energy	\$ 4,815,000	\$ 3,797,000	\$ 4,462,000	\$ 5,303,000
Revenue from Land Sales not reinvested in new properties	\$ 0	\$ 3,751,000	\$ 5,303,000	\$ 1,355,000
Interest income	\$ 215,000	\$ 896,000	\$ 972,000	\$ 343,000
TOTAL	\$ 173,604,000	\$ 191,355,000	\$ 137,277,000	\$ 119,402,000

Source: Office of the State Auditor analysis of the State Land Board's Fiscal Year 2016 Income and Inventory Report, and Fiscal Year 2017 data provided by the State Land Board.

Drought impacts to this revenue stream are mainly incurred through agricultural leases. Based on past conversations with State Land Board representatives, the mineral asset revenue is relatively drought tolerant; while it is likely that mineral producers would incur extra operating costs in a drought, it has not been the experience of the State Land Board that producing companies actually stop operations or postpone expansions. However, most mining activities do require water, and it is possible that, in a severe drought, mining operations would be unable to purchase the water they need for production. For a greater discussion and more information, refer to the Energy Sector analysis which discussing mining and power generation. Given the importance of mining revenue to the State Land Board, this possibility should be taken seriously in any future planning efforts.

While the mineral leases bring in the most revenue every year, the most vulnerable State Land Board revenue stream is actually the agricultural lease revenue. Under drought conditions, rangeland carrying capacity can be significantly reduced, leading to overgrazing concerns and financial hardship for the agricultural lessees. Similarly, crop yields on agricultural leases may be reduced and/or crop failure may occur. Agricultural leases through the State Land Board are issued on a 10-year basis, which makes it difficult for farmers and ranchers to change the amount of leased area in response to drought. However, the State Land Board has a vested interest in the responsible stewardship of the land, and in the past, they have been willing to offer lease discounts during drought in exchange for a reduction in grazing or other detrimental activity. In the 2002 drought, the State Land Board issued blanket lease discounts (between 10% and 40%) in an attempt to reduce grazing activity. The total cost of these discounts was estimated by State Land Board staff to be \$1.9 million. These discounts did not have the intended mitigating impact because many lessees continued to manage the land as usual, however. As of the 2010 Plan Update, the State Land Board was planning on only offering lease discounts during future drought when applied for on a case-by-case basis (personal communication with State Land Board, 2010). However, the lease discount program was discontinued in 2012 (personal communication with State Land Board, 2013), and remains that way as of the 2018 Plan update.

Other potential losses to state departments include reductions in visitation to state parks and fewer hunting and fishing license sales. Both visitation and license sales are important revenue streams for CPW. Data are available showing a decrease in visitation to Colorado state parks during the 2002 and 2011-2013 drought events, but no revenue loss figures are available. Similarly, losses are expected to occur to CPW during future drought, but no exact figures outside of visitation totals were obtainable for this assessment. To give a sense of the relative importance of licensing revenue to CPW, in fiscal year 2002-2003, licensing accounted for \$60.6 million out of the \$87 million revenue stream, and in fiscal year 2003-2004 it accounted for \$67.4 million out of the \$100.3 million revenue stream. As of the 2018 Plan update, CPW attributed \$114 million out of \$212.4 million in revenue to licenses, passes, fees, and permits for the 2015-2016 fiscal year, (CPW Fact Sheet, 2017).

One way to estimate potential losses due to drought is to look at previously-reported losses and existing economic exposure of state assets. Table 13, taken from the 2007 Drought Update Report and updated with current sources, summarizes losses from recent droughts, and tabulates economic exposure of at-risk state assets.

Table 13 Potential Drought Losses Based on Historic Economic Impacts

Potential Economic Impacts to State Facilities	Where Potential Losses and Effects Could be Exhibited	State Economic Exposure and/or Past Drought Impacts
Costs and losses to agricultural and livestock producers	State lands leased for crops to crop producers for farming and livestock producers for grazing Grazing, recreation, and forestry uses of Colorado State Forests	Accounting for the last eight years, the State Land Board has generated \$12-19 million annually in revenues from leases and royalties in land leased for ranching/grazing, farming, and recreation alone (not counting mineral leases or commercial building leases). However, for past drought years, these revenues have been shown to decrease when compared with non-drought years (e.g., Fiscal Year 2011-2012 vs. FY 2013-2014) (Colorado State Land Board Commissioners, 2014). While it is difficult to attribute all revenue differences directly to drought, it is expected that it may be a part of the reason revenues are reduced during dry years.
Loss from fishery production	State-owned fish propagation and restoration facilities Fishing license sales Fish in streams throughout state (since all wildlife is “owned” by the State) Angler visitation and spending	CPW estimates that fishing activities and angler-based spending contributed 1.9 billion to the Colorado economy, both directly and indirectly, for the 2015-2016 fiscal year. CPW operates 15 fish propagation facilities, including the Roaring Judy Hatchery for the propagation of endangered Colorado River fish, which may be affected in times of drought due to reduced revenues and/or water resources. In 2002, fishing license sales declined by about 15% from 2001, and there was a 13.4% decline in fishing recreation days from 2001 to 2002. Salmon runs were impacted by the 2012 (latest) major drought in Colorado (The Journal, 2012). The drought prevented the annual run due to low water levels in the Dolores River, which created a shallow, delta-like area of sediment that blocked the salmon from migrating. Kokanee eggs placed on the Dolores River by CPW to bolster the adult fish stocks in the McPhee Reservoir were not able to reach upstream spawning waters.
Losses to wildlife	Hunting license sales Wildlife throughout the State Management costs	CPW estimates that hunting (big and small game) generated \$292.6 million in direct visitor expenditures for the 2011-2012 fiscal year. This revenue helped support over 900 full time CPW employees. While CPW license sales have generally increased over time, reductions in total sales were apparent during the 2012 and 2013 years (CPW 2015). A possible/partial explanation of the decrease in sales could be drought conditions and negative public perception of the health of State Parks, natural resources, and wildlife. The number of full time CPW employees has reduced slightly since 2011-2012, down to 886, likely due to changes in spending and budgets.

Potential Economic Impacts to State Facilities	Where Potential Losses and Effects Could be Exhibited	State Economic Exposure and/or Past Drought Impacts
Costs and losses to state parks	Revenues Damage to parks themselves	For the 2015-2016 fiscal year, Colorado's state parks had over 13.6 million visitors. Visitors to Colorado state parks contribute over \$6 billion annually to local economies, directly and indirectly. Back in 2002, state parks experienced a 3% decline in visitation.
Losses due to hydrological effects	State-owned instream flows	CWCB has appropriated instream flow water rights on over 1,800 stream segments covering 10,332 miles of streams (as of 2018). Instream flow impacts during the 2002 drought were mitigated somewhat by downstream senior water rights calls. While acquisition of instream flows can benefit state-owned environmental assets, extensive junior rights can prove limiting in times of water scarcity and drought.

Source: 2007 Drought Update Report, CPW 2018. Statistics modified in 2010, 2013, and 2018

Instream flow rights are considered assets, as they have a real value on the water rights market. This market is highly variable and not well-documented; therefore, tabulating the 2018 value of CWCB water rights would be impractical from a logistical as well as value-added perspective. In future droughts it might be beneficial to track the value of instream flow rights to assess whether they gain or lose, and to collect data on additional expenditures by the CWCB to maintain a minimum flow to protect aquatic habitat during droughts.

In 2002 CPW learned that instream flows were not as adversely affected as precipitation conditions would have initially indicated, since low water supplies during the extreme drought resulted in a shift in typical water right administration and water use patterns. In 2002, there were significantly fewer and less depletions from junior water rights and the calling senior water rights were farther downstream thus having the effect of pulling water downstream through the watershed; the junior intervening instream flow water right became the unintended beneficiary of this pattern of water right administration. As a result, a number of higher order streams (e.g., first, second, and third order streams) experienced water levels greater than or equal to what is typically experienced under normal water supply conditions. Further, the 2002 drought experience highlighted the need for CPW and CWCB to increase their cooperative efforts regarding management of the now CPW's (previously DOW) water right portfolio, in particular the use of reservoirs and storage water rights, to examine the feasibility of releasing water to protect instream flows, releasing water to water uses downstream (CPW uses and other downstream uses) with the intervening instream flow reach becoming the incidental beneficiary of such practices.

Another asset heavily impacted by drought is crop yield, and the overall agricultural sector. Table 14 below shows agricultural indemnities from 2007-2017 due to drought in Colorado, by county. The data were obtained from the USDA Risk Management Agency and filtered for losses incurred specifically by drought. 2012 and 2013 had significantly higher totals for reported crop indemnities, which reflects the drought conditions across the state. Crop indemnities are just one

dataset that can be used to estimate potential losses for drought. While not specific to state assets, agricultural losses have the potential to significantly impact a local economy, which in turn can reduce the tax base and cause decreased government revenue.

Based on the information in this table, the total crop indemnity amount for all counties between 2007 and 2017 was over \$550 million. This equates to an average annual drought related crop indemnities amount of \$55 million. The top five counties with the highest losses (in order) are: Baca, Kiowa, Kit Carson, Cheyenne, and Washington.

Table 14 USDA Risk Management Agency Crop Indemnities Specific to Drought, 2007-2017

County	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	County TOTAL
Adams	\$503,968	\$3,529,313	\$723,133	\$216,685	\$2,822,833	\$2,776,135	\$4,950,549	-	\$20,521	\$96,626	\$1,318,466	\$16,958,229
Alamosa	-	-	-	-	-	-	-	-	\$30,308	-	-	\$30,308
Arapahoe	\$54,239	\$1,496,292	\$181,481	\$54,077	\$2,298,024	\$1,872,548	\$2,422,782	-	-	\$32,232	\$725,539	\$9,137,214
Archuleta	-	-	-	-	-	-	-	-	-	-	-	-
Baca	\$1,602,454	\$17,696,922	\$1,946,464	\$248,581	\$17,460,089	\$7,689,184	\$21,931,245	\$10,993,442	\$4,928,643	\$310,225	\$1,618,215	\$86,402,143
Bent	\$18,441	\$202,878	\$163,296	\$17,674	\$493,466	\$109,815	\$751,393	\$526,064	\$5,632	-	\$153,547	\$2,442,205
Boulder	\$13,071	\$1,786			\$16,471	\$4,326	\$7,153	-	-	-	\$10,963	\$53,770
Broomfield	\$2,208	\$18,372		\$787	\$24,892	\$16,066	\$76,064	-	-	-	\$36,710	\$175,099
Chaffee	-	-	-	-	-	-	-	-	-	-	-	-
Cheyenne	\$945,174	\$7,888,562	\$391,249	\$119,675	\$2,395,809	\$11,290,463	\$28,919,862	\$8,142,640	\$274,611	\$383,953	\$562,893	\$61,314,891
Clear Creek	-	-	-	-	-	-	-	-	-	-	-	-
Conejos	-	-	-	-	-	-	-	-	-	-	-	-
Costilla	-	-	-	-	-	-	-	-	-	-	-	-
Crowley	\$118,973	\$214,221	\$67,932	\$3,276	\$204,969		\$4,468	\$36,943			-	\$531,809
Custer	-	-	-	-	-	-	-	-	-	-	-	-
Delta	-	-	-	-	\$3,142	-	-	-	-	-	-	\$3,142
Denver	\$27,306	\$189,666	\$41,523	\$26,221		\$59,569	\$57,310			\$9,798	\$98,059	\$509,452
Dolores	\$67,400	\$15,013	\$67,790	\$33,919	\$5,922	\$192,791	\$82,047	\$21,238			\$17,876	\$503,996
Douglas	-	-	-	-	-	-	-	-	-	-	-	-
Eagle	-	-	-	-	-	-	-	-	-	-	-	-
El Paso	-	-	-	-	-	\$50,355		\$9,864	-	-	\$7,099	\$67,318
Elbert	\$113,246	\$1,372,410	\$115,260	\$81,346	\$2,326,928	\$2,350,947	\$2,072,778	\$226,923	\$12,337	\$77,341	\$710,145	\$9,459,660
Fremont	-	-	-	-	-	-	-	-	-	-	-	-
Garfield	-	-	-	-	-	-	-	-	-	-	-	-
Gilpin	-	-	-	-	-	-	-	-	-	-	-	-
Grand	-	-	-	-	-	-	-	-	-	-	-	-

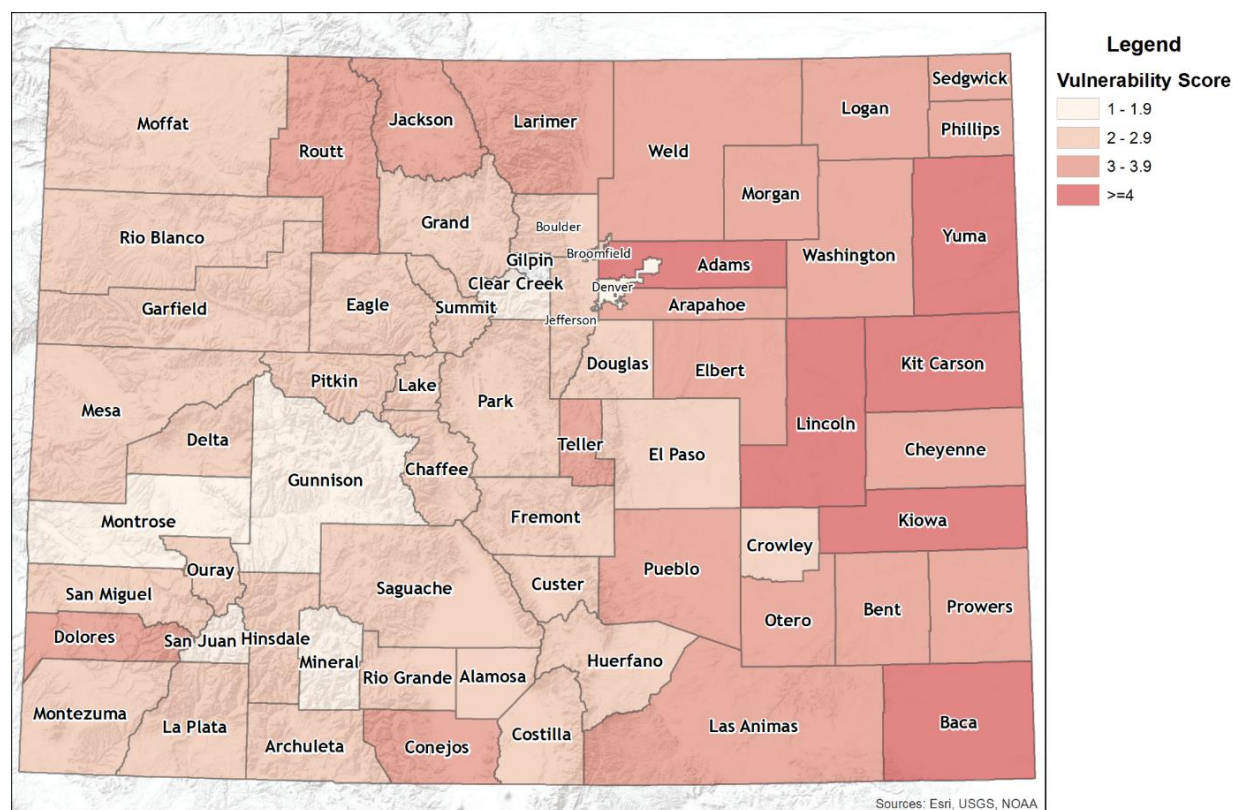
County	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	County TOTAL
Gunnison	-	-	-	-	-	-	-	-	-	-	-	-
Hinsdale	-	-	-	-	-	-	-	-	-	-	-	-
Huerfano	-	-	-	-	-	-	-	-	-	-	-	-
Jackson	-	-	-	-	-	-	-	-	-	-	-	-
Jefferson	-	-	-	-	-	-	-	-	-	-	-	-
Kiowa	\$450,211	\$8,735,942	\$837,016	\$126,083	\$9,335,514	\$16,631,494	\$30,445,877	\$12,296,815	\$746,976	\$2,029,718	\$1,054,803	\$82,489,782
Kit Carson	\$1,406,962	\$6,076,579	\$69,240	\$2,695	\$1,866,837	\$21,161,405	\$32,921,685	\$3,512,724	\$250,178	\$395,990	\$1,235,393	\$68,891,579
La Plata	\$6,786	\$9,818	\$14,588	\$18,022	\$1,647	\$22,805	\$67,106	\$15,593	\$9,977	-	\$8,421	\$174,763
Lake	-	-	-	-	-	-	-	-	-	-	-	-
Larimer	\$1,714	\$11,427	\$985	-	\$28,009	\$8,547	\$29,609	-	-	-	\$39,168	\$119,459
Las Animas	-	\$6,915	\$1,735	-	\$76,936	\$26,720	\$148,832	\$109,033	-	-	-	\$370,171
Lincoln	\$691,723	\$5,261,296	\$546,405	\$274,032	\$8,500,933	\$8,956,940	\$11,121,007	\$2,107,321	\$350,073	\$752,501	\$2,184,995	\$40,747,226
Logan	\$672,616	\$2,417,382	\$142,449	\$92,284	\$229,547	\$4,561,402	\$3,728,355	\$80,864	\$66,477	\$190,096	\$400,923	\$12,582,394
Mesa	-	-	-	-	-	-	-	-	-	-	-	-
Mineral	-	-	-	-	-	-	-	-	-	-	-	-
Moffat	\$8,774	\$22,357				\$29,242	\$128,960		-		-	\$180,559
Montezuma	\$8,951	\$10,124	\$15,359	\$5,511	\$5,752	\$43,392	\$107,168	\$23,283	-	\$975	\$2,536	\$223,051
Montrose	-	-	-	-	-	-	-	-	-	-	-	-
Morgan	\$405,099	\$1,434,712	\$174,484	\$95,986	\$1,049,247	\$1,548,373	\$1,783,875	\$8,776	\$2,295	\$3,278	\$109,206	\$6,615,331
Otero	-	-	-	-	-	\$82,966	\$253,712	-	-	-	-	\$336,678
Ouray	-	-	-	-	-	-	-	-	-	-	-	-
Park	-	-	-	-	-	-	-	-	-	-	-	-
Phillips	\$36,084	\$979,974	\$26,757	\$40,301	\$791,502	\$11,306,964	\$10,503,838	\$108,453	\$420,016	\$9,515	\$705,628	\$24,929,032
Pitkin	-	-	-	-	-	-	-	-	-	-	-	-
Prowers	\$199,326	\$5,312,907	\$713,272	\$139,912	\$4,986,312	\$3,517,762	\$13,950,541	\$5,748,753	\$1,517,310	\$237,729	\$1,041,479	\$37,365,303
Pueblo	\$199,391	\$286,625	\$113,814	\$197,635	\$171,389	\$356,115	\$347,435	\$159,955		\$111,737	-	\$1,744,705
Rio Blanco	-	-	-	-	-	-	-	-	-	-	-	-

County	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	County TOTAL
Rio Grande	-	-	-	-	-	-	-	-	-	-	-	-
Routt	\$842	\$7,745	-	-	-	-	\$98,049	-	-	-	\$15,857	\$122,493
Saguache	-	-	-	-	-	-	-	-	-	-	-	-
San Juan	-	-	-	-	-	-	-	-	-	-	-	-
San Miguel	-	\$115	\$4,525	-	-	\$11,731	\$4,179	\$933	-	-	\$795	\$22,278
Sedgwick	\$39,910	\$62,239	\$11,142	\$4,016	\$406,816	\$4,840,233	\$4,274,744	\$207,761	\$99,196	\$77,522	\$244,593	\$10,268,172
Summit	-	-	-	-	-	-	-	-	-	-	-	-
Teller	-	-	-	-	-	-	-	-	-	-	-	-
Washington	\$838,876	\$4,800,648	\$290,037	\$369,834	\$1,960,595	\$15,668,509	\$18,883,305	\$164,320	\$146,984	\$233,258	\$2,696,826	\$46,053,192
Weld	\$718,172	\$1,598,584	\$189,415	\$130,387	\$1,134,111	\$1,202,956	\$2,310,333	\$37,348	\$13,486	\$42,085	\$932,084	\$8,308,961
Yuma	\$92,118	\$929,365	\$51,824	\$26,117	\$436,494	\$6,358,688	\$10,640,207	\$1,038,989	\$836,638	\$115,138	\$585,177	\$21,110,755
GRAND TOTAL	\$9,244,035	\$70,590,189	\$6,901,175	\$2,325,056	\$59,034,186	\$122,748,443	\$203,024,468	\$45,578,035	\$9,731,658	\$5,109,717	\$16,517,396	\$550,245,120

Source: USDA RMA Reports

Crop indemnities due to drought were one factor in the vulnerability assessment for the Agricultural Sector. Other factors taken into consideration were head of cattle, dryland crop acreage, and livestock indemnities. Figure 22 shows the results of the agriculture vulnerability assessment. See Annex B for a complete discussion of this assessment and the agriculture sector.

Figure 22 Agriculture Sector Overall Vulnerability Ranking



Source: Vulnerability Assessment Tool, 2018 Update

3.5.2 Potential Losses Based on Estimates in Local Risk Assessments

Most county and jurisdictional mitigation plans across Colorado have rated drought as a high significance hazard, as portrayed in Figure 20 of this document, with the rest of those who address the hazard rating it as medium. Only Garfield, Larimer, and Rio Blanco do not include drought in their local plans, while San Juan, Jackson, and Moffat have not rated the hazard due to a lack of a mitigation plan. The cities of Boulder, Thornton/Federal Heights/Northglenn and Westminster as well as the Ute Mountain Ute Tribe have all rated drought as a highly impactful hazard, while Aurora, Colorado Springs, Manitou Springs, and the Southern Ute Indian Tribe rate it as a medium hazard. Drought is considered the top hazard in fifteen communities in the state, then, with areas of El Paso County having the most potential quantified losses from this hazard, followed by the counties of Eagle, Grand, Fremont, La Plata, and areas of unincorporated land in Montrose.

While local hazard mitigation plans often contained information on losses due to drought (e.g., drought rankings, as described under Section 3.3.3), total loss estimations based on crop damages

for those plans that include drought in the top four highest risk hazards was not standard across the board and did not always include losses in a clearly defined way. What becomes clear from reviewing the drought sections of existing local hazard mitigation plans is that not many counties or jurisdictions have quantifiable data available on economic losses due to drought, or on potential losses based on various standard scenarios (e.g., reported damages from prolonged dry conditions); if losses from drought are indeed available, the information is not easy to review alongside other plans. A recommendation moving forward is to begin quantifying economic losses due to drought on a county level, and in a more comparable and standard manner across the state (such as how USDA's RMA losses are presented under Table 14 of this document). Standardizing losses can better highlight areas and/or economic sectors particularly hard-hit, and can help communities anticipate the magnitude of damages that could potential occur in future drought events.

3.5.3 Impacts on Losses from Changes in Development

Drought losses to State Assets, M&I, and the Socioeconomic Sectors in particular are expected to intensify with population growth and development, unless mitigation strategies are adopted. Figure 20 shows projected population growth rates by county and identifies the fastest-growing and potentially most-vulnerable counties. Counties with the highest estimated growth rates from 2010-2030 (according to state demographer estimates) include Weld, Elbert, and San Miguel Counties. The impacts listed in Table 14 above could become more severe in communities with a high rate of development and growth. A more in-depth discussion on growth rates and population change related vulnerabilities is included under Section 3.3.4 Changes in Development Patterns.

3.5.4 Estimating Potential Losses of State Facilities

It is difficult, if not impossible, to put a dollar value on potential losses to state-owned and operated facilities due to drought. The nature of this hazard is that it is slow-moving, long-lasting, and the exact start and end is not always clearly defined. Drought itself does not cause much damage to state facilities; rather, it is usually secondary hazards such as additional maintenance necessary, that arise because of drought and hence have the potential to cause catastrophic losses.

Because data were either not available or non-existent, dollar losses to state assets due to drought by county were not calculated. Instead, drought vulnerability of the state assets was quantified by identifying data that relates to previously-reported impacts. A full discussion of this approach is provided in Annex B, but general results as they relate to this Plan are provided below.

The figures that follow show the overall impact scores and spatial density metrics for the five State Assets sub-sectors. The shading on the maps represents the impact scores/vulnerability rankings, and the size of the gray circle indicates the size of the sub-sector (inventory metric) in a given county.

The state owns structures in every county. As shown in Figure 23, vulnerability for these structures tends to reflect the wildfire threat and dam related data. Highly rated counties are at the

intersection of areas of greatest wildfire threat and locations where the state owns the most dams (e.g., Rio Blanco, Routt, Mesa counties, among others).

Figure 23 State Assets – Structures Inventory and Impact Scores

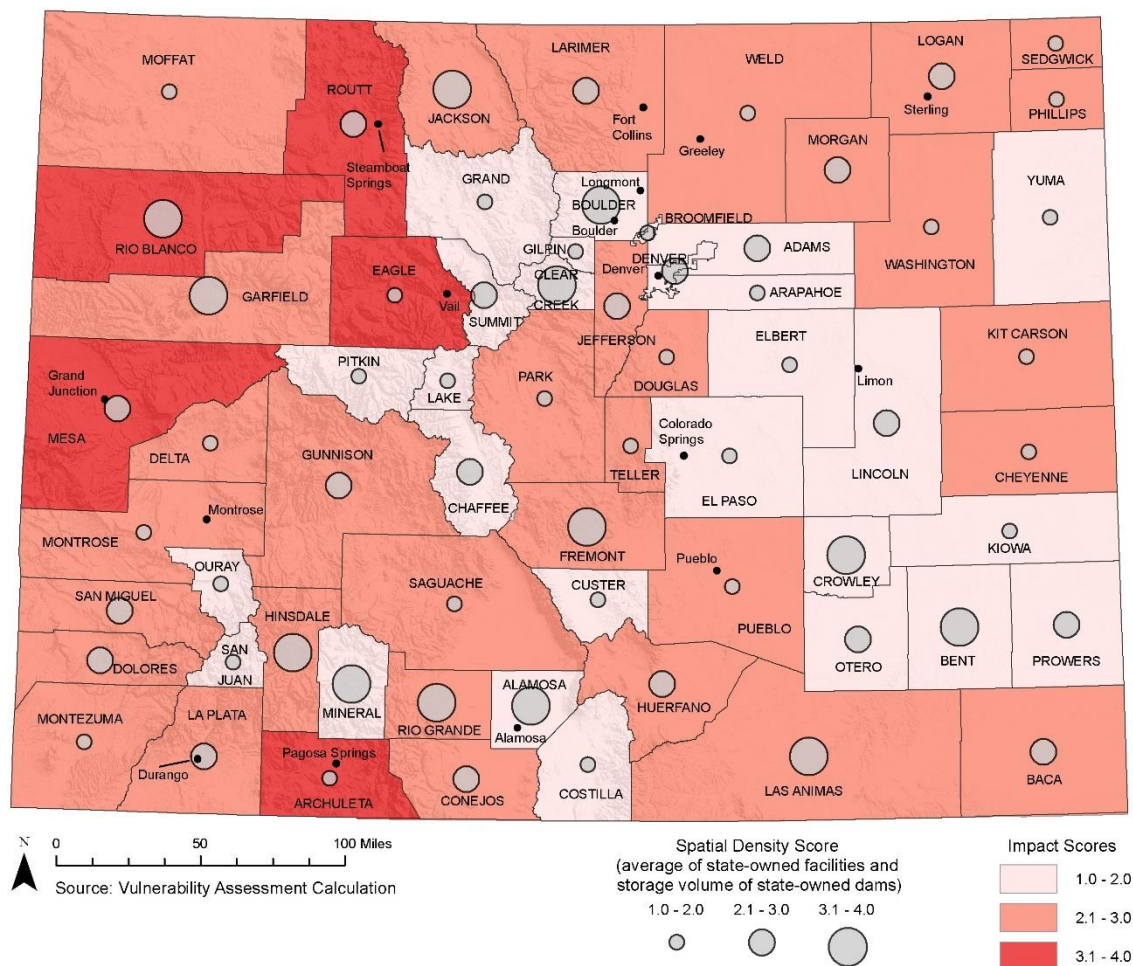


Figure updated in 2018

Vulnerability rankings for the State Land Board are partially dependent on the lease discounts issued in 2002, which although discontinued in present days, can provide context about the effects of drought on leases for agricultural purposes. Figure 24 shows that the eastern half of the state as a whole is more vulnerable than the west, based on again on the lease discounts program which took effect during the major drought of 2002. This is largely due to the significant agricultural presence on the eastern plains (refer to the Agricultural Sector analysis for more information) and because the eastern part of the state received the highest lease discounts of around 40%. Furthermore, many of the counties with high impact scores in eastern Colorado also fall in the largest category for surface ownership by the State Land Board. As discussed previously, the lease discount program was not continued for 2012, so this vulnerability metric could not be updated. Nevertheless, the spatial density metric indicating surface acres owned by the State Land Board, was updated for 2018.

Figure 24 State Assets – Land Board Inventory and Impact Scores

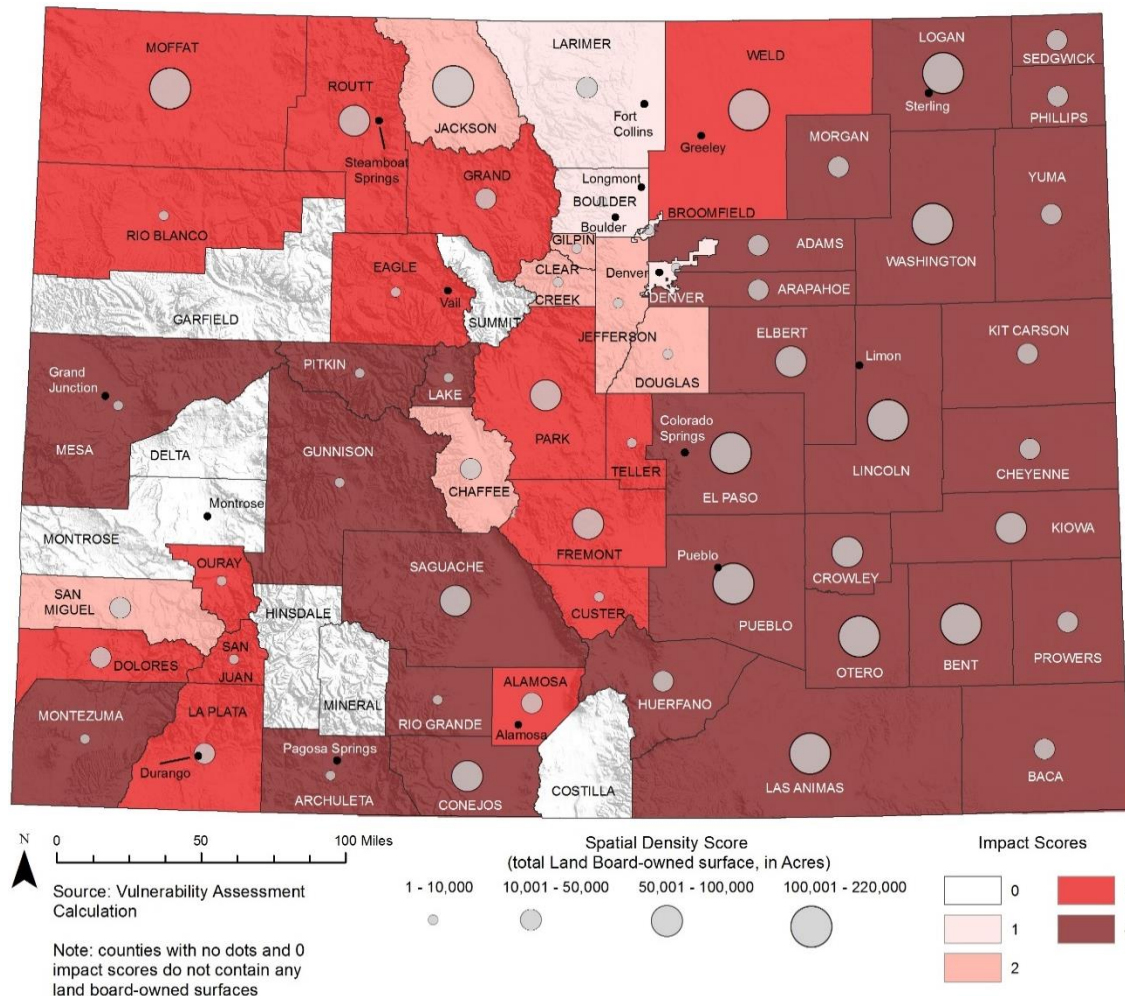


Figure updated in 2018

Figure 25 shows the vulnerability of recreation-based state revenue. Spatial vulnerability of State Parks revenue is highly dependent on the location of water-based state parks, since these tend to see the highest visitation numbers and thus generate the most revenue for the department. Counties located in eastern Colorado with high vulnerability ratings all have state parks with water-based activities, which would be at risk of suffering from revenue income were a drought event to occur.

Figure 25 State Assets – State Parks Recreation Inventory and Impact Scores

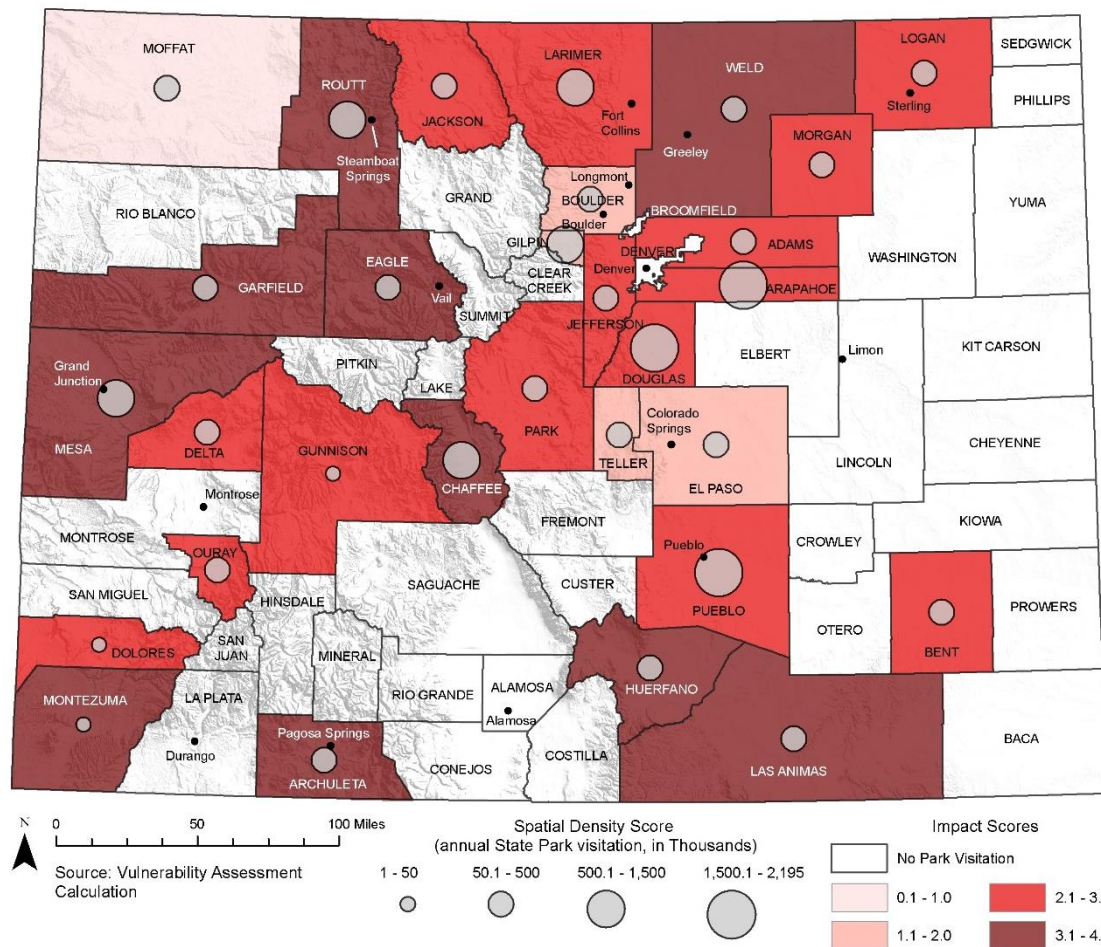


Figure updated in 2018

The final State Asset considered in terms of vulnerability to drought is state-owned aquatic habitat, as defined by instream flows and fish hatcheries. These assets are managed by the CWCW and CPW, respectively. Specific locations of instream flow reaches and fish hatcheries are depicted in Figure 26, as well as maps in Annex B, in the State Assets Sector analysis. Counties with the highest impact scores have the most junior priority dates for their instream flow rights. The spatial density category for the aquatic habitat sub-sector is a count of instream flow reaches and fish hatcheries. El Paso, Mesa, Alamosa, and Pueblo are among those counties with higher vulnerability scores (dark red/brown shading), while Larimer, Garfield, and San Miguel, for example, display higher spatial density rankings (based on the grey dot sizes).

Figure 26 State Assets – State Owned Aquatic Habitat Inventory and Impact Scores

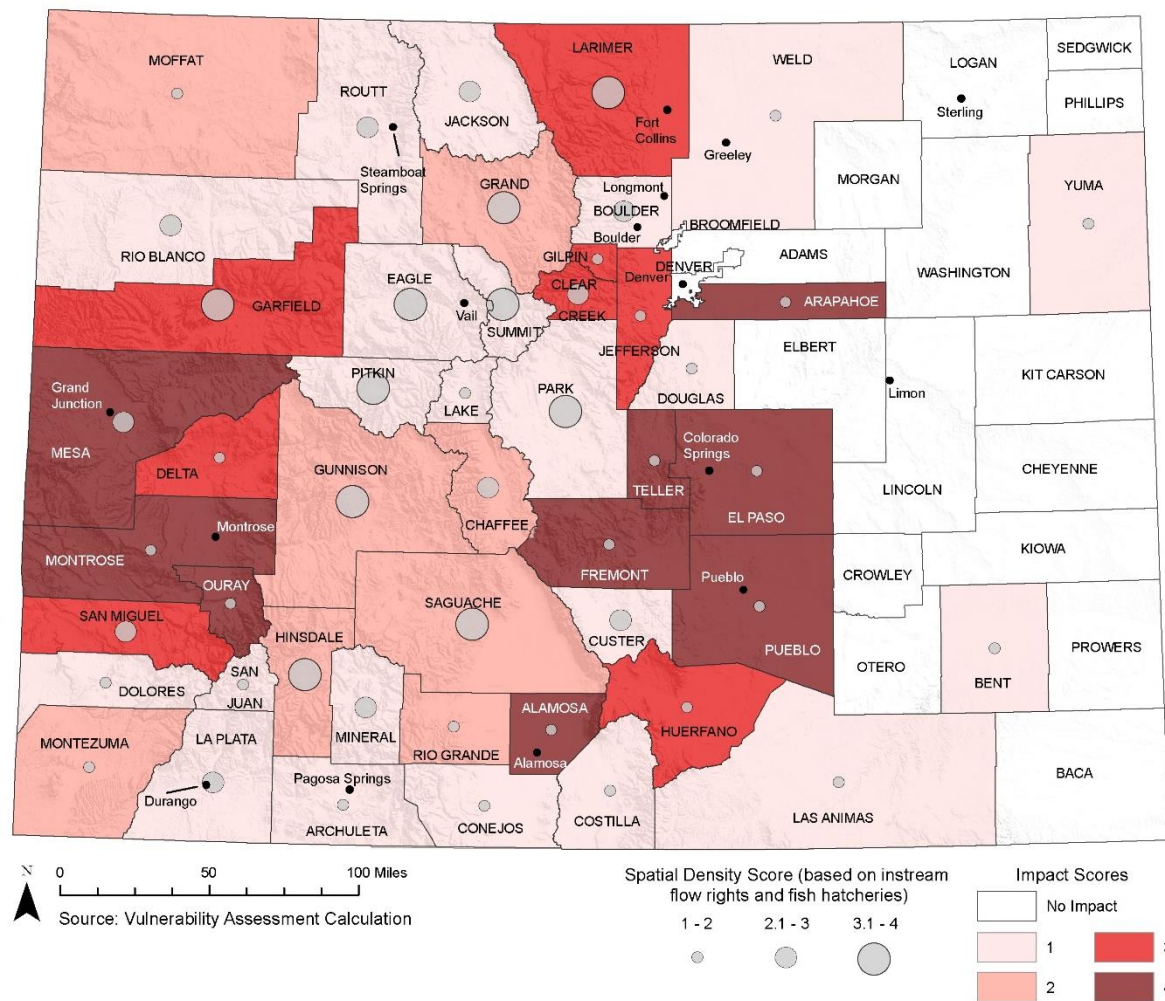


Figure updated in 2018

Taken as a whole, state assets overlap considerably with other sectors considered in this Plan. Work done by the State Parks and CPW helps preserve Colorado's natural environment and promotes public use of outdoor areas. Tourism in Colorado is strengthened by protected areas that are owned and managed by the State. Drought impacts to these assets directly translate to declines in recreation, tourism, and related industries. Furthermore, decreased revenues for state agencies resulting from drought can reduce management budgets, which can have a detrimental impact on lands and wildlife. In 2002, state and local governments received \$550 million in tax revenue from the tourism industry alone (State of Colorado Water Availability Task Force, 2002). For 2015, that number jumps to over \$1.13 billion in state and local tax revenue (The Denver Post, 2016). Clearly, the Environment and Recreation/Tourism Sectors are important to the State. A large portion of the protected areas in the State are government (largely federal) managed, owned or operated, and degradation of natural areas can have compounded effects on society.

Table 14 showed building values per county and indicated the presence of state-owned dams (critical infrastructure). In some counties, the worst-case scenario for building and infrastructure losses would occur in a severe and wide-reaching wildfire, which could arise as a result of hot and dry conditions during a drought. CPW has experienced direct impacts as a consequence of drought-related wildfires in the past. The Hayman fire of June 2002 resulted in increased runoff from the burn areas and a corresponding increase in sediment load and deposition into the South Platte River, via direct input and inflow from its tributary channels. Both Horse Creek and Wigwam Creek tributaries experienced direct loss of instream habitat. Similar degradation was produced in the Poudre River Drainage as a result of the 2012 High Park Fire. Increased sedimentation in the streambed negatively impacted macro-invertebrate (fish food) production and trout spawning habitat.

In addition to the vulnerability information summarized here, recommendations for “adaptive capacities” that could mitigate impacts to the various sectors have been developed. These suggested recommendations are captured in Annex B and organized by impact sector. This annex can serve the State as well as local governments, citizens, businesses and industry as a useful reference for mitigation strategies to be considered in the future. Mitigation action strategies that the State is currently involved with are discussed in the following section.

4 MITIGATION STRATEGY

4.1 Hazard Mitigation Goals

This chapter focuses on the State’s hazard mitigation strategy. It is divided into five parts:

- Hazard Mitigation Goals
- State Capability Assessment
- Local Capability Assessment
- Mitigation Actions
- Funding Sources

4.1.1 Description of State Mitigation Goals

This section describes the goals of the Drought Mitigation Plan and the process used to identify and update the goals over the history of the Plan. The State has revised the framework of its mitigation strategy to improve its ability to track progress in meeting Plan goals and to improve alignment with local mitigation strategies (e.g., goals and actions). The framework of the State’s drought mitigation strategy has two parts: goals and actions, which are defined as follows:

- The goals are broad based and described the overall direction that the State will take to reduce drought impacts.
- The actions describe the activities or projects used to support the accomplishment of the goals.

The following eight goals of the Colorado Drought Mitigation and Response Plan are listed below, in no particular order or priority. Each goal is related to the mitigation actions in Table 19 below.

1. Improve Water Availability Monitoring and Drought Impact Assessment
2. Increase Public Awareness and Education
3. Work collaboratively with water rights holders to voluntarily augment water supply through mechanisms to transfer to areas of shortage during droughts.
4. Coordinate and Provide Technical Assistance for State, Local, and Watershed Planning Efforts
5. Reduce Water Demand/Encourage Conservation
6. Reduce Drought Impacts to Colorado’s Economy, People, State Assets, and Environment
7. Continue to develop Intergovernmental and Interagency Stakeholder Coordination
8. Evaluate Potential Impacts from Climate Change

4.1.2 Reassessment of Goals for Validity or Need for Revision

For the 2018 revision to this Plan the DMRPC also re-evaluated the goals in a planning workshop. The group decided that the number and intent of the goals should remain the same, but that Goal 3 be re-worded. Goal 3 changed from “Enhance mechanisms to provide water supplies to areas of shortage during droughts” to “Work collaboratively with water rights holders to voluntarily

augment water supply through mechanisms to transfer to areas of shortage during droughts.” The group felt that this change better reflected the nature of the action items related to that goal. The DMRPC also determined Goal 7 should be updated to be “Continue to development intergovernmental and Interagency Stakeholder Coordination.”

In 2018, the State Hazard Mitigation Team updated the SHMP also revisited and revised the goals of the State for hazard mitigation. These were shared with the DMRPC during the goals review process and are listed below:

2018 Colorado Hazard Mitigation Plan Goals

1. Minimize the loss of life and personal injuries from all-hazard events
2. Reduce losses and damages to federal, state, local government and private assets and support similar local efforts
3. Reduce state, local, and private costs of disaster response and recovery
4. Support mitigation initiatives and policies that promote disaster resiliency, nature-based solutions, cultural resources and historic preservation, and climate adaptation strategies
5. Minimize interruption of essential services and activities
9. Incorporate equity considerations into all mitigation strategies
10. Support improved coordination of risk mitigation between and among the public, private, and non-profit sectors
11. Create awareness and demand for mitigation as a standard of practice

4.2 State Drought Mitigation Capability Assessment

4.2.1 Introduction

The state mitigation strategy must include a discussion of the State’s pre- and post-disaster hazard management policies, programs, and capabilities to mitigate the hazards in the area, including an evaluation of state laws, regulations, policies, and programs related to drought mitigation as well as to development in drought-prone areas, and a discussion of state funding capabilities for hazard mitigation projects.

A mitigation capability assessment update was conducted as part of the 2018 Plan process. This entailed a review of the Colorado Revised Statutes, rules, regulations, and policy that contribute directly or indirectly to reducing drought losses. The process included incorporating Appendix A of the 2002 Drought Plan, which listed both state and federal drought assistance and related programs, and incorporating a summary of statutory programs related to drought from the 2007 Update report and the 2018 SHMP Update. During this process, the applicable Colorado Revised Statutes were compiled into a master excel spreadsheet and categorized by impact sector for a better synopsis of the strengths as well as any gaps or weaknesses of the State’s existing drought mitigation capabilities across all impact sectors.

The spreadsheet identifies the name of the statute, the statute number and the date enacted, what state agency it affects, a definition of the statute, whether the statute was created for pre- or post-drought conditions, and whether it supports, facilitates, or needs improvement relative to reducing drought or water supply availability impacts. The spreadsheet has become a convenient reference document and has served as a tool to guide decisions through the Plan revision process; the results of this effort are captured in Appendix C Drought Mitigation Capability Summary. The 2018 update solicited input on changes or updates to these capabilities from multiple State and Federal agencies. The agencies had an opportunity to review the 2013 drought plan materials and provide updates on capabilities, mitigation and funding opportunities.

4.2.2 Pre-disaster Hazard Management Policies, Programs, Capabilities

State laws and regulations that provide authority to various agencies for pre-disaster programs are included in the existing State Hazard Mitigation Plan. Programs and the authorizing statutes that are specific to pre-drought disaster situations are identified in Appendix C Drought Mitigation Capability Summary (indicated by an ‘x’ in the pre- or post- disaster columns). In several cases the capabilities are both pre- and post-disaster. An example of this is the State’s drought response capabilities, which can help mitigate losses through early warning and effective post disaster response. This capability has been further refined in 2010 and 2013 and captured in Annex A Drought Response Plan. The State’s Water Availability Task Force, a major component of the response plan and the early warning mechanism, has been active for almost 40 years. Highlights of a few of these capabilities are summarized here:

CWCB

The Colorado Water Conservation Board’s Office of Water Conservation and Drought Planning (OWCDP) promotes water use efficiency while providing public information and technical and financial assistance for water conservation planning. The OWCDP also promotes drought planning by encouraging and assisting communities to prepare and implement drought mitigation plans and by monitoring drought impacts and informing the public, media, and state officials. The office is a subset of the broader Water Supply Planning Section. The Office exists to perform the following:

- Maintain a clearinghouse of water conservation and drought information and disseminates information to the public
- Provide technical assistance and evaluate and approve water conservation and drought mitigation plans
- Provide financial assistance for water conservation planning, water efficiency, drought mitigation planning and implementation, and public education and outreach through one grant program
- Provide leadership through the Water Availability Task Force to monitor, forecast, mitigate, and prepare for drought
- Coordinate with multiple state and local agencies to provide public information

State Land Board

The State Land Board manages more than three million acres of land and four million acres of mineral rights that generate revenue for public education and other state institutions. The State Land Board maintains seven District Offices that follow drought and other disaster problems in their districts. The offices have the ability to handle any issues on State agricultural leases on a case-by-case basis at the request of State lessees, which has been found to be more effective than any broader action taken in anticipation of drought

DOLA

In March 2016, DOLA, DLG launched *Planning for Hazards: Land Use Solutions for Colorado* (www.planningforhazards.com), an online guide and interactive website resource that enables counties and municipalities to prepare for and mitigate multiple hazards through the integration of resilience and hazard mitigation principles into plans and codes related to land use and the built environment. This guide provides detailed, Colorado-specific information about how to assess a community's risk level to hazards and how to implement numerous land use planning tools and strategies for reducing a community's risk. The *Planning for Hazards* guide was developed with help from outside consultants and an Advisory Committee of local, state, federal governments and university representatives.

DOLA held workshops in 2002, 2003, 2004, and 2018 to raise awareness of drought impacts such as water quality impacts, state and federal resources, water rights administration, emergency management principles, the State's plan and response to drought, weather modification programs, funding options, and regulatory perspectives. These workshops will continue to be held again on an as-needed basis.

4.2.3 Post-disaster Hazard Management Policies, Programs, Capabilities

Programs and the authorizing statutes that are specific to post-drought disaster situations are identified in Appendix C Drought Mitigation Capability Summary (indicated by an 'x' in the pre- or post-disaster columns). The State's Division of Homeland Security & Emergency Management coordinates all of the post-disaster management activities and has led to Colorado becoming one of twenty-two states certified by the Emergency Management Accreditation Program in 2009. To maintain accreditation, the State needs to meet certain requirements in all mitigation and response planning efforts.

Highlights of these capabilities are summarized here:

State Land Board

The Board approved the 2013/2014 drought plan for state lands in March of 2013. It gives the authority to District Managers to make the decisions regarding drought management on state lands. The District Managers have the authority to make immediate cuts in carrying capacity,

rental adjustments and refunds in response to requests by lessees. They frequently make adjustments even without a request if they determine it is appropriate.

Such cuts can result in reductions in the carrying capacity for cattle, which in turn can reduce the land rent since rent is based on carrying capacity. Lessees have been advised to contact the District Office if they have already reduced their numbers of cattle or will be reducing their numbers. In areas of severe to exceptional drought the District Manager may make a mandatory reduction in carrying capacity. The Board has authorized a reduction to zero if necessary to protect the long-term productivity of the land.

Reductions also require the implementation of a monitoring plan which must be approved by the District Manager. This program is ongoing to ensure grazing will not be increased until the land is in an appropriate condition to sustain livestock. Lessees will be required to sign a rider to their lease outlining the provisions for managing the drought and the penalties for non-compliance. There will be some funding available to assist with establishing the monitoring plan, for weed and pest control and to improve watering facilities to help better utilize vegetation.

CPW

CPW personnel who are responsible for the day-to-day operation, management, and use of CPW-owned and/or managed water shall endeavor to see that no waste, misuse, or inappropriate use of those water rights is occurring. On May 1, 2007 the Director of CPW (Division of Wildlife at the time) signed Administrative Directive A-9 which is a department wide policy to inform CPW personnel and others of potential drought impacts on CPW's water resources and specific actions needed to manage these drought impacts. The Administrative Directive was updated and replaced by Administrative Directive P-3, which was approved on June 20th, 2018 by the CPW Director. During drought periods changes related to management of CPW water resources may be necessary to ensure compliance with relevant statutes as well as the Colorado's Drought Mitigation and Response Plan. Pursuant to Colorado Revised Statutes, Section 37-88-109 (2), C.R.S., 2017 (County Control of Reservoirs) CPW could be required to release water from CPW-owned and/or managed water resources stored in reservoirs for municipal and domestic purposes during drought. There may also be times and situations where CPW may be requested to bypass some of its senior irrigation rights to make water available for municipal and domestic uses. Any agreement to release or bypass CPW-owned or managed water for domestic or municipal purposes shall be submitted to and approved by the Colorado Parks and Wildlife Commission. In situations where "time is of the essence" the Director of the Colorado Parks and Wildlife department has the authority to act on behalf of the Colorado Parks and Wildlife Commission.

Also, since CPW receives federal fish and wildlife funds the eligibility rules regarding receipt of these federal funds place certain obligations on the management of CPW's properties, including water rights purchased with federal funds or wildlife cash. Prior to any release of CPW water from reservoirs or bypass of any direct flow water for domestic purposes, the State Attorney General's Office shall be contacted regarding federal aid obligations. Further, CPW has developed a detailed

list of criteria to be followed for addressing requests for use of CPW-owned and/or managed water resources under drought circumstances.

Impacts to wildlife, wildlife habitat and to CPW's water resources can be addressed as drought conditions arise. Impacts could include release of water from CPW-owned and/or managed reservoirs for domestic and municipal purposes, or for protection of aquatic and wildlife habitats. Priorities for use of CPW-owned and/or controlled water or water rights during drought conditions will be to protect and conserve, to the extent possible and on a statewide basis, have been identified.

CPW now has an invasive species coordinator. CPW anticipates that during future droughts, increased efforts will be needed to monitor for the presence and spread of aquatic nuisance weed species such as Eurasian aquatic milfoil.

CDPHE WQCC

In 2007, the Colorado Department of Public Health and Environment Water Quality Control Commission (CDPHE WQCC) adopted revised water-quality standards for temperature for protection of aquatic life. The standards include an acute standard (a two-hour daily maximum) for protection from lethal effects of elevated temperature and a chronic standard (i.e., a maximum weekly average temperature) for protection against sublethal effects on behavior, metabolism, growth, and reproduction. The standards also include seasonal adjustment for protection of spawning, and they include a narrative requiring that temperature maintain a normal pattern of daily and seasonal fluctuations and spatial diversity with no abrupt changes. These standards were implemented in the Upper and Lower Colorado basins in 2008 and in the South Platte Basin in 2009. The standards will be implemented in the San Juan, Dolores, and Gunnison Basins in 2012 and in the Rio Grande and Arkansas Basins in 2013.

Colorado's revised water-quality standards for temperature did not exist during the 2002 drought. Now a low-flow exclusion allows for temperature exceedances when the daily streamflow falls below an acute critical low flow or when the monthly average streamflow falls below a chronic critical low flow. This exclusion makes it unlikely that exceedances of the temperature standards during extreme drought would result in an impairment listing on the CDPHE WQCC 303(d) List. Regardless, the basis of Colorado's temperature standards in species-specific physiological tolerances to elevated temperature suggests that the standards will provide a useful benchmark against which to evaluate whether elevated temperatures resulting from drought conditions are likely to contribute to deleterious effects on fish communities. As real-time data capture becomes more economically viable as an option for temperature monitoring, it may become possible to explore real-time water-management alternatives to avoid lethal or chronic effects of elevated temperature during drought conditions. The implementation of the temperature standards has also prompted an increase in temperature monitoring, which will likely facilitate better evaluation of the influence of drought-associated flows and elevated temperature on fisheries during future drought conditions.

DOLA

As a result of the 2012-2013 federally-declared disasters in Colorado, funding through CDBG-Disaster Recovery grant programs (Resilience Planning, Watershed Resilience, and Housing) were made available and administered through DOLA. The funding through these grants have allowed the State to help local communities implement mitigation actions better preparing the State should another disaster of this magnitude occur in the future.

4.2.4 State Policies Related to Development in Drought Prone Areas

All communities in the State are at risk of drought. Although state policies exist related to development in hazard prone areas such as areas at risk of wildfire and flooding, policies related to development in drought-prone areas do not appear to be practical. Few Colorado statutes explicitly integrate land use planning with water planning. Several tools are in place to encourage and permit integration of planning but are voluntary. Legislation passed in 2008-09 requires developers to ensure sustainable water supplies with new development. Further, state statutes support and permit intergovernmental cooperative agreements on water, planning, and service issues; although coordination and sharing of information between local governments and water suppliers is largely voluntary. Several goals and objectives in the 2018 Colorado State Hazard Mitigation Plan relate to increasing the capacity to collaborate with different sectors and levels of government. For example, the Goal: “Support improved coordination of risk mitigation between and among the public, private and non-profit sectors” has several objectives listed under it related to increased collaborations including, “Strengthen continuity of operations at the federal, state, regional, tribal, and local levels of government to ensure the delivery of essential services” and “Strengthen cross-sector connections across the state government”. Given the regional nature of water resources and the impact of local land development and uses on the resource, as water becomes scarcer in Colorado the necessity of collaboration becomes more apparent.

The 2010 document “Colorado Review: Water Management and Land Use Planning Integration” prepared by the Center for Systems Integration on behalf of the CWCB is a compendium of integrated land use planning and water supply planning. The document also reviews the legal context that allows for land use planning, including municipal and county powers, intergovernmental cooperation, and special districts. It also covers state agencies and legislatively created organizations that provide assistance and resources related to land and water planning issues to local and county governments. The document summarizes the key statutes related to land use planning and cross-jurisdictional authorities as well as statutes addressing water conservation, quality, supply, management, and water law that are relevant to integrating land use and water planning. DOLA’s “Planning for Hazards: Land Use Solutions for Colorado” is a guide that provides detailed descriptions of range of land use planning mechanisms that counties and municipalities can implement to reduce risk to hazards. The guide profiles drought including how it relates to other hazards and provides available data sources and case studies and gives suggestions on applicable planning tools and strategies related to drought. This guide is

accompanied by workshops and webinars to continue to share information with local governments and collaborate between jurisdictions.

4.2.5 State Funding Capabilities for Drought Hazard Mitigation Projects

The types of state-funded projects available for drought mitigation are included in Appendix C Drought Mitigation Capability Summary and in Section 4.5. Various limited sources exist including disaster emergency funds, water conservation funding, wildlife cash funds, flood and drought response fund, wastewater treatment plant and drinking water treatment plant construction funds. There are also opportunities for existing funding to be appropriated for drought. For example, following the 2013 floods CDPHE created the Natural Disaster Grant to fund projects for the domestic wastewater treatment works or public drinking water systems that were impacted, damaged or destroyed in connection to the 2013 floods. Although this grant is not specific to drought, if funds were appropriated it would have the potential to also be used to fund drought mitigation projects. Funding options are discussed in the 2018 Colorado Hazard Mitigation Plan. This Plan includes information on state matching funds for federal programs the State Disaster Emergency Fund; grant programs of the CWCB, DWR, DHSEM, Natural Resources Conservation Service, and State Forest Service; and education and outreach program funds. The State Hazard Mitigation Plan also discusses the types of federal mitigation grant programs managed by the Mitigation Staff of the Colorado Division of Homeland Security and Emergency Management.

4.2.6 Changes in Hazard Management Capabilities of the State

Colorado became one of twenty-two states certified by the Emergency Management Accreditation Program (EMAP) in 2009. To maintain accreditation, the State needs to meet certain requirements in all mitigation and response planning efforts. This includes the EMAP accredited Natural Hazard Mitigation Plan which was updated in 2013 and 2018 by DHSEM. The response elements of the Colorado Drought Mitigation and Response Plan underwent significant changes to modernize the Plan in 2010. This included aligning the Plan with modern emergency management standards, revisiting the number and composition of the ITFs, updating the drought indicators and associated responses, and streamlining the communication framework of the Plan. The response element became a “stand alone” annex (Annex A) to this mitigation Plan so that the response procedures are condensed for use during drought emergencies.

The State has undergone the following activities to improve its drought management capabilities since 2013.

- In May 2013 Governor Hickenlooper issued Executive Order D 2013-5 directing CWCB to prepare a water plan for Colorado. Colorado’s Water Plan, completed in 2015, is a framework to guide future decision making and to address water challenges with a collaborative, balanced, and solutions-oriented approach. The goals of the plan are to meet the water supply gap, defending Colorado’s compact entitlements, improving regulatory processes and exploring financial incentives – all while honoring Colorado’s water value and ensuring the state’s water

resources are protected and available for generations to come. The Water Plan implementation grant funds can be used for long-term water supply efforts. The 2018 Projects Bill (SB18-218) included \$7 million to continue the Water Plan Grant program, \$1 million of which went to funding the implementation of long-term strategies for conservation, land use and drought planning.

- Colorado's Resiliency Framework developed after the 2013 floods was created to achieve cross-sector resilience planning. The Framework provides guiding principles around resiliency for the state and defines the structure through which the state will support local agencies and community groups as they identify and implement their own resiliency actions. The Colorado Climate Plan which was initially completed in 2015 and updated in 2018, provides statewide policy recommendations and actions to mitigate greenhouse gas emissions and to increase Colorado's level of preparedness. The 2018 update of the Climate Plan includes the objectives contained in Governor Hickenlooper's executive order from July 2017 that committed the state to additional climate action. The Plan focuses on eight areas including water, public health, greenhouse gas emissions, energy, transportation, agriculture, tourism and recreation and ecosystems. Opportunities for partnerships between the state, local governments and businesses are also highlighted in the plan.
- DOLA, with help from consultants and an Advisory Committee made up of local, state, and federal government and university representative created the Planning for Hazards guide to help local governments reduce risks to hazards through land use planning strategies. Grant-funded recovery staff positions have built capacity through grants, resource development and training efforts.

Additional, information on the initiatives above and additional progress towards drought mitigation project implementation is presented in Sections 4.4.1 and 4.4.2.

4.3 Local Capability Assessment

Local governments in Colorado have a long history of implementing actions that relate to drought mitigation. A summary of policies, programs, and capabilities local governments have in place is presented in this section.

4.3.1 Local Mitigation Policies, Programs, and Capabilities

Information in this section was gathered by reviewing the existing Local Hazard Mitigation plans in Colorado. A total of 56 local hazard mitigation plans were reviewed (2 multi-county regions, 49 counties, 6 cities and 2 Tribes). A comprehensive review of existing local capabilities followed the collection of these plans. Relevant information was gathered to assess the capability of local governments to handle short- and long-term drought, and is displayed in Table 15. As of May 2018, 61 counties (all but three) and two tribes in Colorado have mitigation plans that are either FEMA approved or approvable pending adoption. These 61 jurisdictions covered by FEMA approved or approvable plans encompass nearly ninety-eight percent of the State's total

population. Local capabilities to handle drought may have changed since the writing of a portion of these plans.

Counties and cities in Colorado use a variety of tools to manage drought. Some of these tools can be found in both Table 15 and Table 16. For purposes of this plan, it is assumed that water efficiency is a component of drought mitigation. During the writing of the 2018 Plan Update there were two local drought plans that have been officially approved by the CWCB and 77 State approved water conservation plans, 45 of which are covered entities. The complete list of entities with state approved water conservation plans are listed in Table 15. This list also includes entities that have drought response and management plans that are officially recorded by the State.² Mitigation actions contained in local hazard mitigation plans are contained in Table 19 in Section 4.4.6.

Table 15 Local Mitigation Policies, Programs, and Capabilities

Plan	Policy, Program, or Capability
East Larimer County	Water Conservation Plan
City of Alamosa	Water Conservation Plan
City of Aurora	Drought Response Plan, Water Conservation Plan
City of Boulder	Drought Response Plan, Water Conservation Plan
City of Brighton	Water Conservation Plan
City of Cortez	Water Conservation Plan
City and County of Broomfield	Water Conservation Plan
City of Dacono	Water Conservation Plan
City of Durango	Water Conservation Plan
City of Evans	Water Conservation Plan
City of Fort Morgan	Water Conservation Plan
City of Fort Collins	Water Conservation Plan
City of Fort Lupton	Water Conservation Plan
City of Fountain	Water Conservation Plan
City of Glenwood Springs	Water Conservation Plan
City of Greeley	Water Conservation Plan
City of Lafayette	Water Conservation Plan
City of Lamar	Water Conservation Plan
City of Longmont	Water Conservation Plan
City of Monte Vista	Water Conservation Plan
City of Northglenn	Water Conservation Plan
City of Rifle	Water Conservation Plan

² Other M&I water providers have drought mitigation and/or response plans. However, such plans are currently not tracked by the State.

Plan	Policy, Program, or Capability
City of Salida	Water Conservation Plan
City of Sterling	Water Conservation Plan
City of Thornton	Water Conservation Plan
Town of Castle Rock	Water Conservation Plan, Drought Management Plan
Town of Eaton	Water Conservation Plan
Town of Erie	Water Conservation Plan, Drought Management Plan
Town of Firestone	Drought Management Plan, Water Conservation Plan
Town of Frederick	Water Conservation Plan
Town of Superior	Water Conservation Plan
Town of Windsor	Water Conservation Plan
Arapahoe County Water and Wastewater Authority	Water Conservation Plan
City of Arvada	Water Conservation Plan
Castle Pines Metropolitan District	Water Conservation Plan
Castle Pines North Metropolitan District	Water Conservation Plan
Centennial Water and Sanitation District	Water Conservation Plan
Cherokee Metropolitan District	Water Conservation Plan
Colorado Springs Utilities	Water Conservation Plan
Consolidated Mutual Water Company	Water Conservation Plan
Denver Water	Drought Response Plan, Water Conservation Plan
Donala Water and Sanitation District	Water Conservation Plan
Douglas County Regional Plan	Water Conservation Plan
Eagle River Water and Sanitation District	Water Conservation Plan
East Cherry Creek Valley WSD	Water Conservation Plan
East Larimer County Water District	Water Conservation Plan
Ft. Collins-Loveland Water District	Water Conservation Plan
Grand Valley Regional Plan	Water Conservation Plan
Left Hand Water District	Water Conservation Plan
Little Thompson Water District	Water Conservation Plan
Mount Werner Water District	Water Conservation Plan
North Table Mountain Water & Sanitation District	Water Conservation Plan
North Weld County Water District	Water Conservation Plan
Parker Water and Sanitation District	Water Conservation Plan
Pinery Water and Wastewater District	Water Conservation Plan
Platte Canyon Water and Sanitation District	Water Conservation Plan
Pueblo West Metropolitan District	Water Conservation Plan
Security Water and Sanitation District	Water Conservation Plan
St Charles Mesa Water District	Water Conservation Plan
Tri County Water Conservancy District	Water Conservation Plan
Widefield Water & Sanitation District	Water Conservation Plan

Plan	Policy, Program, or Capability
Willows Water District	Water Conservation Plan

Note: Information for this table was provided by the CWCB. Entities recorded in this table as having a state approved Water Conservation Plan have a plan that meets the requirements set forth in the Water Conservation Act of 2004.

4.3.2 Effectiveness of Local Mitigation Policies, Programs, and Capabilities

Chapter 7, “Tools for Managing Drought at a Local Level,” of the 2004 DWSA presented the tools available to local communities to prepare for and manage the effects of drought. The chapter includes information on which tools are applicable to long-term mitigation or short-term drought response, and which can be effectively used to achieve different demand/supply outcomes. Table 16 summarizes this information for local scale drought management tools. As can be seen in the table, different tools are effective for different planning horizons and influence management goals. A variety of tools have been identified to facilitate development of effective local planning.

DOLA’s “Planning for Hazards: Land Use Solutions for Colorado” is a guide that provides detailed descriptions of range of land use planning mechanisms that counties and municipalities can implement to reduce risk to hazards. The guide profiles drought including how it relates to other hazards and provides available data sources and case studies and gives suggestions on applicable planning tools and strategies related to drought. The suggested planning mechanisms to address drought include: addressing drought in a community’s comprehensive plan, using 1041 regulations to protect sensitive areas, and implement subdivision and site design standards that specific to preventing the escalation of the effects of drought. This guide is accompanied by workshops and webinars, often put on in partnership with DHSEM and FEMA, to continue to share information with local governments and collaborate between jurisdictions.

Additionally, as part of a 2004 DWSA survey, respondents identified what they thought were the “best” tools for managing drought. For municipalities, lawn and garden water restrictions were favored (by 41%), followed by public education/involvement programs (34%), fines for excessive water usage (30%), and water conservation programs (13%). Among agricultural users, the most effective controls were water conservation programs (27%), cooperative agreements (13%), and public education programs (7%).

Table 16 Local Scale Drought Management Tools

Tool	Planning Horizon		Management Impact		
	Short-Term Response	Long-Term Mitigation	Reduce Demand	Increase Supply	Other
Public Policy and Assessment					
Prepare and regularly update comprehensive water management plan with drought component		✓			✓
Establish drought response principles, objectives, and priorities		✓	✓	✓	✓
Establish authority for declaring a drought emergency		✓	✓	✓	✓
Develop triggers for drought-related actions (establishing thresholds for mild, medium & severe droughts)		✓	✓	✓	✓
Prepare ordinances on drought measures		✓	✓	✓	✓
Evaluate impacts of drought on different groups, economic segments, and environmental receptors		✓			✓
Emergency Response					
Declare a drought emergency	✓		✓	✓	✓
Establish water hauling programs	✓			✓	✓
Extend boat ramps and docks	✓	✓			✓
Restrict/prohibit new taps	✓		✓		
Identify state and federal assistance	✓	✓			✓
Public Education and Relations					
Prepare position papers for the public, media and elected officials describing public drought policies		✓			✓
Establish a public advisory committee		✓			✓
Organize drought information meetings and workshops for public and media	✓	✓			✓
Create informational materials and establish a drought information center		✓			✓
Water Rights Management					
Review water rights for modifications/flexibility during drought		✓		✓	
Dry year leasing of water rights	✓			✓	
Water banks established for the sale, transfer, and exchange of water	✓			✓	
Interruptible water supply agreements	✓			✓	
Water Supply Augmentation					
Rehabilitate reservoirs to operate at design capacity		✓		✓	
Inventory and review reservoir operation plans		✓		✓	✓
Aquifer storage and recovery; conjunctive use		✓		✓	
Weather modification (cloud seeding)	✓	✓		✓	
New water storage facilities		✓		✓	
Monitoring and Evaluation					
Monitor water supply components (e.g. snow pack, stream flow, etc.)	✓	✓			✓
Monitor water quality	✓	✓			✓
Track public perception and effectiveness of drought measures	✓	✓			✓
Improve accuracy of runoff and water supply forecasts		✓			✓
Water Conservation					
Develop, implement and monitor ongoing water conservation program		✓	✓		✓
Implement, upgrade water metering		✓	✓		
Implement, upgrade water loss control systems		✓	✓		
Water-efficient fixtures and appliances		✓	✓		
Low water use landscapes and efficient irrigation		✓	✓		
Improve commercial and industrial efficiencies		✓	✓		
Educational programs	✓	✓	✓		
Rate structures to influence water use	✓	✓	✓		
Water reuse		✓	✓		
Soil management such as soil-moisture monitoring		✓	✓		
Improved tillage practices		✓	✓		
Use drought or salinity tolerant crops		✓	✓		

Source: 2004 DWSA

In addition to the drought tools in 0 above, the 2010 Municipal Drought Plan Guidance Document provides another comprehensive list of drought tools that Municipal & Industrial (M&I) water providers can use to select and implement to mitigate and respond to drought. The overall effectiveness of these tools will depend on the unique set of drought-related water supply challenges and set of circumstances faced by individual water users. For instance, the rehabilitation of reservoirs to operate at design capacity may be an effective drought tool for a water user that lost significant storage prior to the rehabilitation; while other users may only benefit moderately from reservoir rehabilitation. The nature of drought can also significantly impact the overall effectiveness of a particular management tool.

Water supply reliability planning can play a key role in the preparedness of M&I water providers. For instance, M&I providers with a junior portfolio of water rights that have not effectively incorporated drought planning into their long-term supply efforts will be more vulnerable to drought than those who have more senior water right and/or effective drought plans.

4.4 Mitigation Actions

The state mitigation strategy must identify, evaluate, and prioritize cost effective, environmentally sound, and technically feasible mitigation actions and activities the State is considering, and an explanation of how each activity contributes to the overall mitigation strategy. Local input should also be included when available. Additionally, with each update cycle the Plan must be reviewed and revised to reflect changes in development, progress in statewide mitigation efforts, and changes in priorities. The updated Plan must identify the completed, deleted, or deferred actions or activities from the previously approved Plan. It must also include any new actions identified since the previous Plan. The mitigation actions take into consideration the vulnerability and capability assessment, and are intended to address areas of high vulnerability or where capabilities should be strengthened.

The recommended actions for this Plan were derived from several sources in the planning process over the past 18 years. Mitigation was first incorporated into the Colorado Drought Response Plan with the 2000-2001 update process when the initial recommendations and actions were developed. These actions were reviewed and expanded during the 2007 update cycle, and incorporated some recommendations from the 2004 DWSA report. During the 2013 and 2018 updates the actions were reviewed for progress made, continued validity, and updates or changes. New actions were also developed through a process described in detail in Section 4.4.3. In the 2013 Plan there were 78 action items total; eight new actions from the 2010 Plan. During the 2018 update the actions identified as ‘completed’ have been separated from the ongoing action plan. In the 2018 Plan, there are 53 active action items total; 48 of the actions are continuing from the 2013 Plan; five new actions were identified in 2018 and six were deleted or deferred.

4.4.1 Identification of Actions under State Consideration

Table 17 identifies the actions under consideration by the DMRPC for the State of Colorado in 2018. The following recommendations represent the collaborative efforts of the DMRPC over the years and in 2018. Consistent with the FEMA and EMAP requirements, those actions that have been completed are identified in Table 18. The completed actions show progress made toward the Plan’s goals. Each project has an action identification number that connects the action to the primary goal they are designed to help achieve, as an indication of how each action contributes to the overall mitigation strategy. Each mitigation action also identifies the mitigation type of the proposed action (natural system protection, planning and regulations, education, awareness, and outreach, structure and infrastructure projects, funding, data and studies, and technical assistance), the resiliency section (community, economic, health and social, housing, infrastructure, watershed and natural resources), and the potential funding sources and the potential benefits of implementing the action. A summary discussion of progress made toward implementing the action is included in the table under the “Additional comments on Status, Implementation, Funding, and Potential Benefits” column, and discussed in the Section 4.4.2. Deleted and deferred actions are discussed in the section that follows the table.

Many of the recommendations can be implemented in the short term which is defined as the next five-year update cycle; others must be viewed as long-term measures, and some will be implemented during drought cycles. The actions are grouped by the goal they most help achieve and prioritized by **High**, **Medium** and **Low** (see Section 4.4.4 for a discussion of the prioritization process). In general, the timeline of implementation is reflected in the prioritization: High- target implementation within three years; Medium – within three to six years; Low - within ten years or as needed. As part of the 2018 update some of the ongoing or periodically completed actions (e.g. periodic workshops) were moved to low priority.

Table 17 Ongoing State Drought Mitigation Actions

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
1.1	Collect climatologic data at mid & lower elevations to fill existing gaps in the data collection network	H	WATF NRCS CCC CoCoRAHS CAIC	Data & Studies	The NRCS has installed one new SNOTEL site at 8920' since 2010, Black Mountain. Three new sites are planned for Colorado, two of which are at low and mid elevations. Additional sites may be installed at a later date if funding is made available. Ongoing based on funding. Action Development Date: 2010
1.2	Demonstrate Gap Filling Radars and Spatial Modeling for Water Supply Forecasts	M	CWCB NOAA NCAR USBR	Data & Studies	A compact compliance DSS tool was developed for the DWR. There was a NOAA mobile radar out winter 2014-15 and winter 2017-18 in Alamosa. There were NASA ASO flights winter 2014-15, 2015-16, and 2016-17. The NOAA radar and NASA ASO data was used to force the national water model to compare the experimental methods with the official water supply forecast methods. Five permanent gap filling snow data are being deployed in the Conejos, permanent weather radar in Alamosa, and continued use of national water model forecasts as value added to the official water supply forecasts from the NWS RFC and NRCS. Action Development Date: 2013
1.3	Funding: stream gage improvements	M	USGS CWCB	Data & Studies	Up to \$250k continuously appropriated through the Construction Fund in collaboration with USGS and the State Engineer. Action Development Date: 2002
1.4	Improved Impact Assessment	M	CWCB ITFs	Data & Studies	Impact analysis has always been a weak link. Need multiple impact reporting and data mechanisms & an impact czar. Adapt the tools developed for the 2010 drought vulnerability assessment. DART study suggests a framework for impact collection for recreation and tourism. CSU Drought Agricultural Impact study completed in 2013 to assess impacts from 2011-2012 drought. Working closely with NDMC on their impact assessments. Western Water Assessment doing survey of agricultural impacts in 2018 Action Development Date: 2010
1.5	Improve soil moisture monitoring	M	NRCS CCC NIDIS	Data & Studies	CCC has expanded CoAgMet sites to 20 stations and will continue to expand the CoAgMet network. CCC is calibrating soil moisture sensor data with soil moisture data collected manually. In addition, CoCoRaHS soil moisture information is now on-line. NRCS's Snow Survey program has expanded and continues to expand its soil moisture program in Colorado. CCC has used NRCS SNOTEL data to create products that can be used for drought monitoring. Preliminary analysis by NRCS indicates

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
					that soil moisture data will improve skill in stream flow forecasting; further analysis is needed to determine whether soil moisture sensor data will improve operational forecasts. A pilot study in Utah seeks to address this question. Quality control of the data is needed; the key constraint to progress on this effort is insufficient staff to quality control and edit historic and current data for the models. A constraint to increasing the network is funding for new sites, particularly mid- and lower-elevation sites, and staff for O&M of the sites. A Federal-State collaboration is needed to develop a long-term solution for funding O&M. Action Development Date: 2010
1.6	Vulnerability-weighted drought indexes	L	NCAR CWCB CCC NRCS	Data & Studies	This effort ties vulnerability issues (e.g., sectors, places, and times of year) with drought monitoring indexes to better gauge and weigh the significance of the drought. NCAR has been studying this and presented initial findings at CO Drought Conference in 2012 2018: Ongoing per input received from CCC and NCAR (revisiting 2012 work and publish findings as funding permits). Action Development Date: 2010
1.7	Test, ground-truth, and verify remote sensing tools for monitoring and analysis of drought	M	NIDIS CCC CWCB	Data & Studies	In 2018, CCC will focus on testing EDDI and the Evaporative Stress Index to assess performance and reliability. It is important to verify that remote sensing products provide relevant, valid, and useable information. A constraint to ground truthing remote sensing data is the need for staff and budget for O&M.
1.8	Extend spatial monitoring networks	M	NIDIS CCC	Data & Studies	CoAgMet stations that have been collecting data for a long time are now able to support more robust climate analyses. CCC will expand the CoAgMet observation network to improve spatial monitoring of drought. In addition, an important new extension of CCC's previous work in improving spatial monitoring is by utilizing CoAgMET data in value-added products and tools. CCC collaborates closely with the PRISM Climate Group and extensively uses PRISM products, which now include COCoRaHS and SNOTEL data, in drought monitoring. CCC is also focusing efforts on evaluating SPEI.
1.9	Continue to strengthen current and develop new remote sensing products and decision-support tools	M	CCC	Data & Studies	Progress has been made on improving the USDM's drought depictions over Colorado. It is essential that this effort continue to be supported and the CCC will continue to explore avenues to strengthen the USDM process. CCC will use validated remote sensing and model products in novel ways to strengthen the available suite of decision support tools

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
1.10	Support dust-on-snow research regarding impacts on timing and magnitude of runoff	L	CSAS CWCB Denver Water City of Grand Junction USBR Water conservation /conservancy districts	Data & Studies	Continue support for this research. The Center for Snow and Avalanche Studies is home to "CODOS", the Colorado Dust-on-Snow program, an applied science effort funded directly by a collaboration of Colorado and regional water management agencies. CODOS provides its funders (various agencies listed on the left) and their agency partners with a series of "Update" analyses of how dust-on-snow is likely to influence snowmelt timing and rates during the snowmelt runoff season. That information assists reservoir operators, municipal and agricultural water providers, flood risk managers, and others at local, state, and federal agencies responsible for managing the spring runoff. Dust on snow updates sent out (when and where, how severe) within 5 days of dust event; summary done every year Action Development Date: 2013
1.11	Research to understand snowpack sublimation	L	CCC NRCS NOAA CWCB NIDIS CSAS	Data & Studies	Understanding snowpack sublimation is an important research question for water supply forecasting. The National Operational Hydrologic Remote Sensing Center produces fully-gridded estimates on snowpack sublimation; however, this work is not yet applicable for drought response planning. Significantly more research and modeling are needed to understand the impact of snowpack sublimation and how the data would be incorporated into operational forecasting. Action Development Date: 2010
1.12	Develop and implement low-flow streamflow forecasts	L	NRCS	Data & Studies	Forecast the date at which a stream reaches a certain low-flow threshold. Action Development Date: 2010
1.13	Continue to Support and Strengthen Intermountain West Drought Forecasting	H	NOAA NIDIS CCC CWCB	Data & Studies	CCC, with support from NIDIS, continues to lead operational drought monitoring, including weekly monitoring for the state of Colorado, and conditions monitoring through CoCoRaHS that serves as a valuable drought calibration tool. CCC has improved and will continue to improve visibility and communication of drought monitoring and assessments through webinars, social media, press releases, YouTube, etc. It is important to invest in research to improve S2S forecasting, with the goal of providing actionable S2S information and data for better drought decision-making. Action Development Date: 2010
1.14	Develop methods to assess rangeland condition of key game species and livestock	L	CPW NRCS BLM CCA	Data & Studies	Rangeland monitoring is needed to gauge drought stress on key game species and livestock, detection of noxious weed spread and other ecosystem health concerns. CPW has been actively researching large game herd size. NRCS monitors private lands.

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
					See related action under Goal 7 regarding the Colorado Cattleman's Association Colorado Resource Monitoring Initiative (CRMI). Action Development Date: 2010
1.15	CoCoRAHS Condition Monitoring	M	CO Climate Center NOAA NIDIS CISA	Data & Studies	House Bill 15-1016 calls for the Board to update the Criteria and Guidelines to allow for the establishment of Regionally Applicable Factors that specify the amount of precipitation consumed through evapotranspiration of preexisting natural vegetative cover. If a sponsor submits an application in a region where a Regionally Applicable Factor has been adopted under these Criteria and Guidelines, the sponsor may propose the use of the Regionally Applicable Factor in SWSPs applied for pursuant to section 37-92-308(4) or (5), C.R.S. and associated with the sponsor's pilot project. The State Engineer shall give the sponsor's use of the Regionally Applicable Factor in said SWSP applications a presumptive effect, subject to rebuttal. Cost estimate: \$50,000 - \$100,000 Each sponsor shall submit a final report to the board and the state engineer by January 15, 2025. The board and the state engineer shall provide a final briefing to the water resources review committee by July 1, 2025. The potential benefit is that it allows for easier entry into pilot program and creates an incentive for more sponsors to implement precipitation harvesting. Action Development Date: New in 2018
2.1	Evaluate, improve, and coordinate the role and relationship of the CWCB public information and education efforts with those being conducted by local water authorities, utilities, users, and suppliers.	H	CWCB	Education, Awareness & Outreach	Initiated with 2010 revision of this Plan's mitigation and response elements. The CWCB hired a Public Engagement Specialist in 2013 to help develop Colorado's Water Plan and engage local stakeholders and partners in the process, and continue fostering public engagement after the plan's development. The position created and managed a website and social media for Colorado's Water Plan to share important public information. Colorado's Water Plan was finalized in 2015 after a multi-year, grassroots planning process that included hundreds of meetings with local water authorities, utilities, users, and suppliers, state agencies, the nine basin roundtables, the Interbasin Compact Committee (IBCC), and other stakeholders. It also engaged over 30,000 members of the public who submitted comments. The Public Engagement Specialist now manages the implementation of the goals and actions set forth in Chapter 9.5 Outreach, Education, and Public Engagement in Colorado's Water Plan. This requires extensive coordination between and collaboration with water stakeholders across the state.

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
					<p>The goals include 1) creating a new outreach, education, and public engagement grant fund, which has been completed, 2) creating a data-based water education plan, which will be tackled in a few phases and is in progress, and 3) improving the use of existing state resources, which is an ongoing endeavor, but the state is working on a few projects to improve this coordination into the future.</p> <p>In addition, the position manages the nine Public Education, Participation, and Outreach (PEPO) Workgroups comprised of local water interests. PEPO works on water education and information projects with each of the nine basin roundtables, the IBCC, and local and statewide stakeholders. The position also created an e-newsletter to share information and highlight different groups and projects.</p> <p>Action Development Date: 2003 (based on DWSA)</p>
2.2	Resources to the Office of Water Conservation and Drought Planning for technical assistance, evaluating of drought plans, administering fund programs, and public education	M	CWCB	Technical Assistance	<p>SB 10-025 The water efficiency grant program re-authorization bill; Request for severance tax funds for 2011 for implementing recommendations of drought mitigation plan. Flood and drought response fund added in 2012 and refunded annually.</p> <p>Action Development Date: 2007</p>
2.3	Workshops: crop survival and livestock management. during drought	M	CSU Coop Ext. Dept. of Ag NRCS Conservation Districts	Education, Awareness & Outreach	<p>Conducted on as needed basis, in coordination with Ag State Conservation Board and NRCS Conservation Districts. CSU is doing a series on 'how to survive the drought 101" through Extension. Two separate actions merged during 2018 plan update.</p> <p>Action Development Date: revised in 2018; formally two actions that have been merged</p>
2.4	Examine the need for new or revised state water policy related to how CWCB provides public information and education, technical assistance, and infrastructure support from the Office of Water Conservation and other CWCB sections with regard to identified water user needs.	M	CWCB	Planning & Regulations	<p>HB 10-1051 requiring data reporting on water conservation and water use annually. This will directly influence policy direction in the future. Use of the Water Conservation Technical Advisory Group to help determine appropriate projects and policy directions for water conservation. [Still exists but on hiatus, CWCB did use them to vet the SWSI water efficiency methodology]</p> <p>Integration of the OWCDP and the Water Supply Section within the CWCB [completed]</p> <p>Colorado's Water Plan was finalized in November of 2015. It is a comprehensive policy document that details Colorado's water resources and lays out measurable objectives, goals, and actions to achieve a balanced water future. It has a chapter dedicated to outreach, education, and public engagement to ensure the public is informed and able to engage in decision-making around water.</p> <p>Action Development Date: 2003 (based on DWSA)</p> <p>Portions of action completed in 2012</p>

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
2.5	Examine and improve role and relationship of public information and education efforts by the CWCB with the DNR, DWR-SEO, and the Governor's Office.	L	CWCB	Education, Awareness & Outreach	This was initiated with the 2010 revision of this Plan's mitigation and response elements and has led to improved coordination. Colorado's Water Plan laid out the goal to improve the use of existing state resources. This includes improving coordination between state agencies on outreach and education activities. The CWCB is currently leading a project to bring state agencies and groups together to develop coordinated data collection and evaluation efforts and a communication plan. The first phase will be complete in June 2018. In addition, the plan calls for involving Colorado's innovation and business communities, education and research institutions, and public and non-profit organizations in collaborative efforts with the water sector to address Colorado's water challenges with "outside-the-box" creativity. The CWCB, along with other partners, created a program called TAP-IN in 2017 to convene these diverse interests to bring fresh voices and new approaches to the conversation about water in Colorado. Action Development Date: 2003
2.6	Implement an improved process for educating municipal water users about conservation, xeriscaping, etc.	L	CO Water Wise	Education, Awareness & Outreach	Published the Guidebook of Best Practices for Municipal Water Conservation in Colorado in 2010; runs Xeriscape Colorado which promotes Xeriscape; working on Value of Water Campaign. The Grand Valley 'DRIP' program is a model example on the West Slope. CWCB with DOLA implementing water and land use integration trainings and guidance Action Development Date: 2010 Aspects of action completed in 2010
2.7	Website hosting all drought information for State	M	CWCB CCC	Education, Awareness & Outreach	The Colorado Drought Response website (www.coh2o.co) came online in 2013 and provides current information on water restrictions and drought response activities for municipalities. The website will be upgraded in 2018 with drought response information and establish links with the CCC website for additional drought data. Action Development Date: New in 2018
3.1	Fund water system improvements for drought mitigation and resiliency	H	DOLA CWCB WPA	Funding	Water and Power Authority (receive EPA funding) Water Project Loan Program DOLA Energy/Mineral Impact Assistance Fund Efforts to fund improvements receiving emphasis in 2013 Funding out of Water Plan and CWCB's loan program Action Development Date: 2002
3.2	Explore technologies for water supply banking, floodwater diversion storage, aquifer recharge, snow banking	M	CWCB CGS	Data & Studies	Arkansas Valley Pilot Water Bank Study completed in 2005 Colorado Water District is working on Water Banking compact. Other studies include the Statewide Aquifer Recharge Study, the Upper Black Squirrel Creek project, the Lost Creek project, the Gilcrest/ LaSalle

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
					project, the Colorado River Basin Study, the Water Bank Working Group, the Aspinall Unit Roundtable Water Banking Project and others. Action Development Date: 2002
3.3	Evaluate the benefits of construction of water storage facilities on State Trust Land	M	State Land Board	Structure & Infrastructure Projects	This project would evaluate the potential benefits of water storage on State Trust Land for municipal and agricultural uses, supplementation of instream flows. Could help fund and would create a revenue stream. Coordination with CGS for possible underground storage. Action Development Date: 2010
3.4	Use of state water resources to address water shortages.	M	CPW SLB CWCBC DWR-SEO AGO USBR COE WCDs	Technical Assistance	Use water, water rights or interests in water to assist water short municipalities, in-stream flow and recreational resources while paying attention to the primary purpose of the agency's water. Could be used to avoid loss of stream fisheries, loss of flat water recreation resources, as well as assisting water short municipalities. Funding could come from rate payers in water short entities Action Development Date: 2013
3.5	Encourage Local Water Providers to include drought in water supply shortage planning	L	CWCBC Local Water Providers	Education, Awareness & Outreach	Natural systems adjust water consumption to adapt for drought and limited water supply. Most human systems are built for uniform and reliable water use regardless of water supply and drought. This is encouraged in the 2010 Drought Management Plan Guidance Document Action Development Date: 2010
3.6	Public/private partnerships to augment local water supplies	L	Local Water Providers	Technical Assistance	SB 02S-001 provides up to \$1M for agricultural organizations for water augmentation in drought emergencies Colorado Water Trust instream flow program Action Development Date: 2002 Aspects of action completed in 2012
4.1	Make completion of local drought plans a priority; include vulnerability & risk assessments; incorporate info into next update	H	CWCBC	Data & Studies	Local drought plan guidance document developed in 2010 to help facilitate local plan development. Sample drought plan completed in 2011. Approximately eight local drought plans have been completed 2010-2018. Action Development Date: 2007
4.2	Integrate results, tools and methods from the 2010 Statewide Drought Vulnerability Assessment to improve and standardize drought risk assessments in local hazard mitigation plans	H	DHSEM CWCBC	Technical Assistance	Utilize in Plan update cycles or in new plans that are developed. Being incorporated by reference into new or updated plans since 2010), but no formal process. DHSEM to include template SOW for sub-applicants. DHSEM will engage early with in-house updates to encourage the incorporation of the Drought Plan.

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
					Action Development Date: 2010
4.3	Develop approaches and technology to help farmers adapt to drought	H	Dept. of Ag State Conservation Board U.S.D. A	Technical Assistance	University research grants to address grazing management, forage and crop systems, and irrigation strategies. The federal agency hopes the grants will lead to improvements such as enhancing soil's ability to hold water and developing grazing systems that can tolerate drought and reduce the potential for dust storms. Increasing demonstrations and adoption of farming methods that improve soil health and water holding capacity so that lands will be more resistant/resilient to and during cyclic drought patterns. Action Development Date: 2004
4.4	Encourage cooperative sharing of water resources between municipalities and water districts within a watershed during a drought	M	CWCB Local Water Providers	Data & Studies	Cooperative projects continue to develop such as WISE and Southern Delivery System, which can improve drought resilience by diversifying water supplies for providers. Action Development Date: 2010
4.5	Encourage "drought resistant" communities	L	DOLA CWCB	Education, Awareness & Outreach	Communities are continued to be encouraged to incorporate drought in multi-hazard risk assessments and mitigation strategies, as appropriate. CWCB has worked with NDMC's "Drought Ready Communities" initiative, which is similar to the NWS StormReady certification. The state recovery plan completed in 2013 has increased emphasis on economic/environmental recovery and community sustainability efforts as part of the operational elements of that plan. Follow CWCB drought planning guidance DOLA provides technical assistance and guidance through the Planning for Hazards guide for local community. DOLA also requires comprehensive plans funded out of the Energy and Mineral Impact Assistance Fund (EIAF) to identify hazard risks, vulnerabilities, and mitigation actions. Action Development Date: 2002 Aspects of action completed in 2002
4.6	Enhanced resource matrix of funding sources across the State and Federal agencies.	L	CWCB	Technical Assistance	The state is working to maintain and make publicly available an overview of current federal and state drought assistance programs. Some of this exists already on the CWCB drought toolbox but will be updated as part of the 2018 revision. Action Development Date: 2018
5.1	Continue development and the appropriate allocation of resources to the Office of Water Conservation and Drought Planning in providing technical assistance to covered entities, evaluating submitted water	H	CWCB	Funding	Funds allocated through construction fund and severance tax fund; Full time drought planner hired in 2008; full time water conservation technical specialist hired in 2009; \$1.1million non-reimbursable for statewide municipal distribution system water loss training commencing Spring 2018 Action Development Date: 2003 (DWSA)

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
	conservation and drought plans, administering fund programs, and disseminating information to the public.				
5.2	Provide technical assistance and information on more efficient agricultural irrigation systems	L	CSU ext. Dept. of Ag USDA CWCB	Technical Assistance	Program is related to irrigation efficiently and conservation through new technology and better management. CSU has installed drip and sprinkler irrigation works at their station in Ark Valley, San Luis Valley, West Slope and S. Platte CSU is in the process (as of June 2018) of standing up a new Irrigation Technology Center in Fort Collins that is working closely with the irrigation industry and has significant funding from the Foundation for Food and Agriculture Research, as well as industry support. The 3 regional extension water specialists are part of this network Action Development Date: 2010
5.3	Encourage and provide incentives for more efficient municipal irrigation systems, including State-owned properties	H	CWCB CRC Green CO Local Water Providers	Funding	Use water efficiency grant program; Center for Resource Conservation irrigation audits funded by CWCB; EPA Watersense specifications for outdoor irrigation technologies Green Industries of Colorado (GreenCO) Best Management Practices; Colorado Waterwise's Guidebook of Best Practices for Municipal Water Conservation in Colorado Use Colorado Water Plan grants to fund landscape retrofits and efficient irrigation implementation Action Development Date: 2010
5.4	Support economic incentives for individual investment in conservation including reduced lawn watering and irrigation maintenance	M	DNR	Funding	Water Efficiency Grant Program – CWCB Colorado Water Plan grants – CWCB Water Smart Home Initiative legislation (HB-10-1358 passed in 2010). Action Development Date: 2002
5.5	Provide technical assistance and information on growing crops appropriate to semi-arid climate, or promote growing drought resistant crops	L	CSU ext. Dept. of Ag USDA	Technical Assistance	CSU has been working on this topic since last update. NRCS can potentially utilize its programs to prepare producers for mitigation measures that may be necessary to get through the drought for both grazing and crop (irrigated and dry) lands. Action Development Date: 2010
5.6	Establish BMP's for landscaping uses	L	CO WWC CWCB	Planning & Regulations	BMPs developed through CO Water Wise Council in 2010; GreenCO developed green industry BMPs in 2008 Additional projects, funded by CWCB water efficiency grant funds, on landscaper certification, creation of landscape ordinances, etc. Action Development Date: 2010

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
5.7	Reuse of water for cooling (full cycle) during power generation at coal and natural gas plants	L	Xcel Energy DORA-PUC	Structure & Infrastructure Projects	Coal and natural gas power generation plants use water for cooling. Coal fired plants use considerably more water than gas fired plants (94% vs. 6%) however in both cases, the water used is recycled. Given the "Clean Air Clean Jobs Act" passed by the legislature, coal fired plants are eventually being replaced with natural gas. Xcel Energy is utilizing water reuse as a strategy to reduce water demands. Action Development Date: 2013
5.8	Precipitation Harvesting Pilot Program	L	CWCB DWR	Structure & Infrastructure Projects	HB 09-1129 authorized up to ten pilot projects for new residential or mixed-use developments, providing an opportunity to further evaluate implementation of rainwater and snowmelt harvesting in Colorado (collectively referred to as "rainwater harvesting"). The goal of the pilot project program is to gain additional field-verified information about the feasibility of rainwater harvesting as a water conservation measure in Colorado, through pairing it directly with advanced outdoor water demand management – particularly efficient landscaping Each sponsor shall submit a final report to the board and the state engineer by January 15, 2025. The board and the state engineer shall provide a final briefing to the water resources review committee by July 1, 2025. and irrigation practices. Potential benefits of action: The Holistic Approach to Sustainable Water Management in Northwest Douglas County study concluded that lawn and garden irrigation demands could be significantly reduced by using rainwater and snowmelt harvesting, particularly when paired with active water management techniques (approximately 65% with "moderate conservation" and approximately 88% with "water wise conservation") while maintaining a landscape appearance acceptable to Coloradoans. Action Development Status: New in 2018
5.9	Rain Barrel Bill	L	DWR	Planning & Regulations	On or before March 1, 2019 and on or before March 1, 2022, the State Engineer shall report to the committees of reference in each House of the General Assembly with jurisdiction over agriculture on whether the allowance of small-scale residential precipitation collection pursuant to this article has caused any discernible injury to downstream water rights. Potential benefits of action: While offsetting a small amount of potable water for irrigation purposes, the main benefit is educational in nature. The idea is that, during a drought, the lack of precipitation will result in empty rain barrels bringing attention to how little measurable precipitation has been collected over a period of time. Action Development Status: New in 2018

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
5.10	Regional Factors for Precipitation Harvesting	L	DWR CWCBC	Data & Studies	<p>House Bill 15-1016 calls for the Board to update the Criteria and Guidelines to allow for the establishment of Regionally Applicable Factors that specify the amount of precipitation consumed through evapotranspiration of preexisting natural vegetative cover. If a sponsor submits an application in a region where a Regionally Applicable Factor has been adopted under these Criteria and Guidelines, the sponsor may propose the use of the Regionally Applicable Factor in SWSPs applied for pursuant to section 37-92-308(4) or (5), C.R.S. and associated with the sponsor's pilot project. The State Engineer shall give the sponsor's use of the Regionally Applicable Factor in said SWSP applications a presumptive effect, subject to rebuttal.</p> <p>Cost estimate: \$50,000 - \$100,000</p> <p>Each sponsor shall submit a final report to the board and the state engineer by January 15, 2025. The board and the state engineer shall provide a final briefing to the water resources review committee by July 1, 2025.</p> <p>Potential benefits of action: Allows for easier entry into pilot program and creates an incentive for more sponsors to implement precipitation harvesting.</p> <p>Action Development Status: New in 2018</p>
5.11	Encourage QWEL Certification	H	CWCB City of Aspen South Metro Water Authority	Education, Awareness & Outreach	<p>The QWEL program provides landscape professionals with approximately 20 hours of education on principles of landscape water management including proper plant selection for the local climate, irrigation system design and maintenance, and irrigation system programming and operation. In order to obtain the QWEL certification, an individual must demonstrate their ability to perform an irrigation system audit as well as pass the QWEL exam. The QWEL program is recognized as a WaterSense labeled Professional Certification Program for Irrigation System Audits and upon certification, graduates receive the WaterSense Certified Professional designation, providing a nationally-recognized level of certification. The Sonoma-Marín Saving Water Partnership in California sponsors the QWEL program and certification. is currently offered in six states across the nation; this would be the first for Colorado</p> <p>CWCB has approved two water efficiency grants to South Metro Water Authority and the City of Aspen. These grants will focus mainly on the preparation and implementation of the training session for the Qualified Water Efficient Landscaper (QWEL) professional certification.</p>

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
					Potential benefit of action: Certifying landscapers in a proven certification program has resulted in an increase in water efficiency in urban landscapes as well as creation of more resilient urban landscapes. Certifications should be completed by end of 2018. Action Development Status: New in 2018
6.1	Continue to pursue implementation funding for recommendations in this plan	H	CWCB	Funding	Funding secured to implement some 2007 recommendations. \$200k funding for implementation was set aside through construction funds in 2010. See Funding Sources of plan for updated details. Action Development Date: 2007
6.2	Create a sustainable funding source within State's Long Bill or CWCB budget to continue implementing all the recommendations in the Drought Plan – including monitoring and data collection	M	State Gov't CWCB	Funding	Flood and Drought Response Fund created in 2012 Action Development Date: 2010
6.3	Continue weather modification research	M	CWCB	Data & Studies	Efforts continue by CWCB and Water Users downstream in the Colorado River Basin to assist water users and develop their programs to industry standards through grants and technical assistance. There are seven wintertime ground based cloud seeding programs in Upper Colorado River, Grand Mesa, Gunnison, Telluride, Western San Juan Mountains, and Eastern San Juan Mountains. A 2012 Rules update require target control evaluations each year and suggest evaluations and refinement techniques. Action Development Date: 2002
6.4	Leverage the NIDIS Drought Portal (www.drought.gov) "Drought Impacts Reporter" to compile Colorado-specific drought impacts	L	WATF NOAA NDMC CWCB	Data & Studies	CWCB sends data to NDMC regularly on drought impacts. Drought Impacts Reporter data summarized in 2010 revision and 2013 update. NDMC working on web tool to allow overlay of drought impact reporter reports with drought monitor historic and present conditions Action Development Date: 2010
6.5	Support agricultural research of drought tolerant species	L	CSU	Data & Studies	CSU has ongoing research into crop improvement for drought tolerance both at the molecular and plant breeding levels. Funded by the Ag Experiment Station and various granting agencies. Action Development Date: 2010
6.6	Incorporate wetlands protection into watershed-scale planning efforts	L	CWCB DOLA CPW	Planning & Regulations	Effectively integrate wetland and aquatic resource protection into the planning process (e.g., plans, policies, codes, and standards). This can be achieved through regulatory and non-regulatory measures, including: watershed-scale/stream management plans, comprehensive plans, etc.

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
					Continue supporting watershed groups carrying out planning and project execution in riparian and wetlands. CWCB has funding support for local efforts DOLA previously had capacity/project grants with CDBG-DR from DR 4145 flood disaster but those monies are fully allocated Potential benefits of action: Wetlands provide a range of ecosystem services including water storage and flood mitigation Action Development status: New in 2018
6.7	River restoration for streams that are most vulnerable to drought impacts	H	CPW CWCB	Watersheds & Natural Resources	In many streams in Colorado flows in normal water years are already below historical flows and thus the stream is more shallow, putting fish more at risk. High priority streams could be identified by CPW, CWCB and other agencies & NGOs. Funding could be made available for river restoration projects that would lower the risk of the stream running dry in the summer. Funding could be for projects implemented by: state agencies, local government, NGOs. Action Development status: New in 2018
7.1	Participate in new monitoring guidelines process for Ag lands being facilitated by Colorado Cattlemen's Association.	L	CCA Dept. of Ag CSU-WRI	Planning & Regulations	The Colorado Cattleman's Association leads a Colorado Resource Monitoring Initiative (CRMI), which is a database for ranchers to input rangeland condition information. 15 ranchers were utilizing the database as of June 2013, with more interest in the program being generated through CCA education and outreach. Has participation from federal and state land management agencies and Ag producers. Action Development Date: 2010

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
8.1	Statewide Climate Change Initiatives	H	CWCB USBR	Planning & Regulations	<p>The state has undertaken many statewide climate change initiatives since 2007. Over the course of the last decade the State's climate change efforts have become increasingly more coordinated. The items listed below are those that have a nexus with drought specifically and do not represent a comprehensive list of state climate actions. These include:</p> <ul style="list-style-type: none"> 2007 Governor's Climate Action Plan developed Dealing with Drought 2008 Climate Change in Colorado synthesis report 2009 Adapting to Climate Change workshops 2010 Climate Change Impacts and Vulnerability Assessment 2011 Colorado Climate Preparedness Project 2012 CWCB Colorado River Water Availability Study 2012 Joint Front Range Climate Change Vulnerability Study 2012 Colorado Climate Action Plan 2012 Colorado River Basin Water Supply and Demand Study 2013 Colorado Drought Mitigation and Response Plan HB13-1293 Called for the development of a statewide climate plan and the appointment of a staff person to coordinate climate change efforts, this position is currently housed in CWCB. 2014 Climate Change in Colorado Report 2014 Colorado's Water Plan 2015 Colorado Climate Plan <p>In July 2017, the Governor put forth Executive Order D 2017-015 committing the state to reduce statewide greenhouse gas emissions by more than 26 percent from 2005 levels by 2025. These goals have been incorporated into the 2018 Colorado Climate Plan. The EO also called for coordination with local governments and utilities, the development of an EV Plan and announced that the state would be joining the US Climate Alliance.</p> <p>Action Development Date: 2007 Action completed in 2007,2008,2009,2010,2011,2012,2013</p>
8.2	Funding Climate Monitoring Stations	H	CWCB CCC	Funding	<p>Through the Construction Fund CWCB and the State have provided \$150K dollars annually to the Colorado Climate Center for the development of a Colorado Mesonet system for climate monitoring. More long-term funding will need to be developed in the future to sustain and support these efforts.</p>

Goal and Action ID	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation, Funding, and Potential Benefits
					Action Development Date: 2007 Completed in 2012
8.3	Assess how the hydrograph will change due to climate change for each major river system/ basin in the State	L	CWCB CPW USBR	Data & Studies	2012 Colorado River Water Availability River Study 2012 Colorado River Basin Water Supply and Demand Study 2012 Joint Front Range Climate Change Vulnerability Study 2013 Climate Variability/Paleohydrology Analysis as part of Drought Plan update. 2015 & 2017 Colorado River Water Availability River Study phase 2. Results incorporated into Annex C Climate Change in 2018 Drought Plan update Action Development Date: 2010 Action completed in 2012, 2013, 2018
8.4	Continue to pursue improved climate data to inform the planning process	L	CCC CWCB	Data & Studies	CWCB continue to work with state, federal and academic partners to ensure that the best available science is being utilized in long term planning processes.

Deleted and Deferred Actions

In 2018 six actions were deleted from the summary table and two actions are being deferred. These actions were either no longer relevant, captured as aspects of other actions, or addressed in other State planning efforts. The actions include:

Deleted Actions:

- Coordinate input of groundwater monitoring into overall water availability picture
- Workshops: livestock management during drought*
- Evaluate, and where appropriate engage alternative funding sources and mechanisms to provide resources for programs water users identified as being needed on s statewide, regional and local basis
- Provide appropriate resources to continue to develop and administer opinion surveys of Colorado water users relative to important water issues, and to create a temporal database related to drought and water supply impacts, limitations, planning needs, and projects
- Develop data base to track key information in local drought plans
- Continue to assess potential climate change impacts on a variety of sectors

*Actions merged with similar ongoing action “Workshops: crop survival during drought”

Deferred Actions:

- Require drought planning by Colorado municipalities, water providers and large agricultural producers
- Evaluate the relationship/interaction between both drought (low flows) and water conservation on water quality of streams as well as health related consequences

4.4.2 Progress in Statewide Mitigation Efforts

As evidenced in the number of completed and/or ongoing projects in the actions summary table the State has been making active progress in the implementation of drought mitigation efforts. Of the 78 ongoing and new actions identified in 2013, 22 have been completed and 57 are ongoing, 6 of which are new actions developed as part of this planning effort. A concerted effort was made to streamline the action table in 2018 to separate out completed actions. The completed actions are noted in the following table. Additionally, several items associated with other State Planning efforts or other existing actions have been removed or deferred from the action table, as discussed in the previous section. This table can be modified to reflect progress made as the Plan matures.

Table 18 Completed/Deleted or Deferred State Drought Mitigation Actions

Related Goal	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation
1	Integrate state flood and drought monitoring	H	CWCB	Data & Studies	Improve efficiency through better integration. The WATF and Flood Task Force have been conducting joint meetings in the spring for several years. CWCB Flood and drought response fund created in 2012 for flood and drought preparedness activities. Refreshes to \$500K each year based on how much is used the previous year (pre- and post-disaster though most is held for post-disaster.) Action Development Date: 2010
1	Additional Drought DSS support and development	H	CWCB DWR-SEO	Data & Studies	Basin Needs Decision Support System development. BNDSS was created to track projects (i.e. reservoirs) and processes (i.e. conservation programs) that are being implemented by providers statewide, to meet the water needs “gap” originally identified by the Statewide Water Supply Initiative (SWSI) study. This could provide a foundation to integrate drought information and local drought plans moving forward. Action Development Date: 2002
1	Additional SWSI Index modernization	H	NRCS DWR	Data & Studies	While this index was refined in 2010, additional work and automation was completed in 2015 and no further changes are planned per DWR. The TSTool pulls data directly from NRCS web services to run statistics. Action Development Date: 2013
1	Colorado Drought Status strategy	L	WATF	Multiple	Monthly drought status update developed for state leadership; www.coh2o.co website developed in 2013 for public access to drought conditions and municipal water restrictions. Expanded distribution of drought status report to media, leadership. More streamlined process for monitoring drought from a leadership standpoint.; periodic briefs from CWCB staff to governor’s staff. Action Development Date: 2002 Completed in 2002 and 2013

Related Goal	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation
2	Drought Info Website	H	CWCB	Education, Awareness & Outreach	Drought information is hosted on the CWCB website including drought status, planning and response. Development of a Colorado Drought Response website in 2012 (www.coh2o.co) that provides current information on water restrictions and drought response activities for municipalities. Website users are able to specify a certain local community and obtain information on water restrictions. Action Development Date: 2002 Completed in 2009
2	Develop technical drought planning toolbox	H	CWCB	Education, Awareness & Outreach	A drought web-based toolbox was developed as part of the 2010 revision of this Plan. The Toolbox is eventually going away in 2018 (replicates what already exists on drought.gov). Action Development Date: 2007 Completed in 2009
2	Workshops: water system management during drought	L	CSU Coop Ext. Dept. of Ag NRCS Conservation Districts DOLA CWCB CRWA USGS USBR CDPHE-WQCD CPW	Education, Awareness & Outreach	Four workshops were held around the State between 2002-2004 which raised awareness of drought impacts such as water quality impacts, state and federal resources, water rights administration, emergency management principles, the State's plan and response to drought, weather modification programs, funding options, and regulatory perspectives. Five municipal drought planning workshops were held in Spring of 2011 DOLA has developed updated training and technical assistance approach/program for this action. Completed in 2002, 2003, 2004, 2011
2	Drought workshop for urban and land use planners	L	CWCB DOLA	Education, Awareness & Outreach Technical Assistance	Focused training efforts for City and County planners Five municipal drought planning workshops were held in Spring of 2011 DOLA developed updated training plan for this action Action Development Date: 2010 Completed in 2011
2	2012 – Year of Water Education Initiative	L	CCC CFWE	Education, Awareness & Outreach	Education initiative for the State. Emphasis on youth education and community involvement. Completed in 2012. Colorado Water 2012 worked to: raise awareness about water; increase support for management and protection of Colorado's water; showcase exemplary models of cooperation, and collaboration; connect Coloradans to their water; and motivate them to participate in the future of their water resources.

Related Goal	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation
					Colorado Water 2012 touched more than 500,000 Coloradans with its message of water awareness. The relationships and partnerships that Colorado Water 2012 facilitated are one of the most powerful, if difficult to measure, successes of the initiative. The initiative also increased the amount of water education happening in Colorado, as well as the number of people participating in the discussion. Colorado Water 2012 was less successful at creating behavior change among the general public, which is generally a longer-term goal. Included the "Rain Gage in Every School" effort and CoCoRaHS outreach from CCC. Action Development Date: 2002 Completed in 2011-2012
2	"Drought Awareness Week"	L	CCC DHSEM CWCB	Education, Awareness & Outreach	This action is related to Drought Conferences action. Action Development Date: 2002 Completed in 2011
2	Drought Information Brochure	L	CWCB Local Water Providers	Education, Awareness & Outreach	CWCB Website has drought information that was expanded with drought toolbox development in 2010. Developed a brochure/flyer on the 2010 State Drought Plan update. Action Development Date: 2002 Completed in 2011
3	Resolve emerging water use conflicts	M	DWR-SEO	Planning & Regulations	DWR-SEO reviews and approves temporary water transfers through Substitute Water Supply Plans (for instream flow and other uses) and interruptible water supply agreements. Additional collaboration between involved parties may reveal creative solutions to water use conflicts. Substitute Water Supply Plans now actively used. Action Development Date: 2010
3	Promote legislation that provides for policy to allow for greater flexibility during drought conditions to protect instream flows and/or wetlands critical to the survival of species of greatest conservation need	L	CWCB Colorado Water Trust Attorney General DWR-SEO CPW	Planning & Regulations	Action completed with enactment of 37-38-105 which enables entities in collaboration with CWCB to lease water for streams on short notice to protect the environment. This tool was the first used in 2012 to add water to streams during the drought and its use continued in 2013. Action Development Date: 2010 Completed in 2012
4	Risk-based water system assessments	H	CWCB	Data & Studies	Tools and methods developed as part of the local plan guidance document in 2010 Action Development Date: 2002

Related Goal	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation
4	Integrate and correlate the State Drought Mitigation Plan with other statewide planning efforts	H	CWCB CSFS CEO	Planning & Regulations	IBCC planning efforts, Forest Resource Assessment Planning; Drought plan integrated with Colorado Energy Assurance Emergency Plan developed in 2012. Integration of the OWCDP and Water Supply Planning Section. Update of the State Emergency Operations Plan in April 2013 The Drought Plan was linked with the 2015 State Water Plan and Colorado Climate Plan Colorado Resiliency Framework (adopted in 2015) State Hazard Mitigation Plan update (in 2017-2018) Action Development Date: 2010 Completed in 2011, 2012, 2015, and 2017-18
4	Workshops for local drought plans	L	CWCB DOLA	Education, Awareness & Outreach	Workshop held in 2010 during the development of local plan guidance document Dealing with Drought – Adapting to Climate Change workshops held in Held five workshops in the spring of 2011 on drought planning Fall of 2009 DOLA's Planning for Hazards webinar series including Climate Planning in November 2017. It was recommended that local plans look at efforts to integrate drought considerations into other planning efforts. planningforhazards.com/webinars Action Development Date: 2002 Completed in 2000-2001, 2009, 2010, 2011
4	Integrate the State Drought Mitigation Plan with Energy Assurance Emergency Plan	L	CEO DORA-PUC	Planning & Regulations	Action Development Date: 2002 Completed in 2012
5	Support development of local water conservation program	H	CWCB	Data & Studies	State Water Conservation planning requirement. To date, 83 water efficiency plans are currently approved. Rainwater Harvesting Pilot Project Program started in 2009 with one pilot project active; Water Conservation Technical Advisory Group meeting once per month but is currently on hiatus; HB 1051 data collection began in 2014 with web portal for collecting data online and currently holds four years of data; Water Efficiency Guidance document revised in 2012; development of several regional water efficiency plans for smaller providers who group resources. Action Development Date: 2002 Water Conservation Planning Guidance document completed in 2012

Related Goal	Action	Priority	Responsible Lead Agency or Work Group	Mitigation Type	Additional comments on Status, Implementation
5	Support economic incentives for individual investment in conservation including reduced lawn watering and irrigation maintenance	M	DNR	Funding	Recharge Colorado: CWCB partners with Colorado Energy Office (CEO) energy and water efficient appliance rebates; Action Development Date: 2002
5	Encourage minimizing building (particularly urban) water usage in cooling towers and explore other water-energy nexus connections	L	Local Water Providers CWCB	Education, Awareness, & Outreach	Recharge Colorado conducted a series of workshops funded by CWCB Action Development Date: 2010
7	Develop a drought exercise to test procedures and train constituents	H	CWCB	Education, Awareness & Outreach	Updated plan was tested during actual drought in 2011-2012 when Agricultural Impact Task Force activated. Municipal Water ITF activated in 2013. Drought response plan undergoing revisions in 2013 based on lessons learned. CWCB and NIDIS co-sponsored the first Colorado 'Drought Tournament' as a daylong event prior to the 2012 Governors Drought Conference. The tournament was designed to enhance multi-sector collaboration and creative response and mitigation in three simulated droughts. Tested during 2012-2013 drought Action Development Date: 2010 Completed in 2013
8	Host Statewide Drought Conference	M	CWCB	Education, Awareness & Outreach	Drought and Climate change conference held in October 2008, 'Dealing with Drought – Adapting to Climate Change' workshops held in Fall of 2009 (three around the State) Water and Land Use Planning for a Sustainable Future symposium Sept 2009 2012 Governors Drought Conference Action Development Date: 2007 Completed in 1999,2008,2009,2012

4.4.3 Evaluation and Selection of Actions and Activities

During the 2018 update process the DMRPC members were asked to generate new ideas for actions to be included in the plan. At a planning workshop DMRPC members were provided with several lists of alternative drought hazard mitigation actions. One of these was a compendium of tools typically used by states to mitigate drought, based on information from the National Drought Mitigation Center’s website. In addition to these handouts, a presentation at the workshop on the vulnerability assessment update included recommendations for “adaptive capacities” that could mitigate impacts to the various sectors. These suggested recommendations are captured in Annex B Drought Vulnerability Assessment Technical Information and organized by impact sector. This Annex can serve the State as well as local governments, citizens, businesses and industry as a useful reference for mitigation strategies to be considered in the future.

The following general categories of state level approaches to drought mitigation were considered:

- Administrative
- Emergency Services
- Financial
- Monitoring and Prediction
- Natural Resource Protection
- Projects to Reduce Impacts to State Assets
- Public Education
- Regulatory
- Structural Projects
- Studies, Publications, Planning efforts
- Technical Assistance
- Training and Exercises

A facilitated discussion took place at the workshop to examine and analyze the alternatives. With an understanding of the alternatives and progress on existing actions, a brainstorming session was conducted to generate a list of preferred mitigation actions. DMRPC members wrote project ideas on sticky notes. These were posted on flip charts organized by goal. The result was a number of new or revised project ideas that help to meet the identified goals. New actions identified through this process are indicated in Table 19 with a 2018 development date. Existing actions were also evaluated and revised during this process and are also included in Table 19.

4.4.4 Prioritization of Actions and Activities

Once the mitigation actions were identified, the DMRPC members were provided with several sets of decision-making tools, including FEMA’s recommended criteria, STAPLE/E (which considers social, technical, administrative, political, legal, economic, and environmental constraints and benefits) as well as Colorado’s Resiliency Framework.

STAPLE/E:

- Social: Does the measure treat people fairly?
- Technical: Will it work? (Does it solve the problem? Is it feasible?)
- Administrative: Is there capacity to implement and manage the project?
- Political: Who are the stakeholders? Did they get to participate? Is there public support? Is political leadership willing to support the project?
- Legal: Does your organization have the authority to implement? Is it legal? Are there liability implications?
- Economic: Is it cost-beneficial? Is there funding? Does it contribute to the local economy or economic development? Does it reduce direct property losses or indirect economic losses?
- Environmental: Does it comply with environmental regulations or have adverse environmental impacts?

In accordance with the DMA requirements, an emphasis was placed on the importance of a benefit-cost analysis in determining project priority (i.e., the “economic” factor of STAPLE/E). Other criteria used to recommend what actions might be more important, more effective, or more likely to be implemented than another included:

- Does action address hazards or areas with the highest risk (from Risk Assessment)?
- Does action protect state assets or infrastructure?
- Does action improve the State capability to manage and implement mitigation (from Capability Assessment)?

Colorado’s Resiliency Framework, which is profiled in Section 4.2.6 of this Plan, sets forth resiliency prioritization criteria that local communities can use to evaluate and prioritize mitigation actions. Moving forward the DMRPC concurred that the criteria could be used as guiding principles for prioritization of mitigation actions. This is also consistent with the Colorado Hazard Mitigation Plan, which utilizes the criteria for allocation of mitigation funding. The prioritization criteria is listed below.

Resiliency Prioritization Criteria:

- Co-Benefits: Provide solutions that address problems across multiple sectors creating maximum benefit
- High Risk and Vulnerability: Ensure that Strategies directly address the reduction of risk to human well-being, physical infrastructure and natural systems.
- Economic Benefit-Cost: Make good financial investments that have the potential for economic benefit to the investor and the broader community both through direct and indirect returns.
- Social Equity: Provide solutions that are inclusive with consideration to populations that are often most fragile and vulnerable to sudden impacts due to their continual state of stress.
- Technical Soundness: Identify solutions that reflect best practices that have been tested and proven to work in similar regional context.

- **Innovation:** Advance new approaches and techniques that will encourage continual improvement and advancement of the best practices serving as models for others in Colorado and beyond.
- **Adaptive Capacity:** Include flexibility and adaptable measures that consider future unknowns of changing climate, economic, and social conditions
- **Harmonize with Existing Activity:** Expand, enhance, or leverage work being done to build on existing efforts
- **Long-term and Lasting Impact:** Create long-term gains to the community with solutions that are replicable and sustainable, creating benefit for present and future generations.

With these criteria in mind, DMRPC members were given a set of eight sticky-dots and asked to place the dots on the identified actions as a means to prioritize projects. The projects with the most dots became the higher priority projects. This process provided both consensus and priority for the recommendations. The number of dots was converted into a relative low, medium, and high prioritization category using a score of 0-2 dots as low, 3-4 as medium, and 4-6 as high. The results of the project identification and prioritization exercise are summarized in Table 19 in the “priority” column.

The action identification and prioritization process is the first step in laying-out, in broad terms, what needs to be done to continue to minimize the impact of the drought hazard in the State. Some of the actions can be accomplished with minimal cost or integrated into the work plans of the lead agency. While cost-effectiveness is required for FEMA funding of projects, many of the projects identified are non-structural and thus difficult to quantify cost-effectiveness. The detailed engineering studies, implementation costs, and benefit-cost analysis of specific projects will come at future points in the process. Additional discussion on this topic is included in Chapter 6 Plan Maintenance Process.

Changes in Priorities

Actions developed prior to the 2018 update were prioritized by using the STAPLE/E criteria only. New actions developed for this update were prioritized using both the STAPLE/E and the Resiliency Framework criteria. The prioritization of actions was reviewed by the DMRPC during the planning process and the priorities were adjusted based on feedback from the DMRPC. The lead agencies were asked to review and rank these projects, based on the STAPLE/E and the Resiliency Framework criteria, for projects that they were responsible for implementing. 0 reflects the new priorities, which are grouped by relative priority under each goal. Some actions that have been partially implemented were revised to Low during the 2018 update.

4.4.5 Contribution of Each Activity to Overall State Drought Mitigation Strategy

Table 19 was reorganized in 2018 to be similar to the organization of mitigation actions in the State Hazard Mitigation Plan. The grouping indicates that a balanced number of activities are proposed or ongoing to meet the eight goals.

4.4.6 Integration of Local Plans into Mitigation Strategy

FEMA recommends that the mitigation actions identified should be linked to local mitigation plans, where specific local actions and projects are identified; however, the absence of information on this piece will not cause FEMA to disapprove the plan. During the 2018 update the available local hazard mitigation plans were reviewed to identify drought-related mitigation projects. 0 contains mitigation actions that local or regional jurisdictions have identified in their plans intended to mitigate the effects of drought. This data originated from local multi-hazard mitigation plans in effect in counties, cities and other local entities in Colorado as of April 2018. By connecting these local actions with the State Drought Plan, opportunities for targeted technical assistance and funding needs can be identified so the State can assist with the implementation of these activities.

Table 19 Drought Mitigation Actions from Local and Regional Multi-Hazard Mitigation Plans

Plan Name/Jurisdiction	Mitigation Action
Archuleta County	1) Water conservation program 2) Drought management plan update
Boulder County	No drought specific mitigation actions, but incorporated into multi-hazard activities
Boulder County City of Longmont	1) Implement Water Supply and Drought Management Plan 2) Implement Water Conservation Draft Master Plan
Boulder County City of Louisville	Implement Drought Management Plan
City of Boulder	1) Identify and implement priority projects identified in the City's Drought Plan 2) Review city landscape codes for drought 3) Implement replacement planting program to meet tree criteria
City of Colorado Springs	Coordinate with Colorado Springs Utilities to review their current water conservation and drought programs
Costilla County	1) Contact Natural Resources Conservation Service regarding opportunities for technical assistance and financial assistance for drought preparedness and response. 2) Initiate appropriate drought preparation actions as specified in the Costilla County Drought Preparedness Action Guide.
Delta County	No drought specific mitigation actions, but incorporated into multi-hazard activities. Various drought-related activities also considered under alternative mitigation actions.
Denver Regional Council of Governments	1) Coordinate with local water providers to continually identify and promote water conservation measures 2) Monitor proceedings of the Colorado Water Availability Task Force. When necessary, support water providers in the implementation of conservation measures.
Dolores County	1) Obtain elevated, high volume/high flow water tanks (at least 6000 gallon) to be spaced throughout the county for an additional potable water source. 2) Update existing water delivery system. Perform leak detection and water loss control measures to minimize water loss during drought periods.
Eagle County	No drought specific mitigation actions identified
Elbert County Town of Elizabeth	Implement water delivery system improvements

Plan Name/Jurisdiction	Mitigation Action
Elbert County Town of Kiowa	1) Implement water delivery system improvements 2) Develop education and incentives program to encourage water saving measures by citizens.
El Paso County	1) Coordinate Conservation and Mitigation Actions with the Water Department 2) Adopt Water Mitigation Plan, Water Conservation Plan and Reusable/Renewable Water Plan
Grand County	1) Update drought management plan 2) Update Annual Operating Plan for Property Owners
Gunnison County	1) Monitor water issues in City of Gunnison area 2) Monitor city's wells for contamination or dropping water tables 3) Continue acquiring water rights in the area
Hinsdale County	No drought specific mitigation actions identified
Huerfano County	No drought specific mitigation actions identified
Jefferson County	1) Partial renovation and improvement to sections of the main pipeline 2) Conduct a leak detection survey 3) Expand storage capacity at upper Beaver Brook reservoir
Mesa County	No drought specific mitigation actions identified but incorporated into multi-hazard activities
Montrose County	No drought specific mitigation actions identified
Northeast Colorado Cheyenne County Kit Carson County Lincoln County Philips County Sedgwick County Washington County Weld County Yuma County	1) Improve water supply Improving water supply 2)-Seek grazing on Conservation Reserve Program land 3)Use of low-water crops 4) Encourage crop insurance awareness and education to offset the crop losses for the pervasive drought 5) Conduct a Public Education Campaign that addresses Water Conservation
Northeast Colorado Logan County	1) Construct a multi-purpose flood control dam at Pawnee Pass 2) Construct additional small retention ponds and new wellheads throughout the watershed
Northeast Colorado Morgan County	Development and implementation of a Source Water Protection Plan
Northern Colorado Region	1) Public information campaign expansion 2) On-line access to water history 3) Low income retrofit program 4) Irrigation technology rebates 5) Facility audit program expansion 6) Financial incentives for commercial water saving upgrades 7) Local water providers implement domestic water use restrictions during identified periods of drought. 8) Provide education to property owners about use of drought-resistant or native vegetation
Ouray County	1) Develop additional raw storage for the Town of Ridgway 2) Continued participation in water conservation and drought status outreach
Park County	1) Educate the public about ways to lessen the effects of drought and the need to be water wise.

Plan Name/Jurisdiction	Mitigation Action
	<p>2) Identify those municipalities and unincorporated communities in Park County most at risk due to drought, develop Community Water Conservation Plans, and alternate water supply locations for those communities, and implement those plans.</p> <p>3) Collect analyze drought-related data using GIS to help in pre-drought preparation</p> <p>4) Identify alternative water supplies for time of drought. Consider the development of mutual aid agreements with alternative suppliers and look at obtaining additional water rights.</p>
Pitkin County	No drought specific mitigation actions, but incorporated into multi-hazard activities
Prowers County	No drought specific mitigation actions, but incorporated into multi-hazard activities
Pueblo County	No drought specific mitigation actions, but incorporated into multi-hazard activities
Rio Blanco County	<p>1) Drought preparedness planning</p> <p>2) Wolf Creek Reservoir, drought, erosion/deposition</p>
Routt County	<p>1) Water use reduction projects</p> <p>2) Water conservation education and outreach</p>
San Luis Valley Multi-Hazard Mitigation Plan Alamosa County	Prepare a Drought Preparedness Action Guide
San Luis Valley Multi-Hazard Mitigation Plan Conejos County	Develop a drought action plan based on state guidelines
San Luis Valley Multi-Hazard Mitigation Plan Mineral County	No drought specific mitigation actions, but incorporated into multi-hazard activities
San Luis Valley Multi-Hazard Mitigation Plan Region-wide	Develop a regional drought action plan
San Luis Valley Multi-Hazard Mitigation Plan Rio Grande County	<p>1) Develop an action/response plan for drought</p> <p>2) Increase public awareness in regards to drought</p> <p>3) Establish/maintain a water conservation process for protecting aquifer levels</p>
San Luis Valley Multi-Hazard Mitigation Plan Rio Grande Water Conservation District	<p>1) Prepare a Drought Preparedness Action Guide</p> <p>2) Establish and maintain a water conservation process for protecting aquifer levels</p>
San Luis Valley Multi-Hazard Mitigation Plan Saguache County	<p>1) Prepare a drought action plan</p> <p>2) Work with Saguache Creek Water Users (and other similar organizations) to develop a plan and strategy for mitigating drought and flooding</p>
San Miguel County	<p>1) Public information campaigns during drought and non-drought periods</p> <p>2) Work with water supply organizations to promote conservation and efficiency initiatives</p> <p>3) Improve water supply systems to reduce the effects of drought</p> <p>4) Identify and implement water restriction policies during drought times</p>
San Miguel County Town of Sawpit	Develop and implement drought awareness for residents
San Miguel County	1) Improve drought awareness through public education campaign

Plan Name/Jurisdiction	Mitigation Action
Town of Norwood	2) Develop water usage restrictions to be used during drought periods
Summit County	No drought specific mitigation actions, but incorporated into multi-hazard activities
Teller County	Strategic snow stockpiling for Cripple Creek
University of Colorado, Boulder	No drought specific mitigation actions
Upper Arkansas Area	1) Acquire more senior water rights 2) Construction of more water storage facilities 3) Establish "Water Banks" or similar mechanism to protect both the agricultural and municipal centers in the region 4) Implement and Promote "Waterwise" programs 5) Implement water-use fee policies that promote conservation 6) Prepare public relations campaign to accurately portray drought impacts to recreational assets 7) Publicize findings of expert panel
Ute Mountain Ute Tribe	No drought specific mitigation actions, but incorporated into multi-hazard activities

4.5 Funding Sources

The state mitigation strategy includes an identification of existing and potential sources of federal, state, local or private funding to implement mitigation activities. Colorado uses a variety of sources to fund state and local drought mitigation activities that are described in the next section.

4.5.1 Identification of Existing Federal, State, Local Funding Sources

The state has loan and grant programs for which drought and other hazard mitigation activities are eligible. Funding sources traditionally used have been energy impact funds, gaming funds, general funds, and severance tax. Many agencies have grant programs, including, but not limited to local and state agencies such as the State Forest Service, CWCB, DWR, and the DHSEM. Existing funding sources available for drought mitigation and recovery projects in Colorado from local and state agencies are presented in Table 20. Drought-related Federal response programs are shown in Table 21. New funding sources made available since the 2013 update are included in these tables as applicable.

Table 20 Local and State Drought Mitigation Funding Sources Available in Colorado

Program	Grant/Loan Funds Available	Uses/Requirements	Agency
CWCB Construction Fund & Severance Tax Trust Fund	-No limit -Loans typically range from \$50,000 to \$5,000,000 Loans can be made up to \$10,000,000 without legislative authorization within the CWCB process	Raw water projects (e.g., dams, pipelines, ditches, wells, new projects or restorations) -Available to any organization (e.g., municipalities, agriculture, ditch companies, homeowners assn., special districts, etc.) -Must receive CWCB Board and Legislative approval if > \$10M; CWCB Board approval if <\$10M	CWCB
Water Pollution Control Revolving Fund (WPCRF)	-Fire-related nonpoint source projects can be given priority status -Direct loans up to \$3,000,000 available with Board approval -\$10K planning grants available for disadvantaged communities (fire-related O.K.)	Low-interest loans for public waste water treatment system needs and watershed nonpoint source control projects -Available to governmental agencies -Emergency projects can be identified at any time throughout the year with WQCC approval. -Loan funds require board review.	Colorado Water Quality Control Division, Division of Local Government, Water Resources and Power Development Authority
Drinking Water Revolving Fund (DWRf)	-Fire-related nonpoint source projects can be given priority status -Direct loans up to \$3,000,000 available for projects that implement green components equal or greater to 20% of the total cost -\$10K planning grants available for disadvantaged communities (including fire-related)	Low-interest loans for drinking water treatment system needs -Available to governmental agencies -Emergency projects can be identified at any time throughout the year -Loan funds require board review, study grants available immediately	CDPHE, Water Quality Control Division Colorado Water Resources and Power Development Authority Colorado Department of Local Affairs, Division of Local Government
Non point Source Pollution Grants	Typical awards range from \$30K to \$150K	-Applicants can include governmental and non-governmental organizations -Applicants generally evaluated through a stakeholder process, but this can be waived -40% non-federal match required	Colorado Water Quality Control Division
Agricultural Emergency Drought Response Fund	Up to \$1 million annually, in the form of loans or grants	-For emergency drought-related water augmentation purposes -Limited to agricultural organizations	CWCB
Community Development Block Grant (CDBG)	\$500,000 (guideline)	Public facilities including water and wastewater	DOLA field staff

Program	Grant/Loan Funds Available	Uses/Requirements	Agency
CWCB Drought Management Planning Grant Program	No limit, as long as funding is available	Water Conservation Planning; Drought Mitigation and Response Planning	CWCB, awarded through the Water Efficiency Grant Fund Program
Natural Disaster Grant	Grants can be awarded to counties in which the governor has declared a disaster emergency by executive order or proclamation order Section 24-33.5-704 C.R. S	Limited to local governments defined as governmental agencies. Repair water and wastewater infrastructure impacted by natural disaster. For planning, design, construction, improvement, renovations and/or reconstruction	CWCB
CWCB Water Efficiency Grant Program	No limit, as long as funding is available	To aid in achieving goals in Water Conservation Plans To promote the benefits of water resource conservation for education and outreach aimed at demonstrating the benefits of water efficiency	CWCB
Flood and Drought Response Fund	Up to \$500,000	Flood and drought preparedness and for response and recovery activities following flood or drought events and disasters	CWCB
Watershed Restoration Grants	\$500,000 (fiscal year beginning July 1, 2012)	Watershed/stream restoration and flood mitigation projects. These grants were utilized in response to the 2012 High Park and Waldo Canyon Fires	CWCB
Energy & Mineral Impact Assistance Fund	Tier I grants of up to \$200,000; Tier II grants, of up to \$1,000,000.	Public facilities including water and wastewater	DOLA Field Staff
Colorado Water Resources and Power Development Authority Revenue Bonds Program	\$100,000,000 (\$300,000 minimum)	Water and wastewater	CWR&PDA
CWCB Water Project Loan Program	Limited to fund availability. Loans typically range from \$100,000 to \$10,000,000	Raw water projects (e.g., dams, pipelines, ditches, wells, new projects or rehabilitation).	CWCB

Source: 2007 Drought Plan Update, modified in 2010, 2013 and 2018

Table 21 Federal Drought Mitigation Funding Sources Available in Colorado

Program	Grant/Loan Funds Available	Uses/Requirements	Agency
Water2025 Challenge Grant Program for Western States	Up to \$250,000	Projects that can be completed within 24 months and that reduce conflicts through water conservation, efficiency, and markets	USBR

Program	Grant/Loan Funds Available	Uses/Requirements	Agency
WaterSMART Water and Energy Efficiency Grants	Funding Group I: up to \$300,000. Funding Group II: Up to \$1,000,000.	Projects conserve and use water more efficiently; increase the production of hydropower; mitigate conflict risk in areas at a high risk of future water conflict; and accomplish other benefits that contribute to water supply reliability in the western United States. Projects must be completed within 2 or 3 years. 50/50 cost share funding between USBR and another agency/source	USBR
Water Conservation Field Services Program	Up to \$25,000	Funds projects that improve water use efficiency and improve water management practices	USBR
U.S. Economic Development Administration Grant (EDA)	No limit (subject to federal appropriation)	Water and wastewater	EDA
General Matching Grants Program	Varies	Funds projects that promote fish and wildlife conservation as well as conservation of their habitats	FWS
Hydrologic Research Grants	Up to \$125,000	To conduct joint research and development on pressing surface water hydrology issues common to national, regional, local operational offices. Eligible applicants are federally recognized agencies of state or local governments, quasi-public institutions such as water supply or power companies, hydrologic consultants and companies involved in using and developing hydrologic forecasts.	NOAA
Natural Resources Conservation Service – Emergency Watershed Protection Program	-Funding available through the Simplified Acquisition Procedures (SAP) ranges from \$25K to \$100K -Funded through contracts between project sponsors and the NRCS. There are no grants. The NRCS pays 75% of the costs.	Installing/repairing conservation measures to control flooding and prevent soil erosion. Generally, more than one individual should benefit from the project. Public or private landowners or others who have a legal interest or responsibility for the values threatened by the watershed emergency	NRCS –Initial contacts should be made with NRCS county offices when an emergency exists.
Rural Development (U.S. Department Of Agriculture)	Subject to federal appropriation	Water, wastewater & stormwater projects	USDA

Program	Grant/Loan Funds Available	Uses/Requirements	Agency
Watershed Processes and Water Resources	\$100,000	Sponsors research that address two areas: (1) understanding fundamental watershed processes; and (2) developing appropriate technology and management practices for improving the effective use of water (consumptive and non-consumptive) and protecting or improving water quality for agriculture and forestry production	USDA
National Research Initiative Standard Research (Part T): Watershed Processes and Water Resources	\$500,000	Innovative research in understanding fundamental processes that affect the quality and quantity of water resources at diverse spatial and temporal scales, ways on improving water resource management in agriculture, forested, and rangeland watersheds, and developing appropriate technology to reach those goals.	USDA
Emergency Community Water Assistance Grants	\$150,000 to \$500,000	Available to rural communities with populations over 10,000 people with a median household income less than \$65,900. Provides assistance to communities who have experienced a decline in quantity or quality of drinking water as a result of an emergency including drought.	USDA
USDA Rural Development 502 Direct Housing Loan Program	-Loans limited by individual county mortgage limits -Most counties have loan limit of \$108,317	Available for wells and water connections – Applicants must be very low income, owner/occupant, unable to obtain conventional credit, and in rural communities and areas	8 USDA Rural Development offices in Colorado
Colorado Rural Water Association (CRWA) Revolving Loan Program	\$100,000 or 75% of the total project (whichever is less)	Provides loans for pre-development costs associated with water and wastewater projects and for existing systems in need of small-scale capital improvements.	USDA Rural Utilities Service
Drought Contingency Planning	Up to \$200,000 per plan, completed within 2 years	Designed for applicants to develop a drought contingency plan or to update an existing plan to meet the required elements described in the Drought Response Framework. 50% non-Federal cost-share	USBR
Drought Resiliency Projects	Funding Group I: up to \$300,000 Funding Group II: up to \$750,000	For drought resiliency projects that will help communities prepare for and respond to drought (i.e. implement mitigation actions). 50% non-Federal cost-share. Group I must be completed within 2 years; Group II must be completed within 3 years.	USBR

Program	Grant/Loan Funds Available	Uses/Requirements	Agency
Emergency Response Actions	Up to \$300,000 in federal funds will be made available for each emergency response action.	Eligible emergency response actions are limited to temporary construction activities and other actions authorized under Title I that do not involve construction of permanent facilities, including water purchases and use of Reclamation facilities to convey and store water. Actions must be completed within 6 months of a contract.	USBR

The State, through DHSEM, has instituted an effective and comprehensive all-hazard mitigation program. Through a variety of programs, and the wise use of available federal and state funds, the State has been successful in mitigating areas against the devastating effects of drought and other hazards. As of the writing of this Plan, FEMA’s hazard mitigation assistance programs are the primary sources of funding for Colorado’s mitigation activities. These programs are the Pre-Disaster Mitigation Program and Emergency Management Performance Grant. Each of these programs, as they pertain to drought, is discussed further below. Additional information on existing funding sources available for mitigation projects can be found in the 2018 State Hazard Mitigation Plan.

Local

Local governments have the required TABOR (Taxpayers Bill of Rights) reserves for use during emergencies. Local districts have used taxing mechanisms, such as mill levies, to support prevention activities. Local governments also actively pursue grant opportunities through federal and state agencies and use general funds or in-kind services to meet the local match requirement.

Local communities are constantly seeking sources of funding to maintain programs and install or upgrade water systems. Unfortunately, funds for these types of projects are limited and the need strongly outweighs the availability. Even if communities get startup funds, continuation of programs creates new financial needs on already very tight budgets with competing demands. Despite this, Colorado communities have made great strides and progress in prevention and preparedness activities and continue to do more each year by taking advantage of limited opportunities.

4.5.2 Identification of Potential Federal, State, Local Funding Sources

Federal

If a disaster occurs, the State may utilize Hazard Mitigation Grant Program (HMGP) and Public Assistance (PA) mitigation funds. PA mitigation funds will be used in accordance with program requirements and will be used for damaged facilities. HMGP funds may be used primarily in the

affected area or may be used statewide at the Governor's and/or his representative's (GAR's) discretion.

Large projects continue to be completed with federal and state funds and technical assistance from federal agencies other than FEMA. Examples include, but are not limited to, the U.S. Department of Transportation (USDOT), BLM, NPS, the USFS, and the USACE. NRCS has programs for projects both exigent and not, including the Emergency Watershed Protection Program.

The Bureau of Reclamation's WaterSMART program provides funding to local governments and special districts for mitigation projects related to water. The Drought Act of 1991 empowered the Bureau of Reclamation to provide support to states and local jurisdictions after they had experienced a drought emergency. In 2015 the program was reformulated to be a more proactive approach through collaborations with federal and non-federal agencies. The WaterSMART program is an umbrella for the six (6) Bureau of Reclamation water programs. The Drought Response program is one program that provides financial assistance to develop or update drought contingency plans and drought resiliency projects. The Bureau will provide a maximum of \$200,000 of funding with a cost-share requirement of 50% federal funding and 50% non-federal funding, which may include state funding. Drought plans are required to include specific elements which include developing an administrative framework, form a drought planning task force, develop a work plan, and a communication and outreach plan. The WaterSMART website has a data visualization tool and provides links to previously selected projects.

<https://www.usbr.gov/watersmart/index.html>; [WaterSmart Data Visualization Tool](#)

Small Business Administration (SBA) has come in on several Presidential, USDA, and SBA Administrative declarations in the past. USACE General Investigations and Continuing Authorities Programs provide opportunities for water resources projects, studies, design and engineering, and technical expertise.

State

The governor can move funds into the State Disaster Emergency Fund to fund emergency types of activities, such as fire suppression or drought response activities. 0 listed previously and Appendix C Drought Mitigation Capability Summary lists the existing funding sources that could be used in pre- or post-disaster situations. Funding for implementing some of the recommendations from the 2010 Plan were appropriated from CWCB Construction Funds, including \$100,000 for fiscal year 2010/2011 and another \$100,000 for fiscal year 2011/2012. Severance tax funding of \$75,000 was set aside for FY2012 and there is \$20,000 available for FY2014. The CWCB has upgraded the funding set-aside for the Flood and Drought Response Fund up to \$500,000 annually.

USDA

The U.S. Department of Agriculture's Household Water Well System Grant Program provides grants to qualified private nonprofit organizations to establish lending programs for household

water wells. Homeowners or eligible individuals may borrow money from an approved organization to construct or upgrade their private well systems. The website for the program is at: <https://www.rd.usda.gov/programs-services/household-water-well-system-grants> . The Notice of Funding Availability is published each year. The funds have never all been used nationwide.

State Land Board

The State Land Board has funding that could potentially be applied to drought mitigation projects including:

- State Land Board - Land and Water Management Fund
- State Land Board - Enhancement Fund
- Potentially, State Land Board Investment and Development Fund
- State Trust Land Improvement Account - SLB funds administered by the Colorado State Forest Service.

CDPHE - Colorado Water Quality Control Division (WQCD)

The eligible projects that can be funded by the Drinking Water Revolving Fund have expanded with the new emphasis on encouraging Green Infrastructure. These projects are primarily water conservation oriented, which could be considered a component of drought mitigation. Funding has been provided to small community drinking water suppliers. Eligible costs associated with water efficiency projects may include:

- Planning and design activities for water efficiency that are reasonably expected to result in a capital project.
- Purchase of water efficient fixtures, fittings, equipment, or appliances.
- Purchase of leak detection devices and equipment.
- Purchase of water meters, meter reading equipment and systems, and pipe.
- Construction and installation activities that implement capital water efficiency projects.
- Costs associated with development of a water conservation plan if required as a condition of DWSRF assistance.

4.5.3 Sources of Funding Used to Implement Previous Mitigation Activities

The CWCB, Colorado Department of Agriculture (CDA), and the Department of Agricultural and Resource Economics at Colorado State University (DARE-CSU) initiated a project in 2011 to develop a better understanding of the 2011 drought impact on the Rio Grande and Arkansas basins. The project consisted of the following: (1) a preliminary assessment of agriculture activity in the Arkansas and Rio Grande River basins from 1998-2011, (2) a survey of producers in the impacted basins, and (3) an analysis of the impact of the drought on economic activity. This project was expanded to a statewide study in 2012 and will be conducted again in 2018. The 2018 study will be broader by expanding the study to the impacts of the 2018 drought on other sectors in addition to agriculture.

DHSEM

FEMA Pre-Disaster Mitigation (PDM) grants and Emergency Management Performance Grants (EMPG) have both been used to fund local plans that include drought components.

CWCB

A comprehensive follow up to the 2004 DWSA was conducted by the CWCB and focused on gathering data on the state of drought planning and preparedness by municipal and industrial water providers throughout the State; this study was completed in 2007 and funded by CWCB.

The following drought-related mitigation and response funds have been provided through the CWCB in the past three years.

- Agriculture Emergency Drought Response Fund
- Flood and Drought Response Fund
- CWCB Watershed Restoration Grants in response to the High Park and Waldo Canyon Fires

Construction Fund and Severance Tax

The following funding sources were used to implement statewide planning activities in the past three years.

Construction Fund \$ (Annual funds rollover if not used)

- FY 08-09 CO Drought Mitigation & Response Plan Implementation (\$300K was the initial allocation)
- FY 08-09 CO Drought Mitigation Planning Technical Assistance (\$150K was the initial allocation)
- FY 08-09 Climate Change Effects on CO Water Resources (\$500K)

Severance Tax

- FY08-09 Drought Toolbox Scoping Document (\$24,000)
- FY09-10 Drought Mitigation & Response Plan – Plan Coordination (\$25,000)
- FY09-10 Drought Mitigation & Response Plan – Vulnerability Assessment (\$50,000)
- FY10-11 Drought Planning and Water Adaptation (\$100,000)
- FY11-12 Drought Planning & Response Implementation (\$60,000)
- FY12-13 Drought Planning and Response Update (\$75,000)
- FY12-13 Conservation and Drought Planning Program Management (\$25,000)
- FY 13-14 Drought Preparedness and Response (\$20,000)
- FY17-18 Conservation & Land Use Water Plan Grants (funds are available to advance drought mitigation planning efforts)

CDPHE

The Nonpoint Source Program administered by the CDPHE's WQCD is charged with monitoring, protecting and restoring the quality of the State waters. Activities under Section 319 of the Clean Water Act fall under this program and typically involve development of watershed-based plans, implementation and construction of best management practices, and outreach/education. Depending upon funding available, water quality assessments may also be conducted.

For the 2013 funding cycle, the Nonpoint Source Program allocated \$400,000 to address reclamation activities associated with the 2012 Waldo Canyon and High Park wildfires. These funds will be leveraged with the CWCB's Watershed Restoration Program's matching funds. In addition, the High Park fire area will likely receive further funds because it was chosen as a 2013 program under the NRCS's Environmental Quality Incentives Program (EQIP) fund. The CDPHE is working closely with local communities at both wildfire sites in developing plans for their reclamation efforts.

Colorado Water Resources and Power Development Authority

The Colorado Water Resources and Power Development Authority donated \$300,000 to CWCB in August 2012 for wildfire restoration work. The CWCB has administered these funds to assist with restoration planning and prioritization of mitigation activities associated with the 2012 High Park Fire near the City of Fort Collins. As well as in 2017 with the administration of \$250,000 in funding to Ark Basin/Lower Ark Water Conservancy District for fire recovery projects from the Beulah, Hayden and Junkins fires.

5 COORDINATION OF LOCAL MITIGATION PLANNING

5.1 Local Funding and Technical Assistance

This section includes a description of the State process to support, through funding and technical assistance, the development of local mitigation plans and drought management plans. This section also describes the funding and technical assistance the State has provided in previous years to assist local jurisdictions in completing approvable mitigation plans, and the process to prioritize planning and project grants.

As water demand and population continues to increase in many areas of the State and climate change is resulting in greater uncertainty regarding the availability of future water supplies, the importance of drought planning at a local level is increasing in necessity. However, many local entities have not yet developed drought mitigation plans. This State Drought Mitigation and Response Plan continues to encourage and emphasize the importance of local drought planning.

5.1.1 Description of State Process to Support Local Plan Development

The overall state process to encourage and support the development of local plans is discussed in the Colorado Hazard Mitigation Plan. As of the writing of this Plan, there is not a requirement for local entities to adopt a drought mitigation plan. However, CWCB strongly supports the development of local drought mitigation plans. State staff continuously meets with local utilities and water suppliers, to provide drought management information, technical assistance, and drought planning at a grassroots level. CWCB is also exploring opportunities to fund future projects through increased coordination with the Bureau of Reclamations' Drought Response Program. Coordination between the state and the Bureau may lead to less of a cost-share from local communities due to the Program's requirement of matching state and federal funds for proposed projects.

In 2010, the CWCB developed a Municipal Drought Management Plan Guidance Document (Drought Guidance Document) as a means to assist municipal providers and local governments with their drought planning efforts. This Drought Guidance Document serves as a reference tool that municipal entities throughout the State can use in developing local drought management plans. The objectives of the Drought Guidance Document are as follows:

- Provide a comprehensive background on municipal drought management planning and recommend drought mitigation and response planning steps and components useful in developing local plans.
- Disclose the essential and recommended elements of an effective local drought management plan.
- Ensure that the Drought Guidance Document is applicable and useful to stakeholders statewide that vary by geographic location, size, water supply sources, financial resources, etc.

In 2011 the CWCB developed a Sample Drought Management Plan (Sample Plan) as another tool to assist in the development of local drought plans. The Sample Plan provides an example of what a plan developed with the Drought Guidance Document might contain and is based on a fictitious jurisdiction/watershed with attributes common to many Colorado communities. The Drought Guidance Document and Sample Plan are designed to be used in conjunction with CWCB's Drought Toolbox and other drought-related information presented on the CWCB website. The CWCB Drought Toolbox is available online and was also developed in 2010 to provide a point location for the state, local government, and the general public to access information on drought and drought planning. The toolbox specifically contains information on the following:

- Resources for local drought planning – links to the Drought Guidance Document, potential funding sources, other drought assistance related programs, examples of municipal drought management plans submitted to the CWCB for approval, information on drought impacts experienced by local entities statewide and other resources water providers and local governments can use for drought planning
- Frequently Asked Questions – geared toward the public to raise drought awareness and educate the public
- Funding sources/financial assistance – list of current and potential funding sources
- Technical resources – links to drought monitoring data and other monitoring resources
- Current drought status – information on the current drought status
- Contacts - regional and field contacts useful to the public and local governments for drought related information
- Internet resources – links to other drought-related websites and general planning sources
- Discussion on drought and climate change

As of mid 2018 the CWCB is considering phasing out the Drought Toolbox as many of the resources can be found through other web-portals such as www.drought.gov and the Colorado Drought Response Portal www.coh2o.co. The Colorado Drought Response Portal came online in 2013 and provides up to date information on statewide drought conditions as well as response activities for municipalities, including municipal watering restrictions. The website will be upgraded in 2018 with drought response information and establish links with the CCC website for additional drought data.

In addition to drought planning the CWCB promotes and provides assistance with local water conservation plan development. In 2012 the CWCB updated its water conservation guidance document with the development of the “Municipal Water Efficiency Plan Guidance Document.” It serves as a reference tool for water providers and local governments throughout the State of Colorado for developing state approved local water efficiency plans. Similar to the Drought Guidance Document, the Municipal Water Efficiency Guidance Document is accompanied by a Sample Municipal Water Efficiency Plan to assist entities in developing their water efficiency plans.

The role of the Mitigation staff within the DHSEM is described in an appendix of the 2018 Colorado Hazard Mitigation Plan. Mitigation staff is responsible to provide technical assistance and training to local governments to assist them in developing local mitigation plans and project applications. The Mitigation staff also is responsible to review and submit all local mitigation plans.

Funding/Technical Assistance Provided in Past Five Years

In the past five years (July 2013 - June 2018) three communities have applied for drought planning grants and two are in the process of completing and submitting revised drought plans to CWCB for review and approval. As of the writing of this plan, one local drought management plan had been approved by CWCB. The CWCB continues to speak with communities regarding their desire to do drought planning and hopes to increase the number of approved plans in the coming years.

Financial assistance was initially made available in 2004 under the Drought Mitigation Planning Grant Program (authorized by §37-60-126.5 C.R.S.), available to local and state governmental entities to assist them in developing drought mitigation plans. In 2007, with the passage of SB07-008, the State's Water Efficiency Grant Program, (authorized by §37-60-126 C.R.S.) provided additional monies through 2012 to support water providers' efforts to plan and implement drought mitigation strategies. The program was extended again through legislation in 2010. Covered entities which are retail water providers that sell 2,000 acre-feet or more on an annual basis, are required to develop water conservation plans. They are also strongly encouraged to develop drought mitigation plans. This group of water providers accounts for the majority, by population, of the municipal water supply in Colorado. Since it was created in 2004, the Water Efficiency Grant Program Fund has given out \$5.7 million for drought and water conservation planning and implementation projects. Currently the CWCB has under \$1 million available for new grants.

In 2004, the Colorado General Assembly passed House Bill (HB) 04-1365, which was then signed by the Governor. HB 04-1365 expanded the mission and duties of the Office of Water Conservation and Drought Planning to reflect the State's involvement in drought mitigation planning and the need to provide more information relating to drought to water users and the public. The Office maintains a clearinghouse of drought information and disseminates information to the public; provides technical assistance and evaluates and approves drought mitigation plans; and provides financial assistance for drought mitigation plans through various grant programs. Further information on available technical and financial assistance, including the Water Efficiency Grant Program, can also be found on the CWCB website.

DOLA noted that eligible projects that can be funded by the Drinking Water Revolving Fund have expanded with the new emphasis on encouraging Green Infrastructure - Eligible costs associated with water efficiency projects may include:

- Planning and design activities for water efficiency that are reasonably expected to result in a capital project.

- Costs associated with development of a water conservation plan if required as a condition of DWSRF assistance.

In the past five years DHSEM has used FEMA PDM, HMGP and EMPG grants to fund local plans that include drought components. The multi-hazard plans funded are detailed in the State Hazard Mitigation Plan. The State will continue to apply for mitigation grants to support multi-hazard plan development. It is the role of the mitigation staff of DHSEM to help communities locate potential sources of available federal and state funding. As grants from different sources are posted, DHSEM staff advertises to the communities and special districts.

As of June 2018, 61 of the 64 counties in Colorado have Hazard Mitigation Plans that are approved, in development, or preparing to be updated. This means that ninety-five percent of the state's population is covered by one of these plans. For more information on local hazard mitigation capabilities refer to the 2018 State Hazard Mitigation Plan.

Since 2000, the Agriculture ITF has attempted to quantify the economic impact of drought on agricultural sectors; provided public education on the impact of drought on agriculture and served as media spokespeople; provided landowner education on drought response; developed a website of drought-related information for producers; offered decision tools to agricultural producers making economic choices; and responded to risk management agency needs for field verification letters.

The Colorado State Forest Service noted the following increases in capabilities since 2013:

- Hazard Fuels Mitigation projects in various locations around the State.
- Increase in local and county level Community Wildfire Protection Plans (CWPPs).
- Increased technical assistance and service.
- Legislative support for technical assistance and incentive programs for landowners.

5.2 Local Plan Integration

The following section includes a description of the State process and timeframe by which the local plans are reviewed, coordinated, and linked to the State Mitigation Plan and Drought Mitigation and Response Plan.

5.2.1 Process and Timeframe to Review Local Plans

In May 2005, the CWCB adopted guidelines that address the process and timeline for review of local drought management plans. These guidelines were revised and adopted again in July 2011 to be more in line with the Municipal Drought Management Plan Guidance Document. These “Guidelines for the Office to Review and Evaluate Drought Mitigation Plans Submitted by Covered Entities and Other State or Local Governmental Entities” are available on the CWCB website. Upon receipt of a completed local Drought Mitigation Plan, the Office must review and either approve or not approve the Plan within 90 days by providing written notice to the submitting

entity. Procedural guidelines for contesting Plan disapproval are also included. Plan content requirements include: 1) Municipal Drought Management Plan Guidance Document (use of this document is strongly encouraged to obtain CWCB approval); 2) Model Plan (preparing a Plan according to this outline will lead to a more valuable planning document); 3) information on Plan Adoption; 4) a discussion of how each of the eight Plan Elements were considered in the entity's program: Stakeholders and Plan Objectives and Principles; Historical Drought and Impact Assessment; Drought Vulnerability Assessment; Drought Mitigation and Response Strategies; Drought Stages, Trigger Points, and Response Targets; Staged Drought Response Program; Implementation and Monitoring; and Plan Review and Updates; and 4) Plan Public Review procedures.

Local hazard mitigation plans are reviewed initially by DHSEM and approved by FEMA and are updated every five years. More specifics can be referenced on this topic in the 2018 Colorado Hazard Mitigation Plan.

5.2.2 Process and Timeframe to Coordinate and Link Local Plans to State Mitigation Plan

Linking local county hazard mitigation plans and water provider drought management plans to the State's Plan is integral to building a more effective mitigation program over time. Local drought plans will first be reviewed and approved by CWCB using the guidelines in Section 5.2.1. Local hazard mitigation plans are reviewed initially by DHSEM and approved by FEMA and are updated every five years. With each State Hazard Mitigation Plan update cycle any new or updated plans will need to be reviewed for assimilation and incorporation of information relevant to the State Plan, including drought related vulnerability and loss estimates, capabilities, and mitigation strategies.

5.3 Prioritizing Local Assistance

5.3.1 Description of Criteria for Prioritizing Planning and Project Grants

As noted above in Section 5.2.1, the CWCB (Board) adopted the most recent guidelines for reviewing and approving local drought mitigation plans submitted to the CWCB in July 2011. Section 9a of these guidelines called for the development of a set of additional guidelines associated with the prioritization and distribution of grant monies for assisting covered entities and other state or local governmental entities in their drought mitigation planning activities.

The "Intent of the Board" is defined as follows: It is the explicit intent of the Board to work with water users and local entities to increase drought planning in the State by: 1) increasing the number of covered entities and state or local governmental entities with CWCB approved drought mitigation plans; 2) improving the nature and breadth of drought mitigation practices at the local level; and 3) increasing the amount of technical assistance that the CWCB provides to local entities. With these objectives in mind, the Board intends to administer the Grant program for

purposes of providing assistance to the following: 1) covered entities or state or local entities that desire to improve, update, and/or create Drought Mitigation Plans; 2) entities, given expected growth trends, which either require or desire Drought Mitigation Plans; and 3) entities which sustained severe adverse impacts during the recent 2000-2003 drought.

Project Grants

The SWSI Phase 1 report prioritized projects for both structural and nonstructural projects to provide additional water supplies to help mitigate the effects of drought. Projects are recommended by basin, county, or subbasins; a table summarizing these projects can be found in the Executive Summary of the SWSI Report. Criteria used to prioritize these projects are described in detail in the SWSI Report.

The criteria and process used to prioritize post-disaster funding assistance requests are described in the State's Hazard Mitigation Plan and Grant Program (HMGP) Administration Plan. When a Notice of Interest (for receipt of financial assistance) is submitted to the State, it must meet certain minimum criteria. These include whether the project: complies with the State's hazard mitigation strategies; meets funding eligibility requirements; is an independent solution to the problem; does not duplicate other funding sources, has a beneficial impact on the declared area, and is cost-effective and environmentally sound. When projects are competing for limited funding, projects are scored and ranked. Under the direction of the State Hazard Mitigation Officer (SHMO) and the Governor's Authorized Representative, a subcommittee of the State Hazard Mitigation Team convenes to score and rank the projects. The ranking is to be based on criteria derived from 44 CFR 206.434(b) in tandem with the Colorado Resiliency Framework criteria, and may or may not be specific to the disaster. There has not been a presidential disaster declaration under the Stafford Act for drought in the lower 48 states since 1980 (as opposed to the more frequently used USDA drought declaration). However, related disasters, such as the 2002 and 2012 fires in Colorado were declared presidential disasters, and as a result HMGP funding was made available.

5.3.2 Cost-Benefit Review of Non-Planning Grants

For projects funded under HMGP or with PDM funds a requirement of eligibility of all projects is cost-effectiveness of the project. The exception would be the HMGP 5% set-aside funds, which could be used to fund projects that are difficult to quantify as cost-effective.

5.3.3 Criteria Regarding Areas of High Risk and Intense Development Pressures

As noted previously, as part of the criteria used to rank projects, points are given for the following: 1) entities that, given expected growth trends, either require or desire Drought Mitigation Plans (Rate of Expected Growth in Service Demand), and 2) entities which sustained severe adverse impacts during the 2000-2003 drought.

6 PLAN MAINTENANCE PROCESS

6.1 Monitoring, Evaluating and Updating the Plan

Implementation and maintenance of the Plan is critical to the overall success of hazard mitigation planning. This section describes the State's system for monitoring implementation of mitigation actions and reviewing progress toward meeting Plan goals, and any changes in the system since the previously approved plan.

6.1.1 Method and Schedule for Monitoring Plan

The CWCB is charged with the overall responsibility for Plan monitoring and evaluation, with assistance from the DMRPC. CWCB, in its capacity as support agency to the DMRPC, is responsible for coordination and leadership of the DMRPC. CWCB's responsibilities for monitoring and evaluating the Plan include the following:

- Communicating the schedule and activities for Plan updating and maintenance to the DMRPC
- Facilitating meetings of the DMRPC
- Assisting other agencies with the implementation of mitigation actions
- Coordinating with agencies between DMRPC meetings
- Coordinating and conducting outreach to other stakeholders or interested parties and the public
- Obtaining local mitigation Plan data to be used in Plan update cycles
- Conducting all Plan evaluation and monitoring activities that are not otherwise assigned to another agency
- Monitoring, capturing, and communicating mitigation success stories
- Documenting and incorporating the findings of the evaluation and monitoring analyses into the next edition of the Drought Hazard Mitigation and Response Plan
- Updating the DMRPC on grant funds available or dispersed for actions
- Engaging and maintaining the interest of the agencies participating on the DMRPC
- Monitoring progress of local drought and water efficiency plan development and providing technical and financial assistance

As participants of the DMRPC state agencies have the following responsibilities for Plan monitoring and evaluation:

- Participating in meetings of the DMRPC
- Leading the implementation of their agency's respective mitigation action(s)
- Providing progress reports on their agency's respective mitigation action(s)
- Monitoring and documenting disasters of significance to state agencies and providing this information to DHSEM
- Suggesting Plan revisions to reflect changes in priorities, regulations, policies, or procedures

- Taking action as needed to effectively monitor and evaluate the agency's role in the planning process

DHSEM will keep the CWCB and DMRPC abreast of changes or opportunities with FEMA mitigation grants or policies

The DMRPC will convene at least once yearly, ideally in the spring. The meeting will include the WATF members and the Chairs of the Impact Task Forces. The meeting will focus on the progress made on mitigation actions, with status reports discussed by the respective agency and/or Task Force so that progress can be noted in the CWCB annual report that is developed in November. This meeting will also be used to discuss any lessons learned from response to drought conditions that may have been present during the year. WATF and Drought Task Force members also meet each as part of regular meetings of the WATF. The spring WATF/DTF meeting will discuss the drought outlook and any preparation needs and review the response procedures in the plan. These regular meetings also will help to ensure that staffs remain up to date on the activities related to the Mitigation plan and the response procedures.

6.1.2 Method and Schedule for Evaluating Plan

A thorough evaluation of the Drought Plan occurred within the 2007-2010 revision cycle, resulting in a concerted effort to modernize the plan. The CWCB recognized that the Plan needed to reflect advances in drought monitoring, integrate the latest climate change science, and re-evaluate the drought response structure. While the Plan will undergo evaluation during each update cycle, the level of effort used in the 2010 revision effort will occur less frequently.

The criteria utilized to evaluate the Plan will be obtained from the FEMA Plan Review Guide (2015), which includes a plan review crosswalk. FEMA uses the crosswalk to record information regarding required and recommended changes during its review of the SHMP and drought mitigation plan annex. The plan's outline mirrors that of the FEMA crosswalk in part to facilitate the review and evaluation process. FEMA will review the SHMP with the crosswalk, and may review sections or elements of the Drought Plan as well. Plan improvement recommendations from FEMA that may be noted in the crosswalk may be addressed, if applicable, in revisions associated with the next update to the plan.

In addition, any drought plan should be evaluated after droughts. Consistent with this commitment, the CWCB undertook the Drought and Water Supply Assessment after the drought of 2000-2003. The goals of this assessment were to determine how prepared Colorado has been for drought, and identify limitations and related measures to better prepare Colorado water users for future droughts. The DWSA was completed in 2004, and contained several findings and recommendations which have been integrated and discussed previously in this document. Following future drought, the actions taken by the State of Colorado to reduce drought impacts should be captured in Appendix B as appropriate.

The response elements of this Plan (Annex A Drought Response Plan) should be exercised periodically to evaluate the Plan and identify any shortcomings, as well as to train and educate Plan users. This should occur at least once every four years, particularly after a change in administration so that Governor's Office staff and departmental leadership are aware of the plan, its intentions, and the key role they have in implementing it. An exercise has not been needed in the 2010-2018 time period since the Response Plan was activated for drought in 2011-2013 and again in 2018.

6.1.3 Method and Schedule for Updating Plan

Updates to state hazard mitigation plans are required the DMA every five years. As an annex to the Colorado Hazard Mitigation Plan, the Drought Plan will need to remain aligned with the update schedule of that plan. Updates to the Plan must conform to the latest DMA 2000 and EMAP planning requirements. The Colorado Hazard Mitigation Plan was updated in 2018. The CWCB and DMRPC will aim to complete the Drought Plan update by early September of the year the update is due to allow enough time for DHSEM to link it with the Hazard Mitigation Plan and submit to FEMA to review the Plan. The Plan will need to be approved by the CWCB by September of the update year. The Plan will be readopted by the Governor as part of the overall State Hazard Mitigation Plan.

DHSEM will coordinate with the CWCB on the schedule and specific needs for the State Hazard Mitigation Plan update. Funding needs for the next update cycle should be identified and pursued so that the necessary resources are in place in advance of the update year. At the spring WATF/DMRPC meeting prior to the update year the CWCB will issue a schedule for the drought plan update. This schedule will establish a timeline for the following (and other activities as needed):

- Plan update meetings
- Determining involvement and activities of newly participating state agencies (as well as changes in existing ones), including assessment of vulnerabilities, analysis of programs and policies, and identification of new mitigation actions
- Updating the status of mitigation actions identified in the 2018 plan
- Contracting consultant assistance, as necessary

6.1.4 Evaluation of Methods, Schedule, Elements, and Processes Identified in Previous Plan

Each update cycle provides an opportunity to evaluate the methods, schedule, elements and process identified in the previous version of the Plan. In general, the overall process defined for monitoring, evaluating, and updating the Plan has been working since 2007. With the 2010 revision this section was made more specific in regards to agency responsibilities, DMRPC duties, and timelines. As a result of the 2018, 2013, 2010 and 2007 review of the existing drought hazard mitigation plan, CWCB staff has identified opportunities to incorporate several expanded elements

into future drought, water and climate change planning efforts. These include statewide water conservation efforts, formulation of a broad drought vision for the State, and a statewide climate change initiative tied to drought planning efforts and an examination of adaptation strategies to deal with potential water shortages.

6.2 Monitoring Progress of Mitigation Activities

6.2.1 Monitoring Mitigation Measures and Project Closeouts

This section pertains to FEMA funded mitigation grant programs. The process used to monitor mitigation project completions and closeouts funded by FEMA is described in the DHSEM HMGP Administration Plan. Projects must be completed and reconciled within three years of the disaster declaration. For project completions, subgrantees shall submit a letter with all final project documentation and a final inspection report to DHSEM requesting closeout. The State Hazard Mitigation Officer, mitigation staff, and financial officer are responsible to review all paperwork for completion and determine that all eligible work was completed within the performance period. Site visits and inspections are conducted when deemed necessary. Procedures regarding the transmittal of closeout documents to FEMA are also described in the HMGP Administration Plan. Similar procedures are used for projects funded through the Pre-Disaster Mitigation Program, also administered by DHSEM.

6.2.2 Reviewing Progress on Achieving Goals in Mitigation Strategy

Progress towards achieving this plan's goals will be checked in on annually through the annual meeting of the DMRPC mentioned previously. The progress will be evaluated and assessed in more detail in the final year of the five-year update cycle. All proposed actions listed in the 0 in Section 4 support one or more of these goals. As the progress on these recommended actions is tracked, progress on achieving the above eight goals will also be monitored and summarized in Section 4.4.2 Progress in Statewide Mitigation Efforts. If any of the goals are not receiving adequate attention, it will become apparent as the table is periodically updated.

6.2.3 Changes in System for Tracking Mitigation Activities

CWCB staff, with input from the DMRPC, will be responsible for reviewing and tracking progress made on all the activities identified on the Mitigation Actions Summary Table (0) in Section 4. This table should be updated at least annually, and new projects or initiatives added as they are developed. In 2018 improvements in the State Drought Mitigation Actions Summary table in Section 4 have been made which should facilitate easier tracking of mitigation activities and better coordination between state planning efforts. The only other change is that the process is more clearly defined in Sections 6.1 and 6.2. In 2018, a process for revisiting these action items at a fall DMRPC meeting was defined in Section 6.1.1. The annual DMRPC meetings were changed from the fall to the spring to align with the WATF/DTF meetings, recognizing that many members of this group also meet as part of the WATF/DTF during the spring each year, or more frequently

during times of drought. Regular meetings continue to be important to allow new DMRPC members to become familiar with the Plan as staff turnover or re-assignment occurs. Colorado Hazard Mitigation Plan enhanced plan implementation requirements will necessitate annual coordination with the State Hazard Mitigation Team, including annual review of progress of mitigation actions. See Section 7 of the Colorado Hazard Mitigation Plan for additional details.

For FEMA-funded projects, quarterly progress reports are required from subgrantees, which are to reflect project and cost status. These reports are reviewed by DHSEM Mitigation staff and the State Hazard Mitigation Officer, and submitted to FEMA. This process is outlined in the DHSEM HMGP Administration Plan, which is periodically updated.

6.2.4 System for Reviewing Progress on Implementing Activities and Projects of Mitigation Strategy

The procedures for reviewing the progress associated with implementing activities and projects related to the mitigation strategy were discussed in the previous two sections. It is further recommended that the CWCB/DMRPC prepare an annual report on progress towards mitigation projects, and incorporate this information into other agencies' periodic reports where applicable (e.g., CWCB, DOLA, Agriculture, etc.), including those associated with annual Colorado Hazard Mitigation Plan enhanced plan compliance.

6.2.5 Implementation of Previously Planned Mitigation Actions

The Mitigation Actions Summary Table (Table 17) and Completed Mitigation Actions Table (Table 18) in Section 4 shows those actions that have been implemented to date, as well as those that are ongoing. Several mitigation actions have been implemented as planned and many more are ongoing. The discussion in the Completed Mitigation Actions Table under Section 4.4.2 Progress in Statewide Mitigation Efforts contains a summary discussion of action implementation. This discussion will be updated with each five-year update cycle so that successes and challenges with action implementation are documented.

COLORADO DROUGHT RESPONSE PLAN

ANNEX A TO THE DROUGHT MITIGATION AND RESPONSE PLAN

August 2018

Prepared Pursuant to
Disaster Mitigation Act 2000 & Section 409, PL 93-288

Prepared by
Colorado Water Conservation Board
Department of Natural Resources
in Cooperation with
the Division of Homeland Security & Emergency Management

The Colorado Drought Response Plan

2018

ANNEX A to the Colorado Drought Mitigation Plan

Colorado Department of Natural Resources
Colorado Water Conservation Board

Original document developed by
Department of Local Affairs
Division of Local Government
Office of Emergency Management

J. Truby, L. Boulas 1981

Revised by J Truby, L. Boulas, and R. Kistner in 1986 and 1990.

Revised by J. Brislawn, M. Gally, L. Boulas, J. Truby, T. Grier, P. White, and M.
Koleis in 2001.

Revised by the CWCB and Wood (formerly AMEC Environment and
Infrastructure) in coordination with the Drought Mitigation and Response Planning
Committee in 2010, 2013, and 2018

Table of Contents

Table of Contents.....	iii
Record of Changes.....	iv
I. Introduction	1
II. Authority	2
III. Special Definitions	2
IV. Purpose.....	4
V. Scope.....	5
VI. Situation	5
VII. Planning Assumptions	6
VIII. Concept of Operations	7
IX. Organization and Assignment of Responsibilities	13
X. Impact Task Force Organization and Assignment of Responsibilities	16
XI. Information Collection and Dissemination.....	29
XII. Communications.....	30
XIII. State Emergency Operations Organization.....	30
XIV. Administration, Logistics, and Mutual Aid	30
XV. Plan Development and Maintenance.....	31
XVI. Addendum.....	33
TAB 1: USDA Drought Declaration Process	33
TAB 2: Sample Drought Emergency Declaration	36
TAB 3: Sample Governor’s Memorandum of Potential Drought Emergency	37

Record of Changes

All changes are to be annotated on the master copy of the Colorado Drought Response Plan. Should the change be significant in nature, updates shall be made to applicable Web pages. If not, changes will be reviewed and incorporated into the plan during the next scheduled update.

Date Posted	Change	Page/paragraph/line	Recommending Agency/Individual
6/2013	See notes below		
8/2018	See notes below		

During the 2010 revision of the Colorado Drought Mitigation and Response Plan, significant changes were made in coordination with the Drought Mitigation and Response Planning Committee (DMRPC), including:

- Separation of response elements from the 2002 document into this Annex A so that the response elements can be easily referenced in one location.
- Modernization and alignment of the response plan in accordance with National Incident Management System (NIMS), the National Response Framework (NRF), and the Emergency Management Accreditation Program standards.
- Evaluation and modernization of drought indices and thresholds used to define drought phases and associated recommend actions.
- Evaluation and revision of the Impact Task Force (ITF) structure, including reducing the number of task forces from nine to seven. The Health Impact Task Force was combined with the Municipal Water Task Force and economic impacts tracking (formerly a responsibility of the Economic Impact Task Force) became incorporated as an element of each of the remaining task forces.
- Update of roles, responsibilities, and membership of the ITFs.
- Renaming of the Review and Reporting Task Force as the Drought Task Force (DTF).
- Replacement of the Interagency Coordinating Group with the Governor’s Disaster Emergency Council.
- Clarification of Drought Task Force framework and State agency roles.

During the 2013 update of the Colorado Drought Mitigation and Response Plan additional changes were made in coordination with the (DMRPC) which are summarized below:

- Revisited and clarified drought indices and thresholds used to define drought phases and associated recommend actions.
- Removal of the Governor’s Disaster Emergency Council from the response framework.
- Review of Drought Task Force framework and State agency roles.
- Evaluation and revision of the Impact Task Force (ITF) structure, including reducing the number of task forces from seven to five. The Tourism Task Force and Wildfire Task Forces have been removed while preserving input and participation from these sectors in the overall Drought Task Force.
- Updated Tab 1 USDA Drought Declaration Process to reflect streamlined procedures implemented in 2012.

During the 2018 update of the Colorado Drought Mitigation and Response Plan minor changes were made including:

- Updated agency name changes where applicable (Office of Emergency Management to Division of Homeland Security and Emergency Management) and minor adjustments to ITF membership.
- Changed references to Colorado Modified Palmer Drought Index (CMPDI) to Palmer Drought Severity Index (PDSI) to reflect the upgrades to the PDSI that no longer necessitate the CMPDI.
- Clarification added to Addendum Tab 1: USDA Drought Declaration Process drought declaration procedures that if the drought occurs outside of a county’s growing season, the declaration must be requested through the Governor.
- Updated reference for CPW Administrative Directive A-9 which was replaced by Administrative Directive P-3 in June of 2018
- Annex was reviewed for conformance with latest EMAP and other emergency planning standards.

I. INTRODUCTION

The Colorado Drought Mitigation and Response Plan is a compilation of an in-depth assessment of the drought hazard and its risk and vulnerability impacts on the State of Colorado. It serves as an annex to the Colorado State Hazard Mitigation Plan, which is itself an annex to the State Emergency Operations Plan (SEOP). The Colorado Drought Response Plan was developed by the Colorado Water Conservation Board (CWCB) as an annex to the Drought Mitigation and Response Plan in 2010 so that response elements could easily be referenced in one location.

In Colorado, each level of government has the responsibility for the safety and security of its residents. Citizens expect both state and local governments to keep them informed and provide ample assistance in the event of an emergency or disaster. There are four phases of Emergency Management: Preparedness, Response, Recovery, and Mitigation. The SEOP serves as a standardized response model that provides emergency operations direction as it relates primarily to the “Response” phase of Emergency Management.

Over the course of a disaster or emergency incident, response activities are normally short-term measures that deal with the immediate needs of the victims and the management of the incident as it unfolds in order to minimize further complications and secondary impacts. However, the mitigation and recovery phase may continue for months or years following the initial event. Preparedness is an ongoing activity developed through training, exercises, policy change, and a variety of other daily functions within state and local government operations.

The drought hazard is characteristically unique and very different from other natural hazards. Where most natural hazards impact quickly and without warning, drought could be characterized as the “slow motion” disaster or a silent calamity. It unfolds initially with hidden symptoms revealed only to those with expertise in a specific field. Sometimes onset impacts are not usually visible to the average citizen.

Initial response activities to a drought hazard event are primarily observatory and often include increased monitoring and data gathering. As drought signs and symptoms intensify, and impacts become more evident across a variety of societal and environmental sectors, response actions involve a consortium of state, federal, and local agencies focused on water conservation and drought relief programs.

The following response framework provides an operational system to serve the State of Colorado in responding to drought from the early stages of a drought event through sustained periods of drought conditions, with the intent to assess and reduce impacts to the State.

II. AUTHORITY

A. State

- i. Title 24, Article 33.5, Part 701 et. seq., Colorado Revised Statutes, as amended; entitled the Colorado Disaster Emergency Act of 1992.
- ii. State Emergency Operations Plan, April 2013

B. Federal

- i. Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 U.S.C. §§ 5121-5207)
- ii. The National Response Framework, May 2013
- iii. Code of Federal Regulations (CFR) Title 44 - Emergency Management and Assistance, revised October 1, 2008
- iv. Title 7 Code of Federal Regulations (CFR) Part 1945 – Emergencies Subpart A and Parts 759 and 762 Disaster Designation Process
- v. Agricultural Assistance Act of 2003, P.L. 108-07
- vi. Plant Protection Act
- vii. Food, Agriculture, Conservation, and Trade Act of 1990

III. SPECIAL DEFINITIONS

The following terms are used throughout this document and have the following special meanings:

- A. **Federal departments and agencies.** Those executive departments enumerated in 5 U.S.C. 101, together with DHS; independent establishments as defined by 5 U.S.C. § 104(1); government corporations as defined by 5 U.S.C. § 103(1); and the U.S. Postal Service.
- B. **State.** For the purposes of the Colorado Drought Response Plan (Plan), when “the State” is referenced, it refers to the State of Colorado.
- C. **Federal definition:** Any state of the United States, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, American Samoa, the Commonwealth of the Northern Mariana Islands, and any possession of the United States.
- D. **Local government.** The elected officials of each political subdivision (counties and municipalities) have responsibility for reducing the vulnerability of people and property to the effects of emergencies and disasters. They should ensure local governmental agencies are capable of efficient and responsive mobilization of resources in order to protect lives, minimize property loss, and expedite response efforts during an emergency or disaster. They should ensure that an Emergency Management Office serves the jurisdiction.

- E. **Non-governmental organization.** Includes entities that associate based on the interests of their members, individuals, or institutions that are not created by a government, but may work cooperatively with government. Such organizations serve a public purpose, not a private benefit. It may include entities in the private sector.
- F. **Private sector.** Organizations and entities that are not part of any governmental structure. It includes for-profit and non-profit organizations, formal and informal structures, commerce and industry, and private voluntary organizations.
- G. **Major disaster.** As defined by the Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended (42 U.S.C. §§ 5121-5206), a major disaster is “any natural catastrophe, including, among other things, hurricanes, tornadoes, storms, earthquakes, or, regardless of cause, any fire, flood, or explosion” determined by the President to have caused damage of sufficient severity and magnitude to warrant major disaster assistance under the Act.
- H. **Disaster.** As defined by State statute (C.R.S. 24-33.5-703(3)), a disaster means the occurrence or imminent threat of widespread or severe damage, injury, or loss of life or property resulting from any natural cause or cause of human origin, including but not limited to fire, flood, earthquake, wind, storm, wave action, hazardous substance incident, oil spill (or other water contamination requiring emergency action to avert danger or damage), volcanic activity, epidemic, air pollution, blight, drought, infestation, explosion, civil disturbance, or hostile military or paramilitary action.
- I. **Emergency.** As defined by the Stafford Act, an emergency is “any other occasion or instance for which the President determines that Federal assistance is needed to supplement state, local, and tribal efforts to save lives and to protect property, and public health and safety; or to lessen or avert the threat of a catastrophe in any part of the United States.”
- J. **Catastrophic incident.** Any natural or manmade incident, including terrorism, that results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, and/or government functions. A catastrophic event could result in: sustained national impacts over a prolonged period of time; almost immediately exceeds resources normally available to state, local, tribal, and private sector authorities; and significantly interrupts governmental operations and emergency services to such an extent that national security could be threatened.
- K. **Preparedness.** The range of deliberate, critical tasks and activities necessary to build, sustain, and improve the operational capability to prevent, protect against, respond to, and recover from domestic incidents. Preparedness is a continuous process involving efforts at all levels of government and between government and private sector and nongovernmental organizations to identify threats, determine vulnerabilities, and identify required resources. In the context of the NRF, preparedness is operationally focused on actions taken in response to a threat or potential incident.

- L. **Prevention.** Involves actions taken to avoid an incident or to intervene to stop an incident from occurring. For the purposes of this Plan, this includes applying intelligence and other information to a range of activities that may include such countermeasures as deterrence operations; security operations; investigations to determine the full nature and source of the threat; public health and agricultural surveillance and testing; and law enforcement operations aimed at deterring, preempting, interdicting, or disrupting illegal activity and apprehending perpetrators.
- M. **Response.** Involves activities that address the short-term, direct effects of an incident. These activities include immediate actions to preserve life, property, and the environment; meet basic human needs; and maintain the social, economic, and political structure of the affected community. Response also includes the execution of emergency operations plans and incident mitigation activities designed to limit loss of life, personal injury, property damage, and other unfavorable outcomes.
- N. **Recovery.** Involves actions and the implementation of programs necessary to help individuals, communities, and the environment directly impacted by an incident to return to normal where feasible. These actions assist victims and their families; restore institutions to regain economic stability and confidence; rebuild or replace destroyed property; address environmental contamination; and reconstitute government operations and services. Recovery actions often extend long after the incident itself. Recovery programs may include hazard mitigation components designed to avoid damage from future incidents.
- O. **Mitigation.** Activities designed to reduce or eliminate risks to persons or property or to lessen the actual or potential effects or consequences of an incident. Mitigation measures may be implemented prior to, during, or after an incident. Mitigation measures are often developed in accordance with lessons learned from prior incidents. The NRF distinguishes between hazard mitigation and incident mitigation. Hazard mitigation includes any cost-effective measure which will reduce the potential for damage to a facility from a disaster event. Measures may include zoning and building codes, floodplain property acquisitions, home elevations or relocations, and analysis of hazard-related data. Incident mitigation involves actions taken during an incident designed to minimize impacts or contain the damages to property or the environment.

IV. PURPOSE

The purpose of the Colorado Drought Response Plan is to:

- A. Provide an effective and systematic means for the State to reduce the impacts of water shortages on Colorado's people, property, and environment over the short term or long term.
- B. Activate a network of task forces that will identify the need and guide response resources to the State and affected local jurisdiction(s). The term "response resources" is normally defined as immediate service (includes, but not limited to, personnel, equipment, and program

assistance) that is intended to restore institutions to regain economic stability and confidence, rebuild or replace impacted property, address environmental contamination, reconstitute government operations and services, and satisfy public safety needs during the response phase of a disaster event. However, due to the long-term nature and slow onset of drought, “response resources” for a drought includes long term situational monitoring from professionals within certain agencies that serve on specific impact task forces that collectively make up the State’s DTF.

- C. Provide in-state mutual aid.
- D. Work within the State Emergency Operations Plan system.
- E. Assist local governments through available State programs relative to drought and drought conditions.
- F. Coordinate Intergovernmental relations throughout the response period.
- G. Provide an operational structure that mirrors the NIMS and the NRF that applies to drought related response necessities.

V. SCOPE

The scope of this Plan applies to the entire state and is designed to be scalable to address events that may impact limited or extensive areas of the state. The scope includes a full range of requirements for response operations to a drought event. The implementation of short, intermediate, and long-term actions will be determined by the degree necessary to adequately conserve and preserve water resources for the purpose of preserving life and wildlife, sustaining the economy, and protecting the environment.

The Drought Response Plan Annex identifies specific response roles and responsibilities of State departments, agencies, quasi-governmental, non-governmental organizations, and non-profit organizations involved in the response phase of a drought event.

The Drought Response Plan Annex has been developed to provide a seamless link between local-state, state-state, and state-federal operations by following the premise outlined in the NRF relative to response operations and more specifically tailored to the drought hazard.

VI. SITUATION

Colorado is susceptible to droughts that can have significant long term impact to the state’s environment, economy, and population. Drought impacts will vary depending on where the drought occurs and how long it persists. Refer to the base Drought Mitigation Plan base plan and Annex B for an in-depth Hazard Identification and Risk Assessment (HIRA). The HIRA includes information on:

- Relative probability and impact of drought
- Vulnerability by jurisdiction
- Estimates of impacts by sectors that include: agriculture, energy, environmental, municipal and industrial, recreation and tourism, socioeconomic, and state assets.

In Colorado, an early drought response is vital. Gathering information that is suggestive of drought conditions allows for early planning discussions specific to the most likely affected impact sectors. Annex D of the base Drought Mitigation and Response Plan captures information on the latest mechanisms for detecting and monitoring drought conditions. Appendix C of the base Drought Mitigation and Response Plan captures information on actions taken to reduce impacts by previous droughts, by impact sector and/or ITF.

The response phase of an emergency or disaster is often defined as restoring a community to its pre-disaster condition or re-establishing a state of normalcy in the affected communities. While immediate lifesaving activities are normally occurring in the response phase, activities are simultaneously occurring to transition from the response phase to the recovery and mitigation phase. For a drought hazard, the situational awareness unfolds much slower than typical emergency response for other hazards.

VII. PLANNING ASSUMPTIONS

- A. A drought emergency or disaster can occur at any time and any location. It may create significant degrees of human and/or animal suffering, property damage, and economic hardship to individuals, governments, the environment, and the business community.
- B. Response and recovery operations may overlap requiring simultaneous efforts; however, recovery and mitigation operations may move into a longer term strategic process.
- C. A standard of operating procedures consistent with the NIMS.
- D. A standard of operating procedures consistent with NRF.
- E. An established central coordination and pre-designated responsibilities exist.
- F. The Colorado drought response team is organized in the form of a DTF comprised of the directors of key State agencies and chairpersons of ITFs that represent specific sectors vulnerable to drought.
- G. The DTF will respond appropriately to the drought conditions with the intent to protect, conserve, and preserve water resources to sustain life; and to advise and make recommendations to the Governor who may provide additional drought assistance or seek a Presidential drought disaster declaration.
- H. Priorities for response management include:

- i. Ensuring health and safety “best practices” are standard protocol for any necessary field response task that is related to drought or water supply availability data collection and considered top priority.
 - ii. Operating consistent with the NIMS standard throughout the disaster event including recovery and mitigation operations.
 - iii. Documenting all response operations expenditures.
 - iv. Following prompt and efficient reimbursement practices.
 - v. If possible, using immediate mitigation strategies to stabilize current vulnerabilities, which reduce harmful effects from possible secondary impacts.
- I. Private and volunteer organizations may provide assistance to the DTF.
 - J. The Governor may request of the President to declare a drought disaster for activation of federal assistance programs to help drought affected communities.

VIII. CONCEPT OF OPERATIONS

A. Drought Response Plan Annex implementation

The Plan consists of four components: monitoring, assessment, mitigation, and response. These four actions are designed to work within the existing framework of government, pulling together key personnel from both federal and state levels. Drought monitoring and long-term mitigation are ongoing activities and the responsibility of the Water Availability Task Force (WATF). Drought assessment involves activation of specific ITFs. When the Plan is activated drought response and incident mitigation is the collective responsibility of the DTF. As drought conditions worsen, the Governor may coordinate assistance among state agencies and request outside assistance from other federal agencies and neighboring states. The general sequence of actions is outlined in Figure 1.

The Drought Response Plan has the force and effect of law as promulgated by the Governor. Implementation and the subsequent supporting actions taken by the ITFs or supporting state agencies are driven by the specifics of the emergency or disaster situation. Implementation is influenced by the timely attainment and assessment of information gathered from affected jurisdiction(s) by the ITFs that collectively make up the DTF. The Director or their designee for the Department of Natural Resources (DNR), the Department of Local Affairs (DOLA), Department of Public Safety (DPS) and the Colorado Department of Agriculture (CDA) will serve as the lead agency(s) for the DTF. They will report and recommend to the Governor (based on information from the ITFs) about the existing and expected conditions of the drought situation and advise the Governor with supporting documentation for his/her decision to activate the DTF and seek federal assistance, possibly through a Presidential Drought Declaration.

The Drought Response Plan can be partially or fully implemented allowing maximum flexibility to meet the unique response requirements for any level of pre-drought or drought conditions. Drought monitoring is ongoing in Colorado under the purview of the WATF. A description of the drought monitoring indices used to recommend activation of various phases of the Plan can be

referenced in Table 1. More information on these indices can be referenced in the base Drought Mitigation Plan in Section 3 and Annex D Drought Monitoring Indices.

B. Drought monitoring and assessment operations include actions required to:

- i. Increase monitoring activities across impact sectors
- ii. Share information among ITF chairs
- iii. Review, report, and recommend based on drought monitoring indices in Table 1
- iv. Determine the level of activation necessary per Table 1 to provide response resources to affected or potentially affected jurisdictions
- v. Activate the DTF

C. General response functions include:

- i. Drought monitoring, warning and information sharing
- ii. Recommendations for DTF and ITF(s) activation
- iii. Initial DTF meeting
- iv. Potential impact analysis across sectors:
 - a. Agricultural
 - b. Energy
 - c. Municipal Water
 - d. Water Availability
 - e. Wildlife Impact
- v. Review and report to Chairs of the DTF
- vi. Implement actions in Table 1 depending on drought severity
- vii. Procurement and resource tracking
- viii. Implement response actions relative to:
 - a. State government
 - b. Local government
- ix. Develop public information messages
- x. Implement applicable state drought programs
 - a. Federal Programs Implementation
 1. USDA Program Assistance
 2. Small Business Administration Declaration
 3. Economic Development Administration (EDA) Program
- xi. Request for Presidential Disaster Declaration (if applicable)
- xii. Long-term drought recovery planning

Figure 1 graphically depicts, and Table 1 outlines, the general sequence of events of the Drought Response Plan. *Severity indices are intended to provide a general framework and by themselves do not initiate response actions.* Expert judgment from the WATF and further data analysis may be required to fully understand impacts of abnormally dry conditions suggested by the indicators. Recommendations for action may also be dependent on timing, location, extent, water supply, and

subjective considerations, and recognize that different parts of the State may be in different phases at different times.

Figure 1 Drought Plan Implementation Cycle

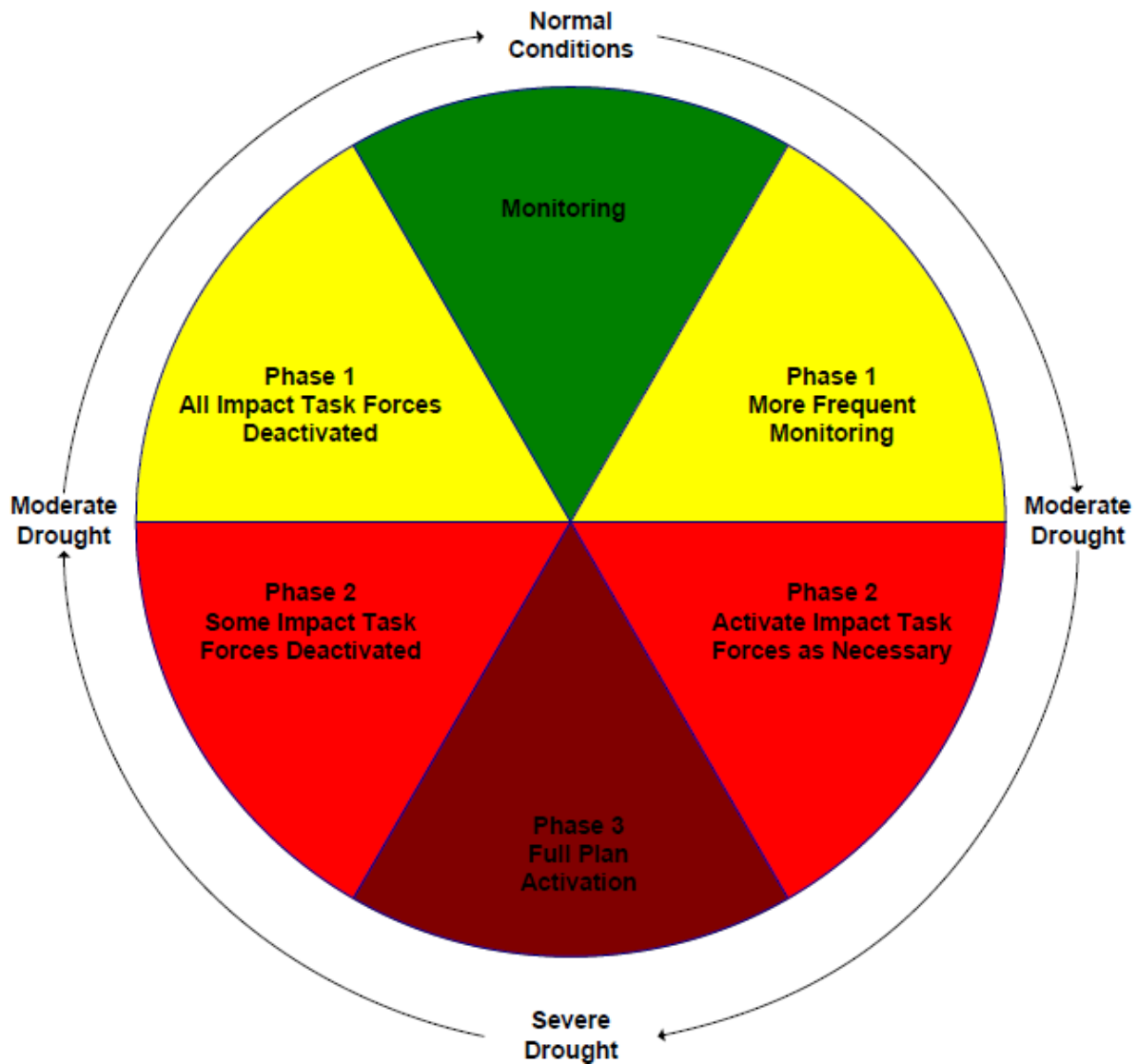


Table 1 Drought Response Plan Summary Action Table

Severity Indicators and Impacts (U.S. Drought Monitor, Palmer Drought Severity Index (PDSI), SWSI, SPI)	Drought Phase and Response Summary	Actions to be Considered
<p><u>Drought Monitor</u> D0 Abnormally Dry D0 ranges: PDSI or SWSI¹: +2.0 to -1.9 SPI²: -0.5 to -0.7 Indicator blend Percentile: 21-30</p> <p>Impacts: short-term dryness slowing planting, growth of crops or pastures.</p> <p><u>PDSI</u> -1 to positive indices in all river basins or modified Palmer climate division</p> <p><u>SPI</u> -0.5 to positive (six month)</p>	<p>Normal Conditions Regular Monitoring</p>	<ul style="list-style-type: none"> CWCB/WATF monitors situation on monthly basis, discusses trends with National Weather Service (NWS), State Climatologist, State Engineer, Natural Resource Conservation Service (NRCS), and others as appropriate. Data reviewed for drought emergence and summarized in monthly drought updates. Implement long-term mitigation actions identified in drought mitigation plan ITF chairs meet once yearly to monitor progress on long-term drought mitigation and review any lessons from previous drought periods, and review the response plan.
<p><u>Drought Monitor</u> D1 Moderate Drought D1 ranges: PDSI or SWSI¹: -2.0 to -2.9 SPI²: -0.8 to -1.2 Indicator blend Percentile: 11-20</p> <p>Impacts: Some damage to crops, pastures; streams, reservoirs, or wells low, some water shortages developing or imminent; voluntary water-use restrictions requested</p> <p><u>PDSI</u> -1.0 to -2.0 in any river basin or modified Palmer climate division</p> <p><u>SPI</u> -0.6 to -1.0 (six month)</p>	<p>Phase 1 More close monitoring of conditions for persisting or rapidly worsening drought; Official drought not yet declared</p>	<ul style="list-style-type: none"> ITF chairs alerted of potential for activation, monitoring of potential impacts. Assess need for formal ITF and DTF activation depending on timing, location, or extent of drought conditions, existing water supply, and recommendation of WATF; DTF is comprised of WATF, ITF chairs, and Lead Agencies. DTF Lead Agencies (CDA/DOLA/DNR/DPS) notified of need for potential activation.
<p><u>Drought Monitor</u> D2 Severe Drought D2 ranges: PDSI or SWSI¹: -3.0 to -3.9 SPI²: -1.3 to -1.5 Indicator blend Percentile: 6-10</p> <p>Impacts: Crop or pasture losses likely; water shortages common; water restrictions likely to be imposed</p> <p><u>PDSI</u> Less than -2.0 in any river basin or modified Palmer climate division</p>	<p>Phase 2 Drought Task Force and Impact Task Forces are activated; Potential Drought Emergency Declared</p>	<ul style="list-style-type: none"> DTF Chairs prepare Governor's Memorandum of potential drought emergency based on recommendations from WATF. Governor's Memorandum activates the Drought Task Force and necessary Impact Task Forces. The DTF Chairs and CWCB meet with activated Impact Task Force chairs to outline Phase 2 activity. Activated ITF's make an initial damage or impact assessment (physical and economic). ITF's recommend opportunities for incident mitigation to minimize or limit potential impacts Periodic reports are made by the ITF chairs to the DTF Chairs.

Severity Indicators and Impacts (U.S. Drought Monitor, Palmer Drought Severity Index (PDSI), SWSI, SPI)	Drought Phase and Response Summary	Actions to be Considered
<u>SPI</u> Less than -1.0 (six month)		<ul style="list-style-type: none"> ITF chairs designate their respective department Public Information Officer (PIO) to interface with media for their relative area of concern and develop media messages. Relevant state agencies undertake response and incident mitigation actions with their normal programs with available resources. The DTF conducts a gap analysis identifying any unmet needs that cannot be handled through normal channels.
<u>Drought Monitor</u> D3 Extreme Drought to D4 Exceptional Drought D 3 Ranges: CMPDSI or SWSI ¹ : -4.0 to -4.9 SPI ² : -1.6 to -1.9 Indicator blend Percentile: 3-5 Impacts: Major crop/pasture losses; widespread water shortages or restrictions very likely to be imposed D4 Ranges: PDSI or SWSI: -5.0 SPI*: -2.0 or less Indicator blend Percentile: 0-2 Impacts: Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies <u>PDSI</u> Lowest reading at -2.0 to -3.9 in any river basin or modified Palmer climate division <u>SPI</u> Less than -1.0 to -1.99 SPI (six month)	Phase 3 Drought Emergency is declared by Proclamation of the Governor.	<ul style="list-style-type: none"> Governor's Memorandum updated to activate additional Impact Task Forces as necessary. Activated ITFs continue to assess, report, and recommend response measures and incident mitigation. Unmet needs are reported to the DTF Chairs. DTF Chairs determine the unmet needs that can be met by reallocation of existing resources. Those which cannot are forwarded to the Governor with recommendations to support a request for a Presidential Drought Declaration. Governor may request a Presidential Declaration. If approved, Federal-State Agreement establishes Colorado DHSEM Director as the State Coordinating Officer (SCO). Work with the Governor's office on long-term recovery operations
Lowest reading at -1.6 in any river basin or modified Palmer climate division -0.8 SPI (six month)	Return to Phase 2	<ul style="list-style-type: none"> DTF Chairs determines if all requirements for assistance are being met within the DTF and State agency channels. DTF briefs the Governor and prepares Proclamation to end drought emergency.
D1 Moderate Drought Coming out of drought: some lingering water deficits; pastures or crops not fully recovered	Return to Phase 1	<ul style="list-style-type: none"> Long-term recovery operations continue ITFs continue assessments. ITFs issue final report and conclude formal regular meetings. The DTF issues a final report and is deactivated.
Lowest reading at -1.0 in any river basin	Return to normal conditions	<ul style="list-style-type: none"> CWCB/WATF resume normal monitoring.

Severity Indicators and Impacts (U.S. Drought Monitor, Palmer Drought Severity Index (PDSI), SWSI, SPI)	Drought Phase and Response Summary	Actions to be Considered
-0.5 SPI (six month)		

¹ SWSI will likely be changed to a percentile-based index by late 2013

²The SPI timeframe used for the Drought Monitor can vary from 1 to 24 months.

D. Impact Task Forces (ITFs)

Specialized ITFs are activated as needed to coordinate the assessment of drought impacts as well as appropriate response and mitigation actions. The ITFs are made up of professionals with specific expertise to monitor and analyze the onset of drought and pre-drought conditions to make informed recommendations for the implementation of measures to reduce existing or potential impacts to Colorado's citizens, environment, and economy. The five Task Forces are:

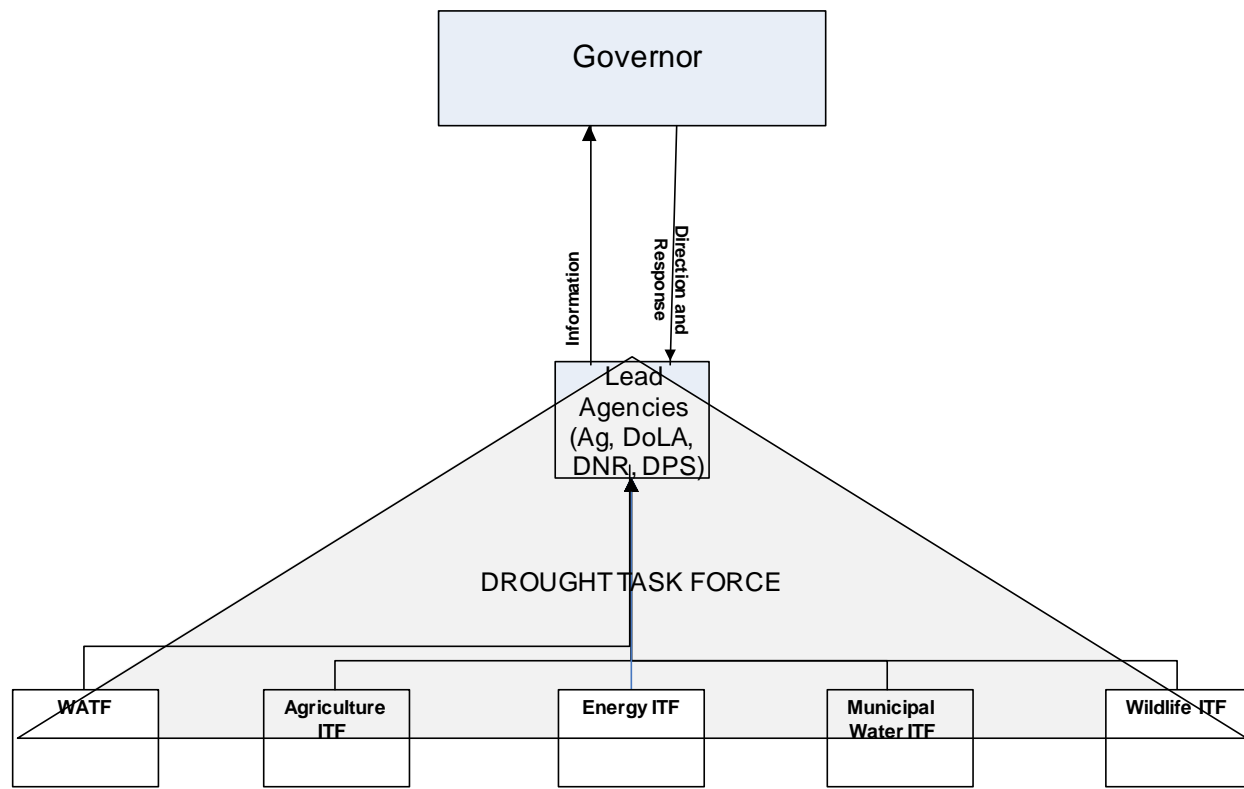
- i. Agricultural Impact Task Force
- ii. Energy Impact Task Force
- iii. Municipal Water Task Force
- iv. Water Availability Task Force
- v. Wildlife Impact Task Force

During the 2010 Plan revision, the number of ITFs was reduced from nine to seven. The Health Impact Task Force was combined with the Municipal Water Task Force and economic impacts tracking (formerly a responsibility of the Economic Impact Task Force) became incorporated as an element of each of the remaining task forces. During the 2013 Plan update the number of task forces went from seven to five. The Tourism Task Force and Wildfire Task Forces, which have historically not been activated, have been removed while preserving input and monitoring from these sectors by representatives participating in the overall Drought Task Force. The State has wildfire monitoring and response mechanisms already in place that are sufficient to meet the needs and do not warrant a separate task force related to drought.

E. Drought Task Force (DTF)

The purpose of the DTF is to evaluate and recognize the need for early implementation of water conservation programs and other drought response measures that are intended to minimize the impacts of drought and reduce the potential for secondary hazard vulnerability. Figure 2 illustrates the DTF framework and how it consists of the ITF chairs and lead agencies. Information is shared and analyzed by the DTF and provided to the Governor, who provides direction for state agencies to implement drought response or mitigation actions.

Figure 2 Drought Task Force Framework



F. Public Information (CRS 24-33.5-704(4))

An executive order will be disseminated promptly to bring its contents (information related to the emergency or disaster) to the attention of the general public. Each ITF will designate a Public Information Officer (PIO), who will be the liaison to the media and/or public interest groups relative to the purpose of that specific ITF.

IX. ORGANIZATION AND ASSIGNMENT OF RESPONSIBILITIES

A. State departments and agencies responsibilities

- i. General: All state agencies or departments are required under the authority of Colorado Disaster Emergency Act of 1992 (Act) and this Plan to carry out assigned activities related to mitigating the effects of a major emergency or disaster and to cooperate fully with each other, the Division of Homeland Security and Emergency Management (DHSEM), and other political subdivisions in providing emergency assistance. In addition to assigned functional responsibilities, all state departments will take the following general actions, as appropriate, in accordance with response operations:
 - a Initial Response Phase (Phases 1 and 2 in Table 1. Upon request, provide personnel,
equipment and other required resources to support initial response relief operations:

- b Intermediate Response Phase (Phases 2 and 3 in Table 1). Continue to monitor response operations, unmet needs, and public information. Analysis and strategic planning is necessary from all involved state agencies and non-governmental agencies to move smoothly into long-term recovery operations.
 - c Long-term Recovery Phase. (Phase 3 and return in Phases 2 and 1 in Table 1).
Develop a long-term response committee (if not already established) to provide multi-agency oversight of the long-term missions necessary to satisfy the unmet needs of victims.
 - d Transition Phase. The long-term recovery committee is tasked with identifying the trigger points that would transition specific recovery projects back to specific local authority oversight
 - ii. A comprehensive list of state agency and non-governmental agencies responsibilities relative to “typical” disaster response and recovery is further defined in the SEOP and the State Recovery Plan.
- B. Specific to drought or water supply availability incidents:
- i. All state agencies or departments are required under the authority of the Colorado Disaster Emergency Act of 1992 to fully cooperate with each other and any other political subdivisions in providing the specific assistance necessary to respond to a disaster or emergency. The Act also applies to all state agencies or departments that serve as members of the DTF and/or ITFs. This Plan identifies the manner in which to carry out assigned activities relative to drought or water supply availability incidents which vary from normal response activities due to the atypical manner in which drought or water supply availability incidents unfold. The roles of state agencies or departments in this Drought Response Plan are specified in Table 2.
- C. The Director or their designee for the DNR, DPS, DOLA, and the CDA will serve as the Lead Agencies for the DTF.
- D. The CWCB will provide coordination and support to the DTF, the WATF, and all ITFs, where needed.

Table 2 State Agency Roles in Drought Emergencies

Agency	Specialization	Responsibility							
		Track Impacts Related to Water Shortages	Improve Water Availability Monitoring	Increase Public Awareness and Education	Augment Water Supply	Facilitate Watershed and Local Planning	Reduce Water Demand/ Encourage Water Conservation	Support Programs to Reduce Impact	Provide Other Technical Support
Department of Agriculture	Support to Agriculture and Agribusiness	X		X		X	X	X	X
Department of Local Affairs	Support to Municipal Water Systems	X		X	X	X	X		X
Department of Military Affairs	Resources Support								X
Department of Natural Resources	Wildlife, Water Administration, Drought and Water Planning	X	X	X	X	X	X	X	X
Department of Public Health and Environment	Public Health and Water Quality	X		X					X
Office of Economic Development and International Trade	Tourism	X		X					X
Department of Public Safety	Life Threatening Situations and Federal Disasters, Wildfires	X	X	X		X			X
Colorado's Energy Office and Department of Regulatory Affairs - PUC	Energy	X		X					X
Office of State Planning/Budget	Economic Impacts	X		X					

X. IMPACT TASK FORCE ORGANIZATION AND ASSIGNMENT OF RESPONSIBILITIES

The following section describes the roles of the WATF and the ITFs, their membership, and responsibilities.

Individual ITF Member Roles and Responsibilities

Each ITF will have designated roles with corresponding responsibilities. Listed below are suggested roles for each task force. Individual task forces will have varying need for these positions. Some task forces will fill all roles, while others may fill only a few. A definition for each role is provided in Table 3. Individual roles can be assigned as needed by each ITF.

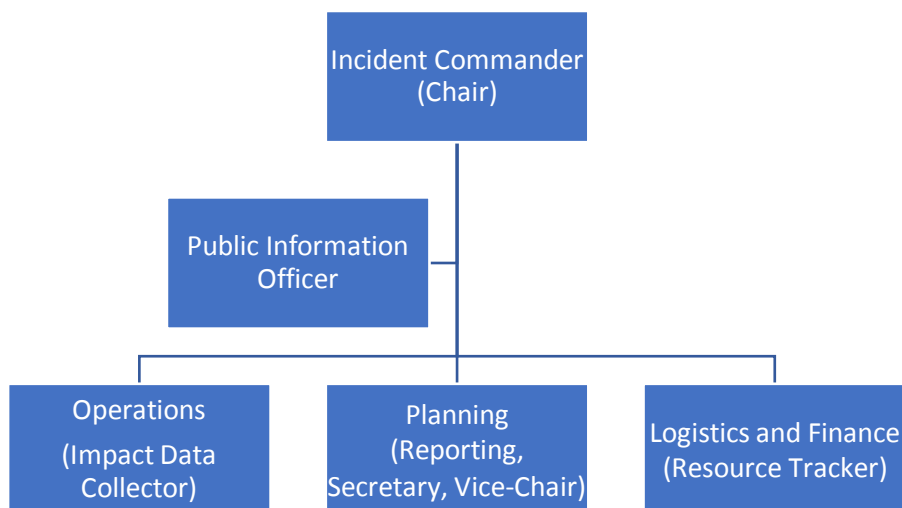
Table 3 Suggested ITF Member Roles and Responsibilities

Role	Definition
Chair	The Chair leads the task force and manages its principal relationships. The Chair ensures that relevant policies are brought to the attention of members of the task force and ensures that it performs appropriately with regard to: adherence to its objectives; risk management; accountability to the CWCB and the Governor; and financial accountability. Other responsibilities include: <ul style="list-style-type: none">• Participate in regular meetings of the WATF.• Recommend activation of the ITF when climatic conditions indicate potential for drought development.• Notify the WATF and ITF members of scheduled meeting dates.• Prepare briefings of findings after each meeting for distribution to the WATF, chairpersons of other ITFs, and other agencies as requested.• Invite participation from agencies or individuals as necessary to enhance the effectiveness of the ITF.
Vice-Chair	The Task Force Vice-Chair assists the Chair where needed.
Secretary	The level of support the Task Force Secretary provides will vary. The Board Secretary may be responsible for administrative support, such as taking Task Force meeting minutes, circulating papers, and liaison between the Task Force and the CWCB and the Governor.
Impact Data Collector	This position supports the Task Force by collecting impact data relevant to the Task Force. The data collected will include economic impacts where possible relevant to the Task Force. (i.e., the Agricultural Impact Data Collector will collect data from the USDA, NRCS, and other agricultural entities).
Resource Tracker	This position supports the Task Force by locating and securing ever changing resources to assist the Task Force in accomplishing its tasks. Tracks financial resources needed and expended.
Reporting	This position supports the Task force by creating situation reports for internal and external distribution regarding the Task Force's area of interest. Analyzes information from the Impact Data Collector and works with the ITF chair as to recommend actions for drought response and mitigation.
Public Information Officer	Public Information Officers (PIOs) are the communications coordinators or spokespersons of the Task Force, typically associated with the department that is the Task Force chair.

Figure 3 is an Incident Command System (ICS) organizational chart that is used as part of the NIMS as a standard, systematic approach to integrate the best existing processes and methods into a unified national framework for incident management. Incident management refers to how incidents are managed across all emergencies, including prevention, protection, response, mitigation, and recovery. Each ITF can apply the concept of ICS to managing their aspect of the

drought response. The items in parentheses suggest how the individual ITF roles could fit with the ICS structure. This structure can be collapsed or expanded to meet the needs of the individual ITF and/or scope of the drought.

Figure 3 ICS Structure Diagram



A. Water Availability Task Force (WATF)

Purpose

The purpose of the WATF is to monitor the state’s water situation to detect signs of emerging drought. In drought situations the WATF monitors the state to detect areas of potential impacts and provides information for decision support. The WATF also serves as the forum for monitoring of implementation of long-term drought mitigation activities during non-drought times.

Activation

The WATF is always activated as the monitoring element of this Plan. Throughout the water year (October through September), the WATF collects data on snowpack, soil moisture, reservoir levels, streamflow, precipitation, and temperatures. The members meet monthly to share information, discuss projections, and assess the water situation. Meetings may occasionally be held in conjunction with the Colorado Flood Task Force. The WATF recommends to the Governor activation of the Drought Response Plan when conditions warrant, based on the indices and phases outlined in Table 1 and expert judgment. When the drought plan is activated, the WATF (in association with the other ITF Chairs) and the Directors of the CDA, DPS, DNR, and DOLA, forms the core of the DTF.

Members

The WATF is comprised of Colorado's water supply specialists, emergency management professionals, federal land managers, scientists, and experts in climatology and weather forecasting.

Lead Agencies

- CWCB (Chair)
- Colorado Division of Water Resources (Co-Chair)

Core

- DHSEM
- Office of the State Climatologist
- National Oceanic and Atmospheric Administration (NOAA)
- NRCS

Supporting Stakeholders

- Chairs of other ITFs
- Governor's Office
- Bureau of Land Management (BLM)
- Bureau of Reclamation (USBR)
- NWS
- United States Geological Survey (USGS)
- Local water providers
- Private parties

Tasks

- Monitor drought forecasts and climate conditions
- Compile and report on the following indicators and outlooks:
 - Snowpack
 - Precipitation
 - Temperatures
 - Streamflow
 - Reservoir levels
 - Groundwater levels
 - Soil Moisture
 - Palmer indexes
 - Historical climate norms

- Long term precipitation and temperature outlooks
- Climate variations associated with La Nina and El Nino conditions
- Determine requirements for routine and special reports.
- Provide other task forces with this information.
- Identify resource information gaps and make recommendations to address them.
- Coordinate and respond to special data requirements of the other Task Forces.

Impact Assessment

The task force assesses current and pending impacts to Colorado's water supply including water storage and precipitation deficits that could lead to potential impacts to sectors. Data reported by the WATF supports other ITFs by indicating the sectors and portions of the state likely to be affected by pending or current drought conditions. Long range forecasting has been improving over the years and may become a factor in the indicators noted in Table 1 in future updates to this plan.

Primary Data Sources and Indicators

- Monthly Water Supply Report
- U.S. Drought Monitor
- Monthly Climate Report
- Historical norms
- Weather forecasts and long-term outlooks
 - Experimental Precipitation Statistical Forecast - three month outlook and others
- Reservoir levels
- Streamflow data
- Rain gauge sites
- NRCS Snow Telemetry Network (SNOTEL) sites
- USBR Snow Data Assimilation System (SNODAS)
- SPI
- SWSI
- PDSI

B. Agricultural Industry Task Force (AITF)

Purpose

The AITF assesses pending and current drought impacts on the agricultural industry and recommends mitigation and response actions. Findings and recommendations of this task force facilitate effective response capabilities, as well as provide documentation for any emergency declaration.

Activation

Activation of this task force occurs upon recommendation of the WATF and/or request of the Governor's Office based on monitoring of the following indicators:

- Precipitation deficits in summer/fall in a major agricultural area resulting in reduced dry-land wheat and pasture land growth.
- Snowpack deficits in mountains, resulting in inadequate irrigation prospects based on drought severity indicators.
- Soil moisture conditions that may result in dust storms in certain critical areas during wind events.
- Federal Drought Designations.
- Prevented Planting Declaration from USDA.

Given that agricultural impacts are typically the first to develop in a drought, it is expected that the AITF will begin monitoring early drought development during Drought Phase 1 in coordination with the WATF.

Members

Lead Agencies

- Colorado State University (CSU) – Water Resource Institute (Co-Chair)
- CDA (Co-Chair)
- Colorado Agricultural Commission
- Colorado Agriculture Council

Core

- USDA
- NRCS (State Technical Committee)
- Farm Services Agency (FSA)
- Colorado Division of Water Resources (DWR)
- State Conservation Board
- Colorado State Land Board
- CSU Extension
- Colorado Climate Center

Supporting Stakeholders

- CWCB
- Agricultural industry groups
- Local conservation districts

- Local and regional water districts
- Cattle, grain, and dairy associations
- Colorado Counties, Inc.
- Colorado Municipal League
- Others as needed

Tasks

- Review drought reporting in relationship to current and/or potential threats on the sector.
- Identify the current or anticipated drought-related problems to the sector.
- Define and assess societal impacts, severity, loss and costs.
- Collect and evaluate impact data.
- Assess current and potential severity of impacts.
- Identify sources of assistance related to agriculture.
- Evaluate state and local capacity for response.
- Identify and recommend response actions.
- Maintain supporting data and records of activities.
- Estimate and report on costs of needed water resource augmentation activities.
- Analyze barriers and needs to meet projected threats.
- Identify key contact points with support service agencies and agricultural industries.
- Coordinate with other task forces.
- Report findings and actions in Drought Task Force memos to the Governor.
- Determine ongoing and residual needs.
- Maintain supporting data and records of activities.
- Provide coordination and liaison with USDA agencies, state agencies, local government, and agricultural industry groups.
- Assess and project the impacts of drought on the agricultural economy and provide information to the DTF.
- Provide input to support Agricultural Disaster Declarations from the USDA.
- Make requests and recommendations on the use of Governor's Agricultural Emergency Fund.
- When an Executive Order is drafted for the Governor's Office regarding the waving of selected regulations on the transport of baled hay or baled livestock feed coordinate with Colorado Department of Transportation's (CDOT) Office of Permits (1-800-350-3765 or 303-757-9539).

Impact Assessment

Collect, record, and analyze impacts from:

- Crop loss
- Livestock loss and sales
- Insect and pest issues
- Highway closures or accidents from blowing dust
- Overall economic impacts to the sector (present and projected)
- Social impacts from loss of farming and ranching income

Primary Data Sources

- Natural Disaster Damage Assessment Report (USDA)
- USDA Flash Situation Report (Department of Agriculture)
- Economic Outlook Reports
- Regional Outlook (Western Livestock Roundup)
- Pest reports (e.g., grasshoppers, etc.)
- Agricultural and Economic Outlook Reports
- Colorado Ag Update
- Crop Progress report
- Colorado Agricultural Statistics

These reports are available from Colorado Agricultural Statistics. Online report sources are www.nass.usda.gov and www.ers.usda.gov/.

C. Municipal Water Task Force (MWTF)

Purpose

The MWTF assesses pending and current drought impacts on municipal water supply and public health impacts and recommends and implements mitigation and response actions. Findings and recommendations of this task force facilitate effective response capabilities, as well as provide documentation for any emergency declaration.

Activation

Activation of this task force occurs upon recommendation of the WATF and/or request of the Governor's Office based on monitoring of the following indicators:

- Declining reservoir levels
- Declining groundwater resources or aquifer depletions
- Activation of local drought management plans
- Activation of local water conservation measures
- Local drought emergency declarations or widespread implementation of restrictions

Members

Lead Agencies

- DOLA-DLG (Co-chair)
- CWCB (Co-chair)

Core

- Colorado Department of Public Health and Environment (Water Quality Control Division and Air Pollution Control Division)
- DHSEM
- DWR
- Colorado Municipal League
- Colorado Counties, Inc.
- Special District Association
- USDA (Rural Development)
- Colorado Rural Water Association

Supporting Stakeholders

- US Army Corps of Engineers
- Department of Fire Science Technology (Red Rocks Community College)
- Colorado Water Utility Council
- Fire Chief's Association
- Fire Marshall's Association
- Economic Development Administration
- Water Resources and Power Development Authority
- Other agencies as needed

Tasks

- Review drought reporting in relationship to current and/or potential threats on the sector.
- Identify the current or anticipated drought-related problems to the sector.
- Define and assess societal impacts, severity, loss, and costs.
- Collect and evaluate impact data.
- Assess current and potential severity of impacts.
- Identify sources of assistance related to municipal water.
- Evaluate state and local capacity for response.
- Identify and recommend response actions.
- Maintain supporting data and records of activities.
- Estimate and report on costs of needed water resource augmentation activities.
- Analyze barriers and needs to meet projected threats.
- Identify key contact points with support service agencies.
- Coordinate with other task forces.
- Report findings and actions in the Drought Task Force Drought Situation Report.
- Determine ongoing and residual needs.
- Assess and prioritize impact of drought conditions on municipalities and report to the Drought Task Force and appropriate response and funding agencies.

- Develop and implement a follow-up process to determine health actions where impact is identified.
- Recommend bottled water advisories.
- Develop and assign reporting responsibilities where appropriate.
- Develop a method for periodic contact with municipalities noted in critical areas.
- The DOLA Division of Local Government will review and evaluate data to determine if the impact of the drought is beyond local capabilities in order to prepare appropriate response to an emergency situation.
- Co-chairs will work directly with municipalities/governments impacted by drought on their options such as substitute water supply plans or temporary water transfers and provide technical and financial assistance as appropriate.

Impact Assessment

Collect, record, and analyze impacts from:

- Municipal water supply shortages
- Municipal water supply water quality impacts
- Overall economic impacts to the sector (present and projected)
- Social impacts from water rationing

Primary Data Sources

- See WATF data sources
- Field reports from Division of Local Government Field Services Staff
- Municipal water providers
- Field reports from DHSEM Regional Field Managers

D. Wildlife Task Force (WTF)

Purpose

The WTF assesses the impacts of drought on wildlife (e.g., fish, game and non-game) and recommends mitigation and response actions.

Activation

Activation of this task force will be upon recommendation of the WATF and/or request of the Governor based on monitoring of the following indicators:

- Young of year monitoring/impacts
- Forage impacts
- Wildfire impacts in critical habitats
- Streamflow forecasts and potential impacts to state wildlife areas

- Reservoir depletions at state parks and wildlife areas
- Fish/fishery impacts and loss

Members

Lead Agency

- CPW (Chair)

Core

- CWCB (Instream flow Section)
- U.S. Fish and Wildlife Service
- National Park Service
- U.S. Forest Service
- BLM
- NRCS

Supporting Stakeholders

- Colorado Wildlife Federation
- Colorado Water Trust
- Trout Unlimited
- The Nature Conservancy
- Others as needed

Tasks

- Identify the current or anticipated drought-related problems to the sector.
- Identify potential and/or existing drought-related wildlife impacts (see Impact Assessment below).
- Manage CPW-owned water rights in accordance with Administrative Directive P-3 (update of Administrative Directive A-9; P-3 became effective June of 2018)
- Recommend measures to prevent or mitigate wildlife losses
- Establish contact with appropriate federal and state agencies to solicit input and assistance.
- Develop and coordinate public information releases regarding assessment of drought conditions on wildlife.
- Synthesize assessment data for the DTF and Drought Situation Reports/Governors Memorandums.
- Coordinate with other Task Forces – notably Municipal Water.

Impact Assessment

Collect, record, and analyze impacts with emphasis placed on:

- Wildlife losses on CPW-controlled properties and public lands such as fish hatcheries, reservoirs, streams, terrestrial wildlife habitats, and associated recreational areas.
- Estimate potential short-term wildlife losses and long-term projections for losses over the assessment periods.
- Evaluate impact on CPW-held water rights on reservoirs, streams, hatcheries, etc.
- Assess impacts to fish/fishery resources for threatened and endangered and priority species, including streams/lakes/reservoirs with potential for significant fish mortality and/or areas where angling restrictions might be necessary.
- Assess overall health condition and distribution of key game species and populations.
- Assess condition of critical winter ranges for key game species including identification of areas with new or expanding weed infestations.
- Assess impacts to bird production, nesting success, and brood rearing for upland game birds and waterfowl species.
- Assess impacts to water levels and wetland dependent vegetation for priority wetlands and riparian corridors.
- Identify wildfires and/or areas with drought-related forest health issues that have potential for direct or indirect impacts to wildlife.
- Economic impacts from wildlife including loss of revenue from decrease fishing and hunting license sales, water rights transfers.
- Assess impacts on state wildlife areas and state parks, including tourism and economic impacts
- Coordinate with other ITFs

Primary Data Sources

- CPW's regional office reports and information provided by other task force agencies.

E. Energy Impact Task Force (EITF)

Purpose

The EITF assesses pending and current drought impacts on the energy sector and recommends mitigation and response actions. Findings and recommendations of this task force facilitate effective response capabilities.

Activation

Activation of this task force occurs upon recommendation of the WATF and/or request of the Governor's Office based on monitoring of the following indicators:

- Declining water availability in relation to hydroelectric generation and other power generation
- Increased wildfire risk

Members

Lead Agency

- Colorado's Energy Office (Co-Chair)
- Colorado Department of Regulatory Agencies - Public Utility Commission (Co-Chair)

Supporting Stakeholders

- CWCB
- Rural Electric Cooperatives and Utility Districts
- Utility providers
- DNR (State Land Board)
- DNR (Oil and Gas Conservation Commission)
- DNR (Division of Reclamation, Mining, and Safety)
- Western Area Power Administration (WAPA)

Tasks

- Review drought reporting in relationship to current and/or potential threats on the sector.
- Identify the current or anticipated drought-related problems to the sector.
- Define and assess societal impacts, severity, loss, and costs.
- Collect and evaluate impact data.
- Assess current and potential severity of impacts.
- Identify sources of assistance related to the sector.
- Evaluate state and local capacity for response.
- Identify and recommend response actions.
- Maintain supporting data and records of activities.
- Estimate and report on costs of needed water resource augmentation activities.
- Analyze barriers and needs to meet projected threats.
- Identify key contact points with support service agencies and energy industries.
- Coordinate with other task forces, particularly the WPTF to identify areas of enhanced risk to utility lines.
- Implement related components of the Colorado Energy Assurance Plan where applicable
- Report findings and actions in the Drought Task Force Drought Situation Report.
- Determine ongoing and residual needs.
- Maintain supporting data and records of activities.
- Develop Media Talking Points specific to the sector.
- Develop assessment and report to the DTF.

Impact Assessment

Collect, record, and analyze impacts from:

- Drought-related power supply interruptions
- Drought-related mining industry interruptions
- Economic impacts related to the sector from drought related interruptions and emergency measures

Primary Data Sources

- Utility providers
- State Land Board
- Public Utilities Commission

F. Drought Task Force (DTF)

Purpose

The DTF reviews all task force assessments and recommends overall drought response and incident mitigation actions. The DTF synthesizes economic impact information from each ITF to aid in decision support and identification of response resources needs.

Activation

Activation of this task force will be upon Governor's memorandum, based upon the recommendation of the WATF.

Members

Lead Agencies

- DNR Executive Director
- CDA Executive Director
- DOLA Executive Director
- DPS Executive Director

Core

- Chair of the Water Availability Task Force
- Chair of the Municipal Water Impact Task Force
- Chair of the Agricultural Industry Impact Task Force
- Chair of the Wildlife Impact Task Force
- Chair of the Energy Impact Task Force
- Colorado Water Conservation Board
- Colorado Division of Water Resources
- Colorado Office of State Planning and Budgeting
- Governor's Office

- Colorado Department of Revenue
- Colorado Department of Public Safety Division of Homeland Security and Emergency Management
- Colorado Department of Public Safety Division of Fire Prevention and Control
- Colorado Office of Economic Development and International Trade - Office of Tourism
- Colorado State University (CSU) – Water Resource Institute
- Colorado Department of Labor and Employment
- U.S. Department of Agriculture - NRCS

Tasks

- Solicit and review the assessments of the ITFs and summarize the findings for a Drought Situation Report to the Governor (when activated).
- Assess overall societal impacts, severity, loss, and costs from drought.
- Assess current and potential severity of impacts.
- Identify sources of assistance.
- Evaluate state and local capacity for response.
- Identify and recommend response actions.
- Maintain supporting data and records of activities.
- Recommend actions to mitigate drought impact.
- Synthesize economic impacts from ITF chairs for the Drought Situation Report for the Governor and decision support.
- Develop coordinated media messages.

Primary Data Sources

- WATF and ITF's
- Governor's Office of State Planning and Budgeting (OSPB) economic model

XI. INFORMATION COLLECTION AND DISSEMINATION

Information collection will be the responsibility of each ITF as outlined in Section IX. Information will be compiled in individual ITF reports. ITF chairs will be responsible for reporting at meetings of the DTF. This information will be synthesized at the DTF level into a Drought Summary Memorandum/Situation Report for the governor..

The CWCB website will be used to synthesize information for local governments and the general public regarding the drought status and response activities. The CWCB will be responsible for updating and maintaining the information on the website on at least a monthly basis.

XII. COMMUNICATIONS

Communications among ITFs will be with typical methods including email, telephone or teleconference, and regularly scheduled meetings.

XIII. STATE EMERGENCY OPERATIONS ORGANIZATION

A. State Emergency Operations

- a General: The SEOC provides the primary location through which the DHSEM Director (or the SCO during a declared disaster emergency) can coordinate support to local governments in disaster situations. The SEOC serves as the principal point for coordinating and tasking State departments and volunteer agencies in the delivery of emergency assistance to affected jurisdiction(s). The SEOC provides the Governor with a secure location to: assemble and analyze critical disaster or Homeland Security information; facilitate the decision making process; coordinate the response activities of State government; and ensure interagency cooperation, coordination, and communications. The State emergency operations organizational structure is designed to be flexible, easily expandable, and proactive to the needs of local government. The organization of state agencies by functional elements provides for a uniform linkage between state and federal systems.
- b Specific to drought or water supply availability incidents: In a drought hazard incident, the State emergency operations organization will be driven by the information delivered by the ITFs and the activation of the DTF. The DTF will report to the Governor and any additional resources necessary to handle the impacts of the incident or ongoing conditions will be determined by the Governor. The Governor may request a USDA Drought Declaration from the Secretary of Agriculture, which activates programs to assist in recovery operations. Water supply availability incidents where the onset of impact is rapid, the State emergency operations organization should follow the components of ICS and NIMS as they are designed in collaboration with the WATF.

XIV. ADMINISTRATION, LOGISTICS, AND MUTUAL AID

A. Administration

During an emergency or disaster, state (and local) government shall determine, if necessary, what, if any, normal administrative procedures shall be suspended, relaxed, or made optional in order to prevent unnecessary impediments of emergency operations and response activities. Such action should be carefully considered and the consequences should be projected realistically. Any state government departure from the usual methods of doing business will normally be stated in the Governor's declaration or Executive Order of Disaster/Emergency, or as specified in this Plan and its supporting documents. Mutual aid, if needed from other states, will follow protocols outlined in the SEOP and any existing memorandums of understanding or mutual aid agreements in place.

B. Finance

- i. A major disaster or emergency may require the expenditure of large sums of state (and local) funds. Financial operations may be carried out under compressed schedules and intense political pressures which will require expeditious actions that still meet sound financial management and accountability requirements. Although drought and water supply availability incidents may dictate a different process for declaration, the requirement for financial support is nonetheless vital.
- ii. State financial support for emergency operations shall be from funds regularly appropriated to state departments. If the demands exceed available funds, the Governor may make additional funds available from the Disaster Emergency Fund. If money available from the fund is insufficient, the Governor has the authority under a State Declaration of Disaster/Emergency to transfer and expend money appropriated for other purposes.
- iii. State departments designated as Lead Agencies for Emergency Support Functions conducting emergency support activities will be responsible for organizing their functional activities to provide financial support for their operations. Each department is responsible for maintaining appropriate documentation to support requests for reimbursement, for submitting bills in a timely fashion, and for closing out assignments.
- iv. State and local government entities are responsible for documenting all emergency or disaster related expenditures using generally accepted accounting procedures. Care must be taken throughout the course of the emergency to maintain logs, records, receipts, invoices, purchase orders, rental agreements, etc. These documents will be necessary to support claims, purchases, reimbursements, and disbursements. Record keeping is necessary to facilitate closeouts and to support post response audits.
- v. Sources of funding for drought mitigation and response efforts are outlined in Section 4 of the Colorado Drought Mitigation Plan. Additional reference for funding and relief options can be referenced in Appendix C Drought Mitigation Capabilities Summary.

XV. PLAN DEVELOPMENT AND MAINTENANCE

- A. Subsequent revisions supersede all previous editions and are effective immediately for planning, training and exercising, and preparedness and response operations.
- B. Individual implementation plans and procedures may be developed by agency or ITF as needed. These procedures will detail who (by title), what, when, where, and how emergency tasks and responsibilities will be conducted.
- C. This Plan and appendixes, state department plans, and implementation procedures shall be maintained and kept current by all parties on the following schedule:
 - i. Updates can occur at any time based upon the change of federal guidance.
 - ii. A cursory review of the Drought Response Plan will occur annually in conjunction with a fall WATF meeting.

- iii. A complete review and update of the Drought Response Plan, its tabs, and appendices will occur every three (3) years (at a minimum), or when a change in administration occurs, or in concert with the update cycle of the Drought Mitigation Plan. This review will consist of all partners having the opportunity to comment on all elements and will be forwarded to the Governor's Office for signature. The CWCB will lead the update effort, with support from DHSEM.
 - iv. Review and revise procedures following critiques of actual emergency or disaster operations and/or exercises where deficiencies were noted.
- D. All changes, revisions, and/or updates to the Drought Response Plan shall be forwarded to CWCB for review, publication and distribution to all holders of the Drought Response Plan following the efforts of the lead agency to coordinate with its supporting agencies. If no changes, revisions, and/or updates are required, CWCB shall be notified in writing by the agency lead that respective plans, annexes, appendices, etc., have been reviewed and are considered valid and current.

XVI. ADDENDUM

TAB 1: USDA Drought Declaration Process

Overview

Agricultural-related disasters are quite common. One-half to two-thirds of the counties in the United States have been designated as disaster areas in each of the past several years. Producers may apply for low-interest emergency (EM) loans in counties named as primary or contiguous under a disaster designation.

The Secretary of Agriculture is authorized to designate counties as disaster areas to make emergency (EM) loans to producers suffering losses in those counties and in counties that are contiguous to a designated county. In addition to EM eligibility, other emergency assistance programs, such as FSA disaster assistance programs, have historically used disaster designations as an eligibility requirement trigger.

The FSA streamlined the USDA Disaster Designation process in 2012 to make assistance more readily available and with less burdensome paperwork.

FSA administers four types of disaster designations:

- 1) USDA Secretarial disaster designation (most widely used)
- 2) Presidential major disaster and Presidential emergency declarations;
- 3) FSA Administrator's Physical Loss Notification, and
- 4) Quarantine designation by the Secretary

The first three types of disaster declarations are authorized under 7 CFR 1945-A. The fourth is the result of a statutory requirement, under the Plant Protection Act or animal quarantine laws as defined in § 2509 of the Food, Agriculture, Conservation and Trade Act of 1990 (mentioned in 7 CFR part 761, which includes a definition of "quarantine" in accordance with 7 U.S.C. 1961). These declarations are described further below.

Secretarial Disaster Designation Procedures for Extreme Drought

The Secretarial disaster designation is the most widely used. In the past the USDA Secretarial disaster designations must be requested of the Secretary of Agriculture by a governor or the governor's authorized representative, or by an Indian Tribal Council leader. As of 2012 the disaster designation process for severe drought occurrences has been streamlined by utilizing the U.S. Drought Monitor as a tool to automatically trigger disaster areas, yet preserves the ability of a state governor or Indian Tribal Council to request a Secretarial Disaster Designation if desired.

The streamlined process provides for nearly an automatic designation for any county in which drought conditions as reported in the U.S. Drought Monitor (<http://droughtmonitor.unl.edu/>) meet

a drought intensity value of D2 (Severe Drought) for eight consecutive weeks. A county that has a portion of its area in a drought intensity value of D3 (Extreme Drought) or higher at any time during the growing season would also be designated as a disaster area. The new process helps reduce paperwork and documentation requirements at the local FSA level, making the process more efficient and timely. Individual producer losses still need to be documented for Emergency Loan (EM) Program eligibility.

For all other natural disaster occurrences and those drought conditions that are not considered severe, the county must either show a 30 percent production loss of at least one crop or a determination must be made by surveying producers that other lending institutions will not be able to provide emergency financing. If the drought occurs outside of the county's growing season, the declaration must be requested through the Governor.

The location of regulation governing the disaster designation process is contained in the Federal Register dated July 13, 2012, at:

<http://www.gpo.gov/fdsys/pkg/FR-2012-07-13/html/2012-17137.htm>

Presidential Disaster Declarations

Presidential major disaster declarations, which must be requested by a governor to the President, are administered through the Federal Emergency Management Agency (FEMA). A Presidential major disaster declaration can be made within days or hours of the initial request. FEMA immediately notifies FSA of the primary counties named in a Presidential declaration.

FSA Administrator's Physical Loss Notification

An FSA Administrator's Physical Loss Notification (APLN) is for physical losses only, such as a building destroyed by a tornado. Livestock related losses are considered physical losses. An APLN is requested of FSA's Administrator by an FSA State Executive Director (SED).

Quarantine designation by the Secretary

A quarantine designation is requested of the FSA Deputy Administrator for Farm Programs by an FSA SED. A quarantine designation authorizes EM loans for production and physical losses resulting from quarantine.

Circumstances Affecting Secretarial Disaster Designations

Disaster designations offer flexibility and can accommodate circumstances such as:

- Continuing adverse weather. When a natural disaster continues beyond the date on which a Secretarial determination is made, and continuing losses or damages are occurring, the incidence period and termination date may be extended up to 60 days.

- Insufficient data. When the data is determined insufficient to make a designation, the request remains active, but is deferred until sufficient information is received to make a determination.

FSA Programs Initiated by Designations and/or Declarations

All four types of designations (Secretarial disaster designations, Presidential disaster declarations, APLNs, and quarantine designations), immediately trigger the availability of low-interest FSA EM loans to eligible producers in all primary and contiguous counties.

Other programs use Secretarial designations as an eligibility requirement trigger. These programs include the Supplemental Revenue Assistance Payments (SURE) Program.

TAB 2: Sample Drought Emergency Declaration

WHEREAS, during the period (day) (month) (year) through (day) (month) (year), increasingly severe conditions of drought have impacted the State of Colorado; and

WHEREAS, the normal system of State Government is not able to cope adequately with the situation; and

WHEREAS, there is every indication that the present drought conditions will not abate in the near future; and

WHEREAS, these conditions may in fact become more severe; and

WHEREAS, extraordinary measures are necessary to protect public health, ensure public safety and welfare and render relief for those most severely impacted; and

WHEREAS, the aforementioned conditions constitute a threat to the safety and welfare of the State, and create an emergency disaster situation within the meaning of the Disaster Emergency Act, 24-33.5-705(2) C.R.S.

NOW THEREFORE, under powers vested in me by section 24-33.5-704 of the Disaster Emergency Act of 1973, and the other enabling provisions, I, (), Governor of the State of Colorado, do hereby declare a State of Drought Emergency to exist. I further declare that based on this State Drought Disaster Emergency, the Drought Task Force in the Colorado Drought Mitigation and Response Plan shall be activated with full power to address those unmet needs brought about by the drought and to take those actions within their authority to address such needs or to recommend for my action or that of the legislature those items that are beyond the authority of the Emergency Council to resolve.

This Executive Order shall expire thirty (30) days from the date hereof unless further extended by Executive Order.

GIVEN under my hand and the Executive Seal of the State of Colorado; this () day of (), A.D., 20_.

()

Governor

TAB 3: Sample Governor’s Memorandum of Potential Drought Emergency

TO: Executive Directors, Departments of State Government

FROM: (), Governor, State of Colorado

RE: Activation of the Colorado Drought Mitigation and Response Plan

DATE:

Drought conditions have developed along the () and () River Basin(s) to the degree that counties in the () and () are likely to receive severe impacts to their environments and to the various sectors of their economy. If present trends continue, other river basins and sectors of the entire state’s economy may soon be affected.

Under these circumstances, and based on a recommendation from the WATF and directors from the Departments of Natural Resources, Agriculture, Public Safety and Local Affairs, I have decided to activate the State’s Drought Mitigation and Response Plan so that specific impacts may be identified, and expeditious and effective remedial action may be taken.

As of the date of this memorandum, the Colorado Drought Mitigation and Response Plan is in effect; the following actions, as specified in the Plan will be taken:

- 5) Drought Task Force will be activated under chairmanship of directors from the Departments of Natural Resources, Agriculture, Public Safety and Local Affairs. The first meeting of the Task Force will be held within five days of receipt of this memorandum.
- 6) The following Impact Task Forces (ITF) will be activated: (), and (). The ITF chairpersons will call their first meeting as soon as possible after the Drought Task Force meeting.
- 7) All addressees will assign: (1) A senior level manager who can commit the resources of the department to act as a drought coordinator and (2) Task Force chairpersons and participants as indicated the Colorado Drought Mitigation and Response Plan Annex A.
- 8) Lead agencies will be prepared to take action for drought response and to mitigate drought impacts as appropriate.



DROUGHT VULNERABILITY ASSESSMENT TECHNICAL INFORMATION

ANNEX B TO THE COLORADO DROUGHT MITIGATION AND RESPONSE PLAN

August 2018

Prepared Pursuant to
Disaster Mitigation Act 2000 & Section 409, PL 93-288

Prepared by
Colorado Water Conservation Board
Department of Natural Resources
and Wood Environment & Infrastructure Solutions, Inc.

Table of Contents

1	Introduction	B-1
1.1	2018 Update Highlights	B-3
2	Drought Vulnerability Assessment Approach	B-5
3	Numerical Vulnerability Assessment Tool	B-7
3.1	General Approach	B-7
3.2	Computation Details	B-8
3.2.1	Determination of Sub-sectors	B-9
3.2.2	Quantitative Metrics	B-10
3.2.3	Quantitative Sub-Sector Impact Scores	B-12
3.2.4	Qualitative Adjustments	B-13
3.2.5	Overall Vulnerability Score	B-14
4	Influence of Water rights on drought vulnerability	B-16
4.1	Drought and Colorado Water Rights	B-16
4.1.1	Introduction to the Prior Appropriation System and Drought	B-18
4.1.2	River Administration during the 2002 Drought	B-20
	South Platte River Basin - Division 1	B-21
	Arkansas River Basin - Division 2	B-21
	Rio Grande River Basin - Division 3	B-22
	Gunnison River Basin - Division 4	B-22
	Colorado River Basin - Division 5	B-22
	Yampa River Basin - Division 6	B-23
	San Juan/Dolores River Basin - Division 7	B-23
4.1.3	Recommendations for Future Studies	B-23
5	State Assets Sector	B-27
5.1	Introduction to Sector	B-28
5.2	Vulnerability of State Asset Sector to Drought	B-30
5.2.1	Aspects of Vulnerability	B-30
5.2.2	Previous Work	B-32
5.3	Assessment of Impacts and Adaptive Capacities	B-34
5.3.1	State-Owned Buildings	B-34
5.3.2	Critical Infrastructure	B-37
5.3.3	Land Board	B-40
5.3.4	Colorado Parks and Wildlife	B-46

5.3.5	Instream Flow and Natural Lake Rights	B-62
5.4	Measurement of Vulnerability	B-68
5.5	Vulnerability Metrics	B-68
5.5.1	Structures	B-68
5.5.2	Land Board Revenue	B-70
5.5.3	Recreation	B-70
5.5.4	Aquatic Species and Habitat	B-71
5.5.5	Protected Areas	B-72
5.5.6	Results	B-73
5.5.7	Spatial Analysis	B-80
5.5.8	Compound Impacts	B-81
5.6	Recommendations	B-81
5.6.1	Adaptation to Drought	B-81
5.6.2	Improving Vulnerability Assessment	B-82
6	Agriculture Sector	B-86
6.1	Introduction to Sector	B-86
6.2	Vulnerability of Agricultural Sector to Drought	B-102
6.2.1	Aspects of Vulnerability	B-102
6.2.2	Previous Work	B-104
6.3	Assessment of Impacts and Adaptive Capacities	B-123
6.3.1	Potential Impacts	B-123
6.3.2	Adaptive Capacity Actions	B-128
6.4	Measurement of Vulnerability	B-131
6.5	Vulnerability Metrics	B-132
6.5.1	Livestock	B-132
6.5.2	Crops	B-135
6.5.3	Green Industry	B-136
6.5.4	Results	B-137
6.5.5	Spatial Analysis	B-140
6.5.6	Compound Impacts	B-143
6.6	Recommendations	B-144
6.6.1	Adaptation to Drought	B-144
6.6.2	Improving Vulnerability Assessment	B-145
7	Energy Sector	B-147

7.1	Introduction to Sector	B-148
7.2	Vulnerability of Energy Sector to Drought	B-155
7.2.1	Aspects of Vulnerability	B-155
7.2.2	Previous Work	B-158
7.3	Assessment of Impacts and Adaptive Capacities	B-166
7.3.1	Potential Impacts and Adaptive Capacities of Mining	B-166
7.3.2	Potential Impacts and Adaptive Capacities of Power Production	B-174
7.4	Measurement of Vulnerability	B-180
7.5	Vulnerability Metrics	B-181
7.5.1	Mining	B-181
7.5.2	Power	B-182
7.5.3	Results	B-184
7.5.4	Spatial Analysis	B-186
7.5.5	Compound Impacts	B-187
7.6	Recommendations	B-188
7.6.1	Adaptation to Drought	B-188
7.6.2	Improving Vulnerability Assessment	B-189
8	Environmental Sector	B-191
8.1	Introduction to Sector	B-192
8.2	Vulnerability of Environmental Sector to Drought	B-196
8.2.1	Aspects of Vulnerability	B-196
8.2.2	Previous Work	B-197
8.3	Assessment of Impacts and Adaptive Capacities	B-204
8.3.1	Potential Impacts	B-204
8.3.2	Adaptive Capacity Actions	B-206
8.4	Measurement of Vulnerability	B-211
8.5	Vulnerability Metrics	B-212
8.5.1	Environment	B-212
8.5.2	Results	B-215
8.5.3	Spatial Analysis	B-218
8.5.4	Compound Impacts	B-220
8.6	Recommendations	B-221
8.6.1	Adaptation to Drought	B-221
8.6.2	Improving Vulnerability Assessment	B-222

9	Municipal & Industrial Sector	B-227
9.1	Introduction to Sector	B-228
9.2	Vulnerability of M&I Sector to Drought	B-231
9.3	Assessment of Impacts and Adaptive Capacities	B-231
9.3.1	Potential Impacts	B-232
9.3.2	Adaptive Capacity Actions	B-239
9.4	Measurement of Vulnerability	B-248
9.4.1	Regional Assessment	B-254
9.4.2	Aspects of Vulnerability	B-292
9.5	Recommendations	B-295
9.5.1	Adaptation to Drought	B-295
9.5.2	Improving Vulnerability Assessment	B-296
10	Recreation Sector	B-298
10.1	Introduction to Sector	B-299
10.2	Vulnerability of Recreation Sector to Drought	B-321
10.2.1	Aspects of Vulnerability	B-321
10.2.2	Previous Work	B-323
10.3	Assessment of Impacts and Adaptive Capacities	B-327
10.3.1	Impacts and Adaptive Capacities	B-327
10.4	Measurement of Vulnerability	B-335
10.5	Vulnerability Metrics	B-336
10.5.1	Skiing	B-336
10.5.2	Wildlife Viewing	B-337
10.5.3	Hunting, Fishing, and Camping	B-337
10.5.4	Golfing	B-338
10.5.5	Boating	B-339
10.5.6	Commercial Rafting	B-339
10.5.7	Results	B-340
10.5.8	Spatial Analysis	B-349
10.5.9	Compound Impacts	B-352
10.6	Recommendations	B-353
10.6.1	Adaptation to Drought	B-353
10.6.2	Improving the Vulnerability Assessment	B-354
11	Socioeconomic Sector	B-359

11.1	Introduction to Sector	B-359
11.2	Vulnerability of Socioeconomic Sector to Drought	B-360
11.2.1	Aspects of Vulnerability	B-360
11.2.2	Previous Work	B-362
11.3	Assessment of Impacts and Adaptive Capacities	B-366
11.3.1	Secondary Economic Impacts	B-366
11.3.2	Behavioral Health Impacts	B-374
11.3.3	Public Health	B-377
11.4	Measurement of Vulnerability	B-381
11.5	Vulnerability Metrics	B-381
11.5.1	Results	B-383
11.5.2	Spatial Analysis	B-387
11.5.3	Compound Impacts	B-389
11.6	Recommendations	B-389
11.6.1	Adaptation to Drought	B-389
11.6.2	Improving Vulnerability Assessment	B-390
12	References	B-392
12.1	Chapters 1 - 4	B-392
12.2	Chapter 5	B-392
12.3	Chapter 6	B-394
12.4	Chapter 7	B-397
12.5	Chapter 8	B-401
12.6	Chapter 9	B-404
12.7	Chapter 10	B-406
12.8	Chapter 11	B-411

1 INTRODUCTION

A vulnerability assessment is the process of identifying, quantifying, and prioritizing (or scoring) the vulnerabilities in a system. Vulnerability from the perspective of drought planning means assessing the threat from potential drought hazards to various sectors across social, economic, environmental, and political fields. In this study, the assets of the State of Colorado, as they pertain to drought, are considered in detail. Vulnerability assessments are typically performed according to the following steps:

- 1) Cataloging assets and resources in a system and across sectors
- 2) Assigning quantifiable value (or at least rank order) and importance to those resources
- 3) Identifying the vulnerabilities or potential threats to each resource
- 4) Mitigating or eliminating the most serious vulnerabilities for the most valuable sectors/assets

Vulnerability assessment has many things in common with risk assessment. Risk assessment for natural hazard planning is principally concerned with investigating the risks surrounding infrastructure (or some other object) and people. Such analyses tend to focus on causes and the direct consequences for the studied object. Risk assessment thus involves determination of vulnerabilities and hazards to establish risks and risk probabilities in terms of frequency of occurrence, magnitude and severity, and consequences.

Vulnerability analyses, on the other hand, focus both on consequences for sectors (as well as objects such as physical plant assets) and on primary and secondary consequences for related sectors and/or the surrounding environment. It also examines the possibilities of reducing such consequences and improving the capacity to manage future incidents by adapting. A drought vulnerability analysis serves to categorize sectors and assets in order to drive the risk management process. It is necessary for a comprehensive vulnerability assessment to be conducted prior to starting a risk assessment. The simplified, standard formula for assessing the risk posed by natural hazards ($\text{Risk} = \text{Hazard} \times \text{Vulnerability}$) highlights that a highly vulnerable sector can be impacted significantly by even a moderate hazard (in this case drought). Assessment of a sector's or asset's ability to withstand a hazard is as important as assessment of the hazard itself. Both hazard and vulnerability aspects need to be handled thoughtfully and preferably within the same assessment framework.

In Colorado, the drought hazard can be both spatially and temporally variable, while the various sectors vulnerable to drought have variable distributions and often possess complex interrelationships. Much can be gleaned by considering the drought hazard simultaneous with the elements at risk, and this is the approach taken in this study. By incorporating the notion of differential susceptibility and differential impacts of the drought hazard, this Drought Plan revision seeks to incorporate both the negative and positive attributes from the physical and social environments that increase risk and susceptibility and/or limit resistance and resilience to drought events.

Because of the challenges presented in assessing both the drought hazard and the vulnerable sectors and assets at risk, the science and process of drought vulnerability assessment is not well developed, at least when compared to other natural hazards such as flood and earthquake. Until recently, drought assessment and management has, in most states, been largely response oriented. A detailed vulnerability assessment can assist with the development of targeted drought mitigation and response strategies.

The vulnerability assessment, initially developed as part of the 2010 Drought Mitigation and Response Plan, created a new platform for drought risk assessment by developing an enhanced drought vulnerability assessment approach that highlighted drought exposure and adaptive capacity for sectors and state assets, county-by-county within Colorado.

Vulnerability sectors included in this study are:

- State Assets
- Agriculture
- Environment
- Municipal and Industrial Water Supply (M&I)
- Recreation and Tourism
- Socioeconomic

Vulnerable state assets included in this study are:

- State buildings and critical infrastructure (dams)
- Land Board revenue
- State-based recreation and park visitation
- Aquatic Species and Habitat (fisheries)
- Protected State-owned areas (based on stewardship statuses)

Since the development of the 2010 Drought Mitigation and Response Plan, Colorado has been impacted by a significant drought. This event, which started in 2011 and continued through September 2013 (heretofore referred to as the 2011-2013 drought or the 2012 drought), had a severe impact in multiple sectors. The drought was largely broken by a massive rain and flood event along the northern Front Range in September 2013. Since 2013 many Front Range and northeast counties in Colorado experienced a period of water surplus. Drought and long-term drought impacts lingered for several years in the southeastern parts of the State. As of the spring of 2018, when this vulnerability assessment was updated, the southern half of Colorado was again experiencing drought conditions. This has resulted in the activation of the Colorado Drought Mitigation and Response Plan by the Governor in May 2018. These recent droughts have, and will continue to, reveal new information regarding drought vulnerabilities in Colorado. For example, the 2011-2013 drought seriously impacted the agricultural economy, and extreme dry conditions have been at least partly responsible for several damaging wildfires. Agricultural economics studies and reports on damages to property and infrastructure resulting from wildfire are just two

areas where new economic impact information have recently been collected and analyzed. The results of such studies have provided the opportunity to assign new and reliable vulnerabilities to specific sectors, or to validate the results of the initial vulnerability study conducted in 2010.

1.1 2018 Update Highlights

During the 2018 update an effort was made to update the various sector analyses using the best available data. Some formal reports and/or quantitative data have been released that describe the impacts of, and responses to, the 2011-2013 drought event. For example, a survey of farm and ranch managers' responses to the drought beginning in 2011 was completed by Colorado State University researchers. In cases where new reports and data regarding drought vulnerabilities in Colorado have been developed since the 2013 Drought Mitigation and Response Plan update, this information has been integrated into this 2018 vulnerability assessment. In other cases, new information regarding the impacts of the 2011-2013 drought event are either anecdotal or qualitative, and thus required validation and interpretation to ensure it was suitable for this update. Data and reports describing impacts of the latest major drought of 2011-2013 were used to update the 2013 Drought Mitigation and Response Plan, since many of the impacts of the drought have persisted for years. Finally, as a result of this vulnerability study update, it is apparent that a lack of systematic impact data collection is still a major challenge. This is likely due to the challenges associated with collecting and processing data, and the reality that responding agencies do not always intend to gather the data with the purpose of analyzing drought and its effects. As such, available data is not always targeted towards addressing drought and related vulnerabilities or risk or may not get updated frequently enough to be incorporated into the vulnerability study mentioned herein. Certain mitigation strategy recommendations for impacts data collection improvements were made in the 2010 Drought Mitigation and Response Plan and its 2013 update, and implementing these should remain a high priority in future assessments to come.

Where possible, the 2018 Drought Mitigation and Response Plan Update used new and/or updated drought impacts data across the various sectors to update the existing Vulnerability Assessment Tool (VAT), to re-compute the overall vulnerability scores for each sector and for state assets. Due to the reasons noted above, much of the available data was not in formats consistent with the previously collected information, nor was it in a geographically comprehensive format (e.g., useful impacts data might be available for one major basin in Colorado, but not the others, or perhaps the data is not broken down by counties). For example, considerable but indirectly pertaining data about drought impacts has emerged for the Socioeconomic sector since 2013 as a result of various demographic surveys and research studies. However, this new information focuses on tangentially related aspects not quite correlating to drought vulnerability as was developed for the original VAT, and as such may not be consistent, applicable, or even available across all counties. While extremely useful for updating direct or indirect impacts in study-specific locations such as rapidly growing cities, this information was often not in a format that could be easily integrated into the VAT approach to provide a full Colorado-wide update. Table 1.1 below summarizes the main highlights obtained from this latest vulnerability assessment by sector.

Table 1.1 Summary of the 2018 Update Highlights by Sector

Sector	Update Highlight
State Assets	<ul style="list-style-type: none">• With growing populations and demands across agencies to serve Colorado, the number of State Asset structures and buildings continue to grow, so this sector may be more heavily affected by increased management costs of state buildings and structures, coupled with decreased revenue during times of drought (related to lower State Park visitation numbers, etc.).• Over 100 water rights and instream flow reaches have been appropriated since the last Plan update.• Water-based Park visitation continues to grow by the year; State revenue from managing agencies may be greatly compromised during times of drought, which may experience reduced visitation as perception of the state assets is negatively impacted (causing people to visit less and hence spend less).• Based on the VAT update, vulnerable counties include many in the eastern plains (Kit Carson, Sedgwick, Phillips, Kiowa), and west (Mesa, Montrose).
Agriculture	<ul style="list-style-type: none">• New impact metrics were introduced into the VAT calculation to more appropriately describe vulnerability and adaptability. These include crop indemnities due to drought, indemnity allotments, herd reduction statistics, and number of green industry producers.• Based on the VAT update, most vulnerable counties include those on the eastern plains (Yuma, Kiowa, Baca, Kit Carson, Lincoln) and Adams County, largely due to high amounts of acreage used for agriculture.
Energy	<ul style="list-style-type: none">• Mining operations can be impacted by increased costs of water for operations, or limited water available (though most are rather drought tolerant due to more senior water rights).• The move towards renewable power generation, given it is less water dependent, helps increase drought adaptability and hence reduce risk• Colorado is moving away from coal-based energy generation and toward less water demanding options not requiring cooling – wind and solar power have grown significantly in the last few years, with expectations for this trend to continue• Overall water use for mining and power generation operations have slightly decreased as of a 2010 USGS water use study, compared to the previously used data from 2005.• Most vulnerable counties include those heavily reliant on water for energy production and mining operations, including Routt, Moffat, Cheyenne, Washington, and Fremont counties.
Environment	<ul style="list-style-type: none">• Increasing temperatures, longer warm seasons, and ephemeral snowpack due to climate change conditions are causing mountain and alpine sensitive species such as the American Pika to be at risk of becoming threatened.• Warming temperatures and a drying climate are the prime conditions that enable bark beetle pests to continue to spread at about 600,000 acres a year in Colorado. If conditions worsen (i.e., during drought), infestations coupled with increased risk of wildfire could take a heavy toll on local species and habitats.• An updated instream flow rights dataset for 2017 was used as a quantitative adaptive capacity metric for the VAT calculation in this sector, reflecting increases in the number of instream flow rights since 2013; ensuring minimum flows for environmental preservation purposes as an adaptation measure has resulted in lowered vulnerability scores in certain counties that gained additional instream flows.• Based on the VAT update, most overall vulnerable counties in this sector include Larimer and Weld up north, though the counties of Chaffee, Custer, Denver, and Lake have increased their vulnerability rankings the most since the 2013 Plan. A reason for the increase relates to the higher amount of impaired waters now present in those counties.
	<ul style="list-style-type: none">• Vulnerability to drought by this sector can vary greatly based on: water supply, water distribution, water demand, adaptive capacities.

Sector	Update Highlight
Municipal and Industrial	<ul style="list-style-type: none"> • A quantitative vulnerability assessment would require consideration of the uniqueness of each M&I provider, and was beyond the scope of this study. Instead, the qualitative regional basin-wide level approach was found to be appropriate for this Plan update. • The State's municipal diversions total 970,000 acre-feet per year. 2050 projections range from 1.5 million AF/yr to more than 1.8 million AF/yr., depending on growth and climate. • The relevant references to the 2015 Colorado Water Plan were summarized where applicable including Identified projects and processes based on the Basin Implementation Plans.
Recreation/Tourism	<ul style="list-style-type: none"> • Updated information on state park visitation data was integrated. • A changing climate (warming temperatures and drier conditions) may push animals to move away from traditional habitats and viewing/hunting areas, due to lack of water, loss of vegetative cover, and or/increased heat. This in turn can hurt revenue for Colorado. • Public perception regarding conditions and issues in the sector has been found to prove critical; recreational areas recognize this and employ public relations firms to control messages. • Diversification of recreational offerings is a way to buffer against drought impacts, but all assessed subsectors (skiing, wildlife viewing, hunting/fishing/camping, golfing, boating, and rafting) are at some risk of drought due to reliance on healthy water resources and/or colder conditions. • Based on the vulnerability assessment, most vulnerable counties include Moffat, Routt, Larimer, Mesa, Garfield, Fremont, and Pueblo, due to the presence of water-based parks and other water-reliant recreation and tourism activities.
Socioeconomic	<ul style="list-style-type: none"> • New data on West Nile Virus correlated to drought and changing climate conditions. • Social vulnerability index metrics integrated, to account for population specific risk (e.g., aging populations) was included in the VAT calculation. • Counties with the largest rates of growing populations coupled with lack of economic diversification are most vulnerable during drought. The most vulnerable county is Routt, followed by mountain counties such as Eagle, Pitkin, Summit, and Grand, and others throughout the State.

Source: Amec Foster Wheeler Vulnerability Assessment Tool

In most cases adaptive capacity metrics had only minor changes or updates to qualitative discussions during the 2018 update. One exception to this was the use of an updated instream flows database as an adaptive capacity metric for the VAT calculation in the environmental sector. Overall vulnerability ranks have lowered in some counties as a result of the additional adaptive capacity associated with these instream flow rights.

2 DROUGHT VULNERABILITY ASSESSMENT APPROACH

The approach for this study developed in 2010 and utilized again in 2013 and 2018 employs a hybrid quantitative and qualitative approach, described in more detail in Chapter 3 Numerical Vulnerability Assessment Tool Technical Methodology. It is important to recognize that little of this type of work has been done to date, thus integration of qualitative data and use of quite broad definitions of drought “impacts” and “vulnerabilities” during data collection and interviews were necessary to gather all relevant information, and to encourage the inclusion of sometimes only marginally relevant efforts. Results provided an empirical basis for reporting vulnerability across

assets of state agencies as well as sectors of the economy. Results were analyzed spatially and used to make recommendations for drought planning and mitigation.

Quantitative elements of the vulnerability assessment were conducted where sound data existed to support this, or where data could be developed efficiently. A focus of the quantitative approach was to assess impacts and the ability to reduce and mitigate those impacts, both short term and long term. Each sector analysis also includes recommendations on what data will be required to improve this approach in the future, and how this information can or should be collected. Qualitative information, particularly data gained from interviews, was also introduced where appropriate. The VAT developed for this study was, via a process of scoring, normalization, and weighting, able to integrate these informal data into the assessment as well, enhancing the analysis based on quantitative data alone.

The approach incorporates information on impacts and adaptive capacities. The combination of these components results in a net impact or vulnerability to drought. For example, a greater hazard exposure and higher sensitivity lead to higher potential impact and higher vulnerability; higher adaptive capacity reduces vulnerability due to resilience, and this adaptability capacity was also assessed for counties and sectors, where applicable. Finally, these data were used to calculate vulnerability scores for elements being assessed, to extrapolate these results as necessary (e.g., when a sample has been used to represent the larger group), and then generate average results for sectors within each county.

Results have been analyzed spatially in GIS and are presented in map form to illustrate how drought vulnerability varies across the State for state assets and critical sectors. In almost all cases, assessment of each asset/sector is dependent upon a combination of both qualitative and quantitative analysis. Portrayal in a GIS enabled depiction of drought vulnerability patterns (low, moderate, high, severe) by county allows for identification of spatial patterns (e.g., mountain counties were found to be most vulnerable to wildfire and recreation/tourism impacts, while agriculture was found to have the greatest loss potential in the eastern plains).

The results presented in following sections also consider drought vulnerability from the perspective of indirect impacts on society and the economy (e.g., increased unemployment due to failure of an industry because of drought). For example, during and following the 2002 drought, many rafting businesses failed in Colorado, and many water-reliant businesses again struggled as a result of drought in 2011-2013. The reduced numbers of adventure tourists visiting towns near rafting waters also had a serious impact on the hospitality and other industries dependent on tourists and recreation revenue. In order to assess the overall vulnerability of communities in counties across Colorado, various organizations were surveyed and data were sourced from business associations, agricultural extension agents, the census, state agencies, and employment figures and demographics.

The following sections identify, quantify, prioritize (score), and generally describe the drought vulnerabilities of state assets and private economic sectors by county. Section 3 opens with a description of the VAT general methodology, to provide context.

3 NUMERICAL VULNERABILITY ASSESSMENT TOOL

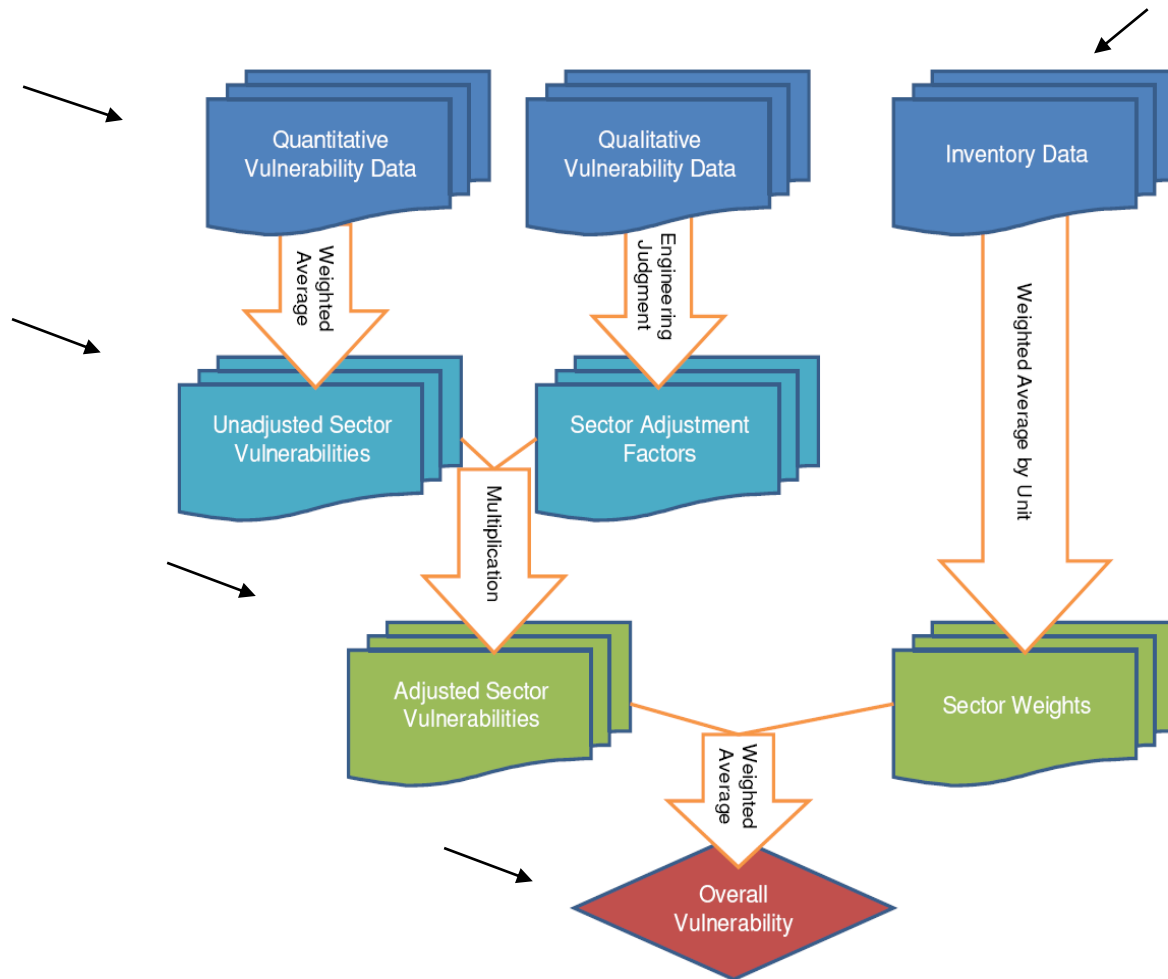
3.1 General Approach

This section describes the methodology used in the VAT. This excel-based tool was developed to assess drought vulnerability primarily in a quantitative spatial manner. Separate workbooks were set up for each sector discussed in the report. All numerical analysis was performed on a county scale following the general framework described herein. However, the metrics used and other adaptations vary from sector to sector, such as for M&I, where major river basins were utilized instead of counties, due to the nature of the sector relying on water in such a basin-driven manner. These variations are described in individual sector reports. Please refer to the Vulnerability Metrics section of each report for detailed data descriptions, methodology, and results.

The outputs of the vulnerability assessment tool are numerical vulnerability scores of 1-4 for each county and each sector (except again for M&I, due to the usage of basins instead of counties). For this VAT analysis, a final score of 1 means lowest vulnerability, and a score of 4 means highest vulnerability. The list below outlines the general steps that were followed for each sector. Figure 3.1 is a graphic representation of the vulnerability assessment methodology. Numbers in this diagram correspond to the five steps listed below.

- 1) Divide sector into impact categories (sub-sectors) if appropriate, and gather spatial density data as inventory metrics
- 2) Define impact metrics (quantitative) and assemble all data (including adaptive capacities metrics)
- 3) Combine impact metrics to one sub-sector quantitative impact score
- 4) Scale sub-sector quantitative impacts using qualitative information and uncertainty flags to get a sub-sector adjusted impact score
- 5) Combine sub-sector impacts scores to obtain a final, overall sector vulnerability score. Sub-sectors are combined using a weighted average where weights are determined based on spatial density

Figure 3.1 VAT Methodology Schematic



3.2 Computation Details

The following sections detail the five computation steps outlined above and the methods used to transition from one step to the next. The information in this section of the report relates to the general methodology framework. As previously noted, this framework was adapted for each of the sectors analyzed for this project, except for M&I, which uses a more qualitative assessment. For information on specific sector methodology adaptations, refer to sector write-ups in Annex B.

3.2.1 Determination of Sub-sectors

Figure 3.2 Sub-Sector Division

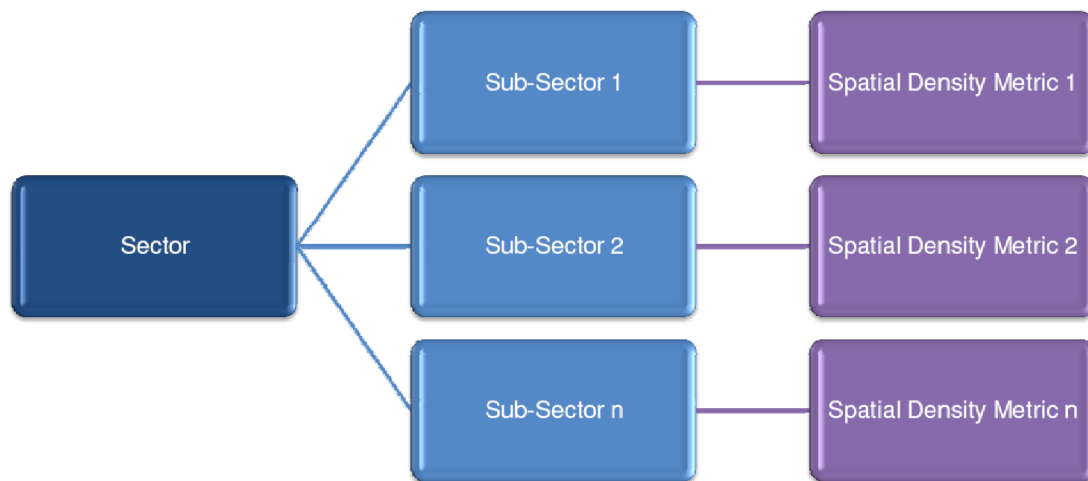
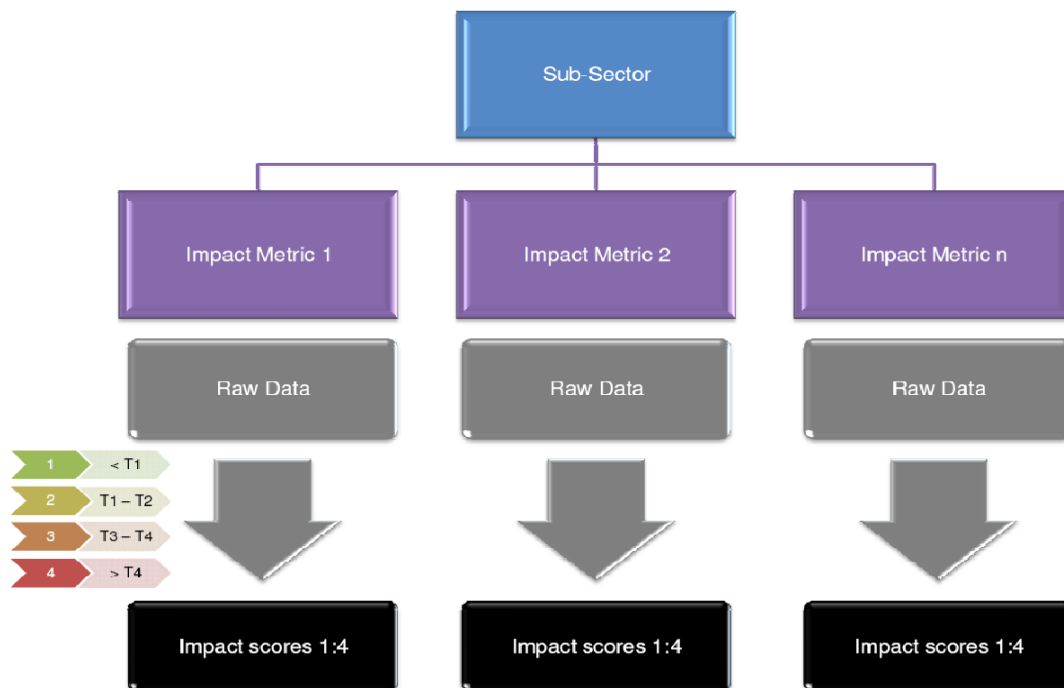


Figure 3.2 outlines the process of assigning spatial density metrics to sectors. Sub-sectors, also referred to as impact groups, are defined when the sources of vulnerability within a sector are sufficiently diverse to warrant separate consideration. For example, the Energy Sector covers power providers and mining operations. The different water dependencies of these two groups make it difficult to analyze impacts together. Therefore, the Energy Sector is divided into two sub-sectors. Impact group division is not necessary in all cases. The Socioeconomic Sector was not divided because all of the impacts to this group relate to the population and economy as a whole.

Once it has been determined whether or not sub-sectors are necessary, and once they have been appropriately defined, spatial density metrics must be determined for each group. The purpose of the spatial density metric is to define the spatial extent of an impact group. For example, in the State Assets Sector one impact group is State Land Board (Land Board) revenue. The spatial density metric for the sub-sector is the total surface acres leased by the Land Board per county.

3.2.2 Quantitative Metrics

Figure 3.3 Quantitative Data Adjustments (T = Threshold)



One or more quantitative impact metrics are defined for each sub-sector. Quantitative metrics are impacts that can be measured and reported on a county scale across the State. Example impact metrics include total water use for the power sub-sector of the Energy sector, or economic diversity for the Socioeconomic Sector. As these examples demonstrate, impact metrics can take a variety of forms and there is little consistency of units. Therefore, raw impact data are translated to impact scores of 1 through 4. This is accomplished using thresholds. Typically, though not always (depending on the type of data), the data set is divided into quartiles. The bottom quartile of data is assigned an impact rating of 1, up to the top quartile of data which is assigned a value of 4. This process is illustrated in Figure 3.3. In cases where there are no data for a significant number of counties, thresholds are adjusted so that only the non-zero values are divided into four groups.

In many cases, quantitative data are not available for many of the direct vulnerability measures that would be most informative. Therefore, proxy metrics are often used. Metrics that are applicable but may require further examination are marked with an “uncertainty flag.” For example, in the Energy Sector, the percentage of groundwater (as opposed to surface water) used by power producers is a quantitative metric. Generally speaking, groundwater users are less vulnerable to drought. However, there is a large amount of uncertainty in this assumption depending on the specifics of water rights administration and where the water sources. Therefore, these data were assigned an uncertainty flag. The choice of quantitative impact measures and uncertainty flags is discussed in detail in individual sector reports.

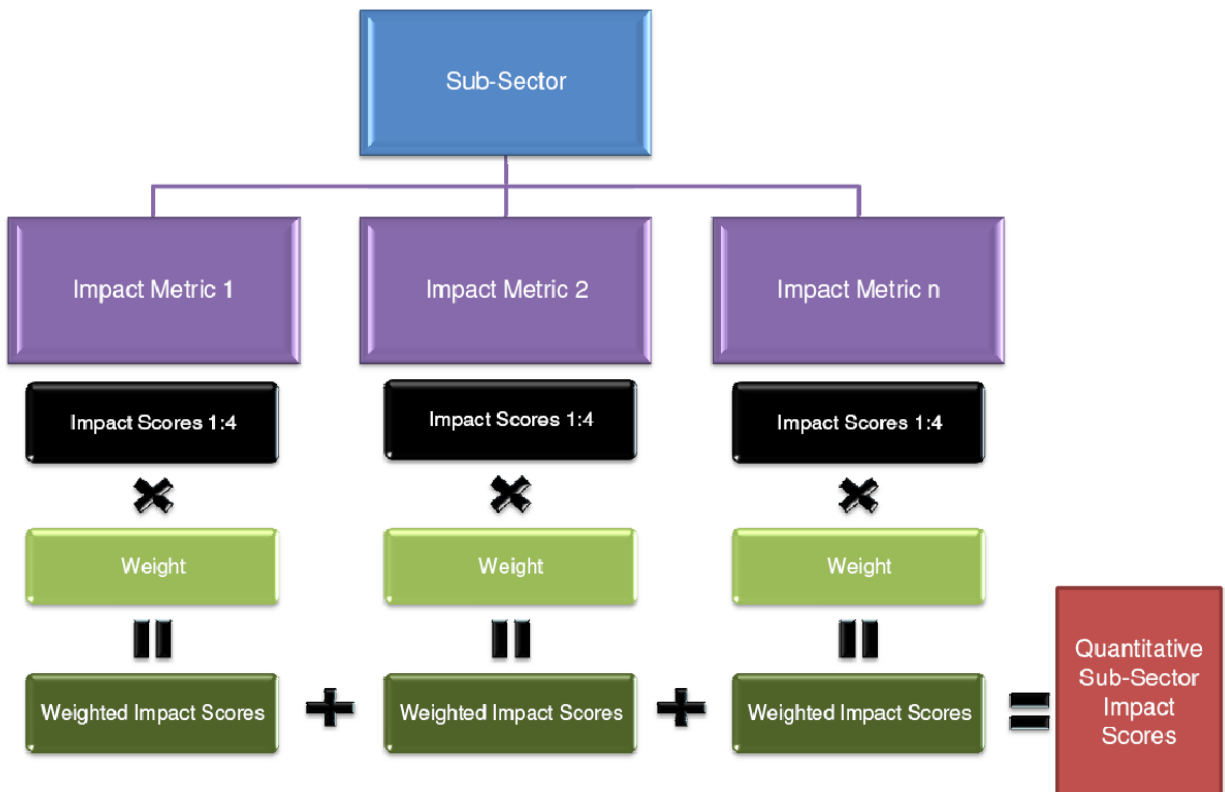
In other situations where it may not be relevant to divide data into quartiles this way, more subjective measures are taken. For example, in the State Assets Sector, one of the impact metrics relates to the relative importance of water based recreation, and is calculated from whether or not a county contains parks allowing water-based recreation activities. In this case, an impact score of 4 was assigned to all counties within major river corridors (namely the Arkansas Headwaters and Yampa basins), a score of 3 was assigned to counties with all other parks engaging in boating or fishing activities, then finally scores of 2 were given to counties with State Parks but no water-based activities as their sources for visitation (and hence revenue). No scores of 1 were assigned.

All threshold adjustments are noted in the “Vulnerability Metrics” section of each sector report. The final results of this step are county scores of 1 to 4 for each quantitative impact metric in a sub-sector.

In some cases, quantitative adaptive capacity metrics are also defined. For example, the presence of renewable energy development areas in a county can make power providers less vulnerable, as renewable sources are less water dependent. Adaptive capacity data are translated to adaptive capacity scores of 1 to 4. However, with adaptive capacities, a score of 4 represents a county with the highest adaptive capacity, and a score of 1 is for counties with the least adaptive capacity. This relationship enables the adaptive capacities to be calculated properly when combined with impact metrics, so that the ratios can be appropriately computed (one divided by the other) and results be logical.

3.2.3 Quantitative Sub-Sector Impact Scores

Figure 3.4 Quantitative Impact Calculations

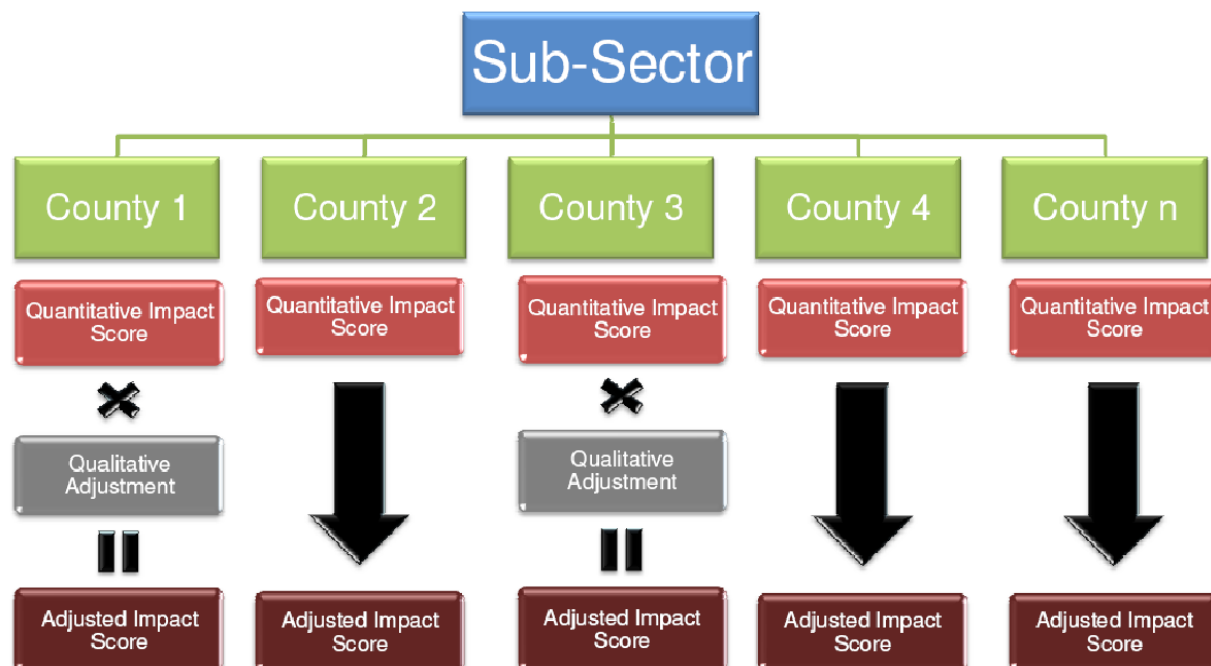


In cases where there is more than one impact metric per sub-sector, these metrics must be combined to get one quantitative sub-sector impact score (refer to Figure 3.4). To do this, weights are assigned to each of the impact metrics using engineering judgment. Metrics are combined using a weighted average based on the determined weights. This process is repeated for each sub-sector. If there is only one metric for a sub-sector, no additional adjustment is required.

If there are multiple adaptive capacity metrics, they are combined the same way as impact metrics to determine an overall sub-sector adaptive capacity score. When quantitative adaptive capacity data is available, overall impact rating is determined by dividing the total impact score by the total adaptive capacity score.

3.2.4 Qualitative Adjustments

Figure 3.5 Qualitative Adjustments



In many cases there are additional variables that significantly influence the vulnerability of a specific county or region that cannot be accounted for in quantitative metrics. Often this information may come from interviews or personal experience, generating uncertainty flags. For example, a water commissioner may say that a specific group in his or her region is less vulnerable because of a cooperative agreement that they have in place. In situations like this, it may be appropriate to adjust the quantitative impact score for a sub-sector. The goal of the qualitative worksheet is to make these adjustments transparent and easily traceable.

Qualitative vulnerability information is recorded for specific counties and sub-sectors, when applicable, and the descriptions are translated into impact scalars according to Table 3.1. In cases where the qualitative information is particularly subjective, an uncertainty flag can be added to the adjustment. This flag will be counted along with the quantitative uncertainty flags. Where qualitative adjustment data exists, sub-sector quantitative impact scores are adjusted by multiplying by the qualitative scalar (refer to Figure 3.5). For example, if for a given sub-sector there is one county which is known to be “highly adaptive”, for whatever reason, their impact score will be cut in half. It is at this step that the number of uncertainty flags associated with metrics to be combined are counted along with any other qualitative adjustments.

Table 3.1 Qualitative Adjustment Levels

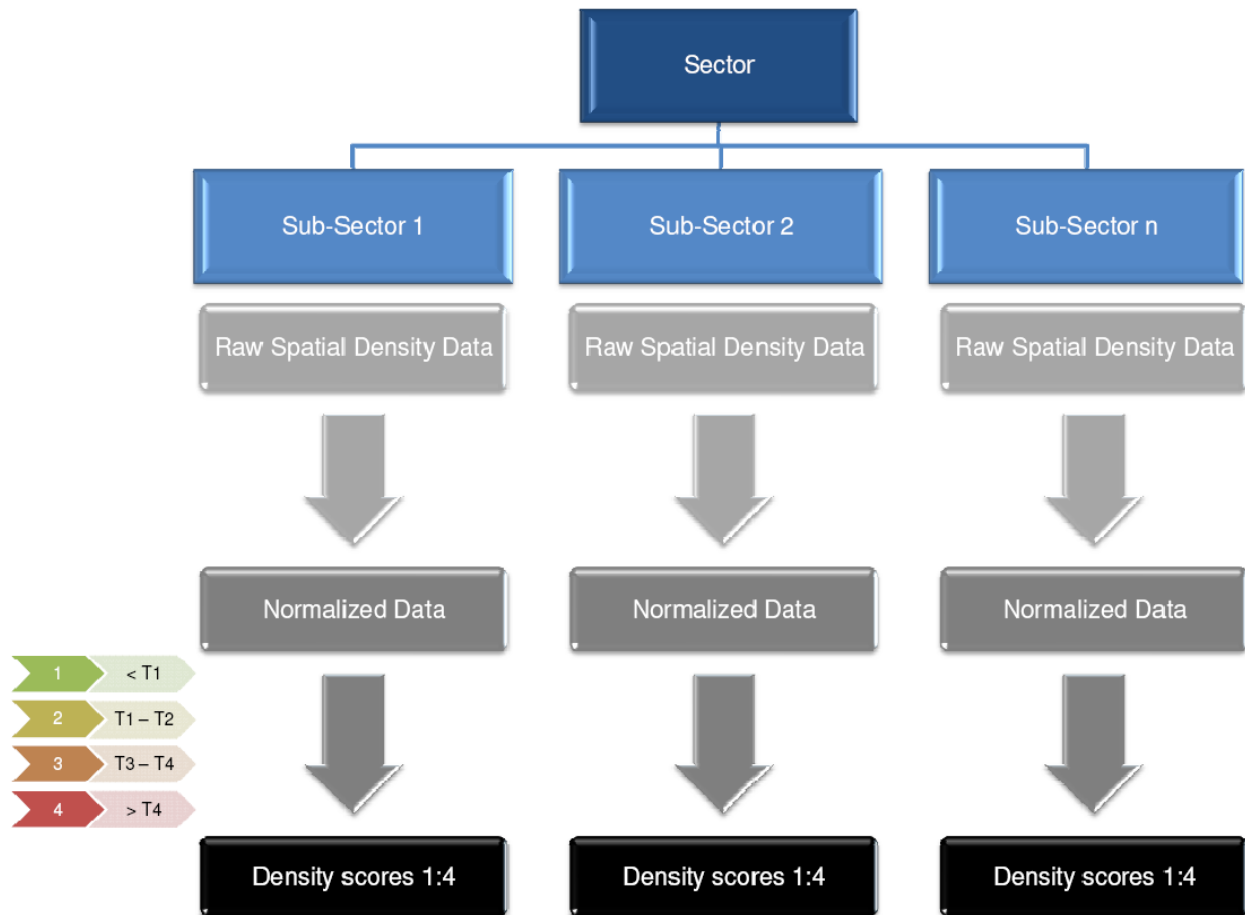
Qualitative Adjustment Description	Numerical Scaling
Highly adaptive	50%
Somewhat adaptive	25%
Somewhat greater impact	125%
Much greater impact	150%

3.2.5 Overall Vulnerability Score

The result of steps 2 through 4 are adjusted impact scores for each sub-sector. Sub-sector scores are combined to an overall sector vulnerability score using weighted averages. The weight of each sub-sector varies by county according to its spatial density.

In step 1, spatial density information was gathered for each sub-sector. As with impact metric data, there is a lot of variability in metrics and raw data must be translated to a consistent scale of 1 to 4, before any comparisons can be made. Given the range of county sizes within the State, most spatial density metrics have to be normalized using either the population or the size of the county. For example, one inventory metric for agriculture is the total area harvested. To determine the relative importance of agriculture within a county, the area harvested has to be normalized by dividing by the total area of the county. In some cases, as with state assets, this normalization step is not necessary because the assets are not relative to the size of the county. Next, the normalized values are converted to scores of 1 to 4 using the same threshold method described in step 3. Figure 3.6 outlines this process.

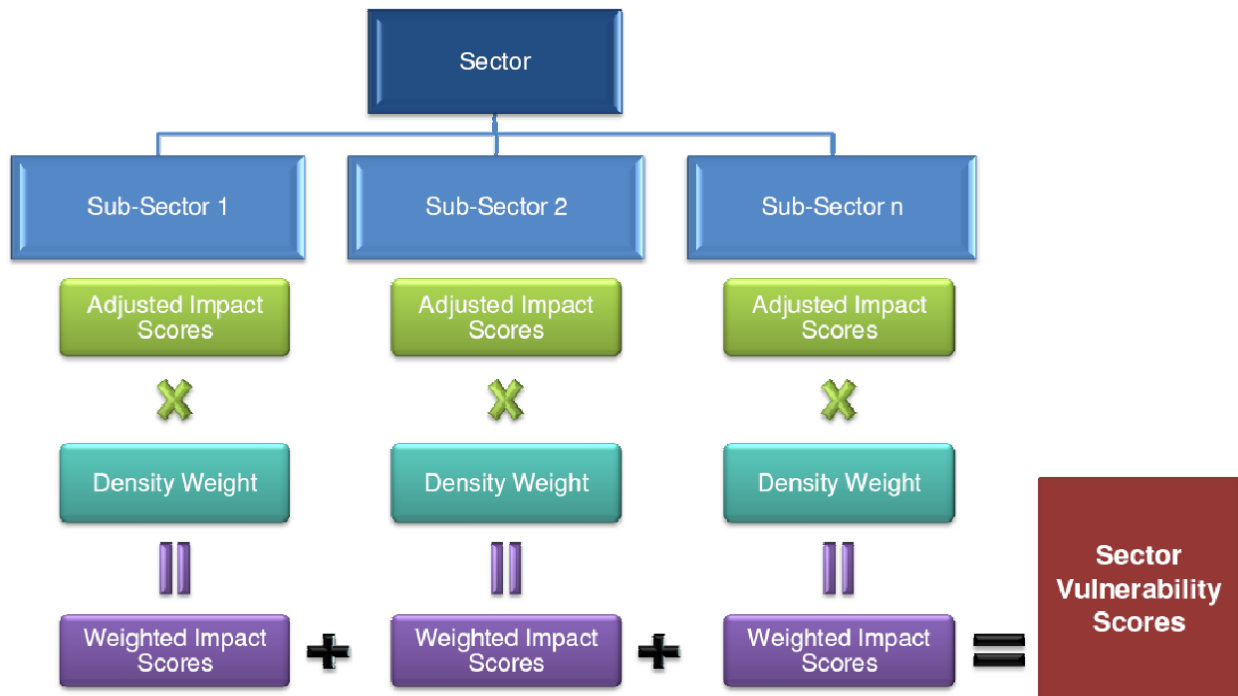
Figure 3.6 Spatial Density Score Calculation (T=Threshold)



To determine the relative weight of each sub-sector within a county, the density score for a given sub-sector is divided by the sum of the density scores for all sub-sectors with the county.

Overall sector vulnerability is calculated by multiplying the sub-sector adjusted impact scores by the county specific sub-sector weights, and summing across all sub-sectors (refer to Figure 3.7). Any quantitative or qualitative uncertainty flags from previous steps are counted, and a total uncertainty flag count is assigned to the overall vulnerability score if applicable.

Figure 3.7 Overall Sector Vulnerability Calculation



4 INFLUENCE OF WATER RIGHTS ON DROUGHT VULNERABILITY

4.1 Drought and Colorado Water Rights

Drought vulnerability within the State of Colorado is highly affected by the legal framework used to allocate water in Colorado. This framework is based on the prior appropriation doctrine described as “first in time first in right.” Under this doctrine, rights to water are granted upon the appropriation and beneficial use of water. The dates of appropriation and adjudication determine the priority of the water right, with the earliest dates of appropriation and adjudication establishing the most senior or superior rights. Thus, the right to the beneficial use of water in Colorado is based on a diversion for beneficial use through prior appropriation and adjudication confirmed by water right decrees obtained by a water court, rather than by grant, or permit, from the State (DWSA, 2004).

While the allocation of water supplies during dry periods via the prior appropriation system is essential to a comprehensive evaluation of drought vulnerability, the nature of individual water users’ water right portfolios, general allocation of these rights, and historical water right case studies is extremely complex. Although some generalizations may be developed for study

purposes, each water user has a unique portfolio of water rights and consequently neighboring water users can be impacted very differently during periods of drought.

The inclusion of the prior appropriation system as a means to evaluate drought vulnerability is beyond the scope of this study. However, future drought vulnerability studies that incorporate the prior appropriation system at a level that is both feasible and sufficiently addresses drought vulnerability on a water division or district level, when viable data are available, could provide useful information that would enable communities to better prepare for potential impacts of drought in the future.

While some information is available on river administration based on previous recent droughts in the state (namely the 2002 and 2011-2013 droughts), including aspects about leasing instream flow rights and utilizing reaches to protect assets, more time and collaborations would be necessary to acquire and process data that captures the extent of the impacts of the latest 2011-2013 drought, in particular, into this 2018 Plan update. Future endeavors could address some of these water rights complexities, to highlight issues behind water appropriation and administration during and after times of water scarcity.

One example of the State Legislature working in concert with state and non-profit agencies is the Colorado Revised Statute 37-83-105, which allows owners to loan agricultural water rights to CWCB for instream flows. For example, the statute enabled water rights owners to temporarily lend water to rivers for environmental purposes in 2003, following the 2002 drought, when many people realized there was no legal way to “lend” water to rivers/streams with low flows without putting the water right at risk. In 2012, the non-profit Colorado Water Trust issued notices seeking people interested in the voluntary leases, offering financial compensation for owners willing to leave their water in the stream. The Colorado Water Trust was the first entity to use this legislative tool in times of need, by coordinating the leasing of water rights to preserve instream flows during the droughts. The program was implemented again in 2013, following the 2012 drought. This is an example of an innovative adaptive capacity that can be operated within the framework of the State’s prior appropriation system to reduce drought-related environmental and recreational impacts. Such adaptive capacities, in addition to drought impacts, are important data to acquire during and immediately following drought. For example, the Colorado Water Trust prepared a summary document following the 2012 drought to evaluate their request for the water leasing program. Via the evaluation report, the Water Trust identified four general goals intended to: 1) keep water in important flow reaches to maintain aquatic life and habitats; 2) prove the feasibility of the short-term leasing mechanism as a viable avenue in Colorado for river administration and stewardship; 3) increase awareness of the instream flow program to engage in discussion about the program and how critical it could become in restoring and protecting flows, while at the same time studying the potential for further partnerships and efforts to be built between water users regarding the environment; and 4) increase awareness about the impacts that hazards like drought can have in Colorado, its water resources, and organisms.

After the latest drought in the State (2011-2013), agencies and policy makers came together to devise a new plan that could provide opportunities to modernize how water in Colorado is managed, given the scarcity and invaluable nature of the resource. As a result of collaborations aimed at addressing this water management issue, the Colorado Water Plan was published in 2015, with three key goals: to enable a “productive economy that supports vibrant and sustainable cities, viable and productive agriculture, and a robust skiing, recreation and tourism industry; efficient and effective water infrastructure promoting smart land use; and a strong environment that includes healthy watersheds, rivers and streams, and wildlife.”

Both the efforts taken by the Colorado Water Trust to maintain river flows and the creation of the State Water Plan are two examples of endeavors aimed at managing and protecting Colorado rivers and streams during and after times of drought. However, updates of the State’s Drought Mitigation and Response Plan could benefit from providing additional information on river administration in relation to more recent droughts, specifically, to highlight (e.g., at a basin-wide level) solutions to the water scarcity problem.

The remainder of this section provides a general overview of Colorado’s prior appropriation system, an overview of basin-wide river administration during the 2002 drought, and general recommendations for future studies, though again future assessments should strive to include pertinent information about the more recent drought events in order to supplement the below information.

4.1.1 Introduction to the Prior Appropriation System and Drought

This section describes the prior appropriation system and drought. Information in this section is directly taken from Colorado Water Conservation Board’s (CWCB) 2004 Drought and Water Supply Assessment (DWSA) study. For specific case study citations relevant to this discussion review the 2004 DWSA posted on CWCB’s website.

The right to appropriate and use water is a valuable property right that arises by the act of placing unappropriated water to beneficial use. This right is protected under Colorado law and is rooted in Colorado’s Constitution, which establishes that public uses of water in Colorado are subject to the right to appropriate a water right for private use:

The water of every natural stream, not heretofore appropriated, within the State of Colorado, is hereby declared to be the property of the public, and the same is dedicated to the use of the people of the State, subject to appropriation as hereinafter provided. Colo. Const. Art. XVI, § 5.

The right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied. Colo. Const. Art. XVI, § 6

Like other property rights, vested water rights may not be taken without payment of just compensation, and may be bought and sold separately from land on which they are used. Colorado does not have a “public trust doctrine” like some states, and “the public interest” is not a factor

considered in adjudicating a water right. However, while the legislature in Colorado cannot prohibit the appropriation or diversion of unappropriated water for beneficial use based on public policy concerns, it can regulate the manner of affecting an appropriation. Important tools for the management of water resources have been developed through case law and statutory enactments governing the diversion and use of water.

As the doctrine of prior appropriation has been interpreted through case law, two major principles have emerged based on the constitutional requirement of “beneficial use” and the conception of water as a property right. First, water must be used efficiently and a water right does not include the right to waste the resource. Second, the right to use water must be sufficiently flexible to accommodate changes of use and the free transferability of water rights in order to allow the maximum use of water in times of scarcity. With regard to the former principle, Colorado courts have required water users to employ an efficient means of diversion, and have limited the amount of water that may be appropriated to the amount necessary for the actual use. Regarding the second principle regarding flexibility of water rights, Colorado law recognizes water storage rights, conditional water rights, augmentation plans, changes to water rights, and instream flow rights, all of which allow water users to make the most of a scarce resource.

In summary, the absence of a permit system or a public interest test in Colorado requires the State to work within the bounds of the priority system, and to respect private property rights, in managing the resource for public purposes in times of drought. However, the prior appropriation system itself provides opportunities for management of the resource.

The DWSA 2004 provides additional information on: 1) the elements of the prior appropriation doctrine which promote efficient use of a scarce resource, and which, themselves, are tools for drought management; 2) a summary of federal, state, and local legal tools available for drought management in Colorado; and 3) statutory tools adopted by Colorado’s legislature to manage water resources within the parameters of the prior appropriation system. The statutory tools are instrumental to managing water supplies during periods of drought for many water users throughout the State, and the bulleted items below introduce these tools.¹

- Instream flows – The ability of the State to appropriate and acquire water within the priority system for instream flow purposes is essential to its ability to protect wildlife and the environment during times of drought.
- Conditional water right – A conditional water right allows an appropriator to secure a priority before water has been applied to beneficial use, based on a showing that the “first step” towards the appropriation has been taken. Conditional water rights are a tool that may be used by cities or individuals to complete major water projects, including storage reservoirs, trans-mountain diversion projects, or pipelines, for managing scarcity in times of drought.

¹ Additional information on each of these tools is provided in the DWSA 2004.

-
- Storage water rights - A storage right allows the user to store water for later application to beneficial use. Storage rights, like other water rights, are assigned a priority and must be exercised without injury to other water rights. Storage rights are a very important mechanism for ensuring that water supplies will be adequate in times of drought.
 - Change in water right – A change in water right allows water users flexibility to maximize potential uses of water by changing the beneficial uses of a water right. A change of water rights includes “a change in the type, place, or time of use, or a change in the point of diversion,” and changes in the manner or place of storage. A change of water rights must be approved by the water court and is subject to the “no injury rule,” which requires a finding that the change “will not injuriously affect the owner of, or persons entitled to use, water under a vested water right or a decreed conditional water right.”
 - Leases of water rights – Leases of water, particularly by municipalities during dry years, are common in Colorado. Municipalities will often temporarily lease senior agricultural water rights from farmers to meet demands during a drought. This provides the municipality additional water while allowing farmers to earn some income during a drought year when their crops are not likely to be successful, without permanently changing or selling their water rights. Additionally, the State can lease agricultural and other water rights for instream flow use, which can assist in preserving the natural environment during a drought and provides the same benefits to farmers and municipal leases.
 - Augmentation and substitute water supply plans - Augmentation plans and substitute water supply plans allow a water user to divert water out-of-priority from its decreed point of diversion, so long as replacement water is provided to the stream from another source, to make up for any deficit to other water users. An augmentation plan must be approved by the water court while a substitute water supply plan may only be implemented on a temporary basis until an augmentation plan is decreed and is administered by the State Engineer. In times of scarcity, these plans allow a water user to continue diverting even under a relatively junior priority, so long as it can purchase replacement water to satisfy the needs of downstream senior water users.
 - Voluntary Measures - During the summer of 2002, when Colorado’s drought was at its worst, many water users undertook voluntary measures to ease the impact of drought on other water users and on the environment by abstaining from enforcing their priorities against junior water users. Some water users developed payment arrangements under which senior water users temporarily agreed to forego calling out junior users.

4.1.2 River Administration during the 2002 Drought

Historical drought impacts are not a direct predictor of future potential drought impacts. Each drought is unique in severity, spatial scale, and duration and can impact a water user in different ways. Furthermore, water users may have improved their overall adaptive capacity in response to a drought through water supply and drought planning efforts. However, historical impact data can provide valuable insight into the general vulnerability of a water user/region, including a useful set of lessons learned to apply to future drought planning and response efforts. Historical data also

provide useful information on how river administration can change during a drought and consequently impact water users without requiring a thorough examination of the prior appropriation system.

The remainder of this section provides an overview of changes to river administration brought on during the 2002 drought, by Colorado's seven water divisions. This overview is simply a summary of some of the administrative changes and drought impacts that occurred in 2002 based on a presentation by the State Engineer, Hal Simpson, at the 2004 Colorado Drought Conference, and information provided in the 2004 DWSA. It is recommended that a more thorough assessment of historical drought-related administrative changes be conducted in follow-up studies.

South Platte River Basin - Division 1

In 2002, the calls came on in the South Platte River Basin very early (April 1) and there were direct flow calls all summer into the end of October. Normally the call changes from direct flow to storage, sometime around October 1. However, in 2002 the direct flow rights call extended until November 1, and storage water rights did not become active until after November 1. Generally, the majority of reservoirs on the plains that served the South Platte River were emptied. Because of the long call, the amount of augmentation water for the wells, including that held by the largest augmentation associations on the South Platte (Groundwater Appropriators of the South Platte [GASP], Lower South Platte Water Conservancy, and Central Water Conservancy District [Central]) was insufficient, and well users had to acquire additional replacement water or face the potential of curtailment. As a result, there were a lot of creative actions taken by the water users and the State Engineer's Office (SEO) to maintain pumping during the irrigation season.

There was a lot of cooperation among water users within the basin. M&I water providers in the Denver Metropolitan Area leased usable return flows to GASP to help them continue pumping by offsetting depletions in the upper part of GASP's service area. Denver, Aurora, and Thornton developed a three-way deal that resulted in effluent being made available to GASP and Central. Additionally, the Colorado legislature appropriated \$1 million towards grants for augmentation associations to acquire additional water.

Arkansas River Basin - Division 2

The Arkansas River Basin ran into a number of very senior calls in 2002. Generally, there is a call on the Arkansas River year-round as a result of the Arkansas River being heavily over-appropriated, although the seniority of the call varies. For the first time in history, in 2002, the 1869 water right of the Rocky Ford Highline Canal called. This call took out the Pueblo Board of Water Works' 1874 water right for 45 cubic feet per second (cfs), which is the foundation of their water supply. Pueblo assumed that they would always have the 45 cfs available, so when the call came they had to quickly adapt. In response, Pueblo reduced demand by instituting mandatory outdoor watering restrictions and temporarily suspending extra-territorial raw water lease contracts for what they thought was surplus water to downstream augmentation groups and the City of Aurora. The decline in available augmentation and replacement supplies caused the SEO to cut

back the pumping of some of the augmentation associations. The Arkansas Groundwater Users Association had to cut back allocations by 25 %.

Rio Grande River Basin - Division 3

The drought conditions in 2002 resulted in record low streamflows in the Del Norte and Rio Grande Rivers. Releases from Rio Grande, Continental, and Santa Maria reservoirs were initially maximized; however, the reservoir owners stopped making releases due to high transit losses which were as high as 50%. The owners thought that the releases were too much of a waste of a valuable resource, so they stopped running reservoir water and decided to carry it over into the following year. Significant problems also occurred with the Closed Basin in 2002. Decreases in groundwater levels caused a number of wells to pump air where water levels in the aquifer were below the intake to a number of pumps. There was fear that if the following year did not receive sufficient runoff and recharge the aquifer, there would be a very serious impact of drought carried into 2003.

Gunnison River Basin - Division 4

One of the most notable situations in the Gunnison River Basin during the 2002 drought was administration with respect to the Gunnison Tunnel call. Since the Blue Mesa Reservoir was constructed, the Gunnison Tunnel call had never moved upstream of Blue Mesa Reservoir. Historically, there had been sufficient water in the river in addition to releases from Blue Mesa Reservoir to keep the senior call off. However, in 2002, the call was placed in April and stayed on most of the summer which caused the SEO to regulate junior water rights, or those prior to 1901. This had not happened for about 50 years and there was a new generation of ranchers and people living in the area that did not understand the priority system and how the SEO could shut down their water rights. It was a difficult situation for the water commissioner to have to regulate water rights that had not been regulated for over 50 years.

Between the fall of 2002 and April 2003, Redlands Power Authority reduced its demand from 750 to 600 cfs, benefiting the entire Gunnison River Basin and allowing water to be stored in the Aspinall Unit. Redlands was compensated primarily by the Colorado River Water Conservation District for revenue lost due to decreased electrical generation.

Colorado River Basin - Division 5

Reservoirs within the mainstem of the Colorado River Basin had to be managed very closely in 2002. Up to 20,000 acre-feet of replacement water generally stored in Green Mountain Reservoir was not available. This required a lot of cooperation between the Colorado River Water Conservation District, and the Northern Colorado Water Conservancy District in finding an additional 20,000 acre-feet. Surplus water in Ruedi Reservoir was eventually purchased to offset the 20,000 acre-feet of replacement water not available out of Green Mountain.

Also during the summer of 2002, certain Grand Valley entities, including the Grand Valley Water Users Association, Orchard Mesa Irrigation District, and the Grand Valley Irrigation Company reduced their call for water to conserve water stored in upstream reservoirs for the next year. This had the added benefit of helping Denver Water by reducing the water it owed under certain contractual arrangements to Green Mountain Reservoir. In addition, during 2002, several large power companies reduced their demand in order to allow reservoirs to fill, benefiting water users all over Colorado who were dependent on stored water.

Yampa River Basin - Division 6

Water users in the Yampa River Basin used most of the reservoir water available to them in 2002. Several reservoirs including Stagecoach, Steamboat, and Elkhead Reservoirs release water for power plants in dry years. In order to sustain the power plants through the summer in 2002, when they had very little, if any, direct flow rights, reservoir releases were necessary to meet the power plant needs. This was a new situation for the water commissions who had never had to protect reservoir releases that far down into the system where the power plant divisions are located.

San Juan/Dolores River Basin - Division 7

In 2002, many of the perennial streams in the San Juan/Dolores River Basin that normally flow year-round went dry. This was not due to diversions but simply to low runoff. Many of the reservoirs went down to dead storage or to Division of Wildlife (now CPW) conservation pools to protect the fish population. Colorado was not able to meet the La Plata River Compact obligations to New Mexico. In 2002, 26 miles of the La Plata River dried up and the SEO ceased deliveries to New Mexico because the transit losses were too high. In response, diversions below the critical reach of the river were curtailed and return flows were delivered to New Mexico. However, it was only about half of what they were entitled to. This was the fourth consecutive year Colorado did not meet its La Plata River Compact obligations.

4.1.3 Recommendations for Future Studies

The prior appropriation system coupled with river administration during periods of drought is an essential component to assessing drought vulnerability throughout the State of Colorado. While a thorough evaluation of these efforts is beyond the scope of this particular study, the following recommendations address how the prior appropriation system and river administration can be incorporated into follow-up drought vulnerability studies. Specific issues and projects that could impact future drought vulnerability are also addressed.

- *Basin-wide assessment of river administration* – The existing and future water demands, types of water use, politics, economic base, water development, etc. within each of the seven water divisions in Colorado is very different. Consequently, the future challenges faced by each division basin to administer supplies and meet future water demands during both normal and drought years are unique to each basin. Future drought vulnerability studies should assess river administration at the division level, and where appropriate at the water district level too.

-
- *Basin-wide assessment of water users* – Water users throughout Colorado have water right portfolios of various seniority and consequently drought vulnerability is essentially unique to individual users. While it is not feasible to evaluate the vulnerability of each water user within the State, larger water users, in addition to users of highest vulnerability (which are often smaller water users), should be identified for each water division basin, and where appropriate at a water district basin scale.
 - *Historical drought data* – Historical drought data provide useful information on how river administration can change during a drought and consequently impact water users without requiring a thorough examination of the prior appropriation system. These data include historical drought indicators data (e.g., streamflows, reservoir storage levels, snowpack), applicable diversions, interstate compact compliance, call data, and others. At a minimum, 2002, 2003 and 2011-2013 drought-related data should be closely examined and, where appropriate, previous drought-related information of different magnitudes and scales may also provide insight into the vulnerability of a region. These data should be reviewed on a water division level at a minimum, and at a local district level when appropriate. Comprehensive surveys distributed among water users in the State, and/or an interactive web-based programs designed to receive drought impact data from water users would be useful tools to compile historical and future drought-related data.
 - *Basin-wide modeling of river administration* – In order to thoroughly assess future administration during periods of drought and overall drought vulnerability, basin-wide modeling will be necessary. Historical drought-related data discussed above could be used to help calibrate or verify the model.
 - *Future river administration changes* - As Colorado continues to grow and develop, water demands will increase, placing greater stress on the State's finite water resources, further causing changes to river administration. Additionally, there are several relatively large-scale water development projects that involve transbasin diversions in the state, which if expanded, could have significant impacts on streamflows in certain river reaches and affect future river administration. Furthermore, as the State's water resources continue to be developed, meeting compact obligations during dry periods could be a greater challenge. In particular, there is concern that a Colorado River Compact call could result in the curtailment of all water users. The earliest date of curtailment would be November 24, 1922, the date of the compact signing. Future drought vulnerability studies should consider the potential administration changes previously described and quantitatively assess how these changes could affect drought vulnerability on a regional scale, where feasible, and at a local scale where appropriate.

5 STATE ASSETS SECTOR

Key Findings

- Key drought vulnerabilities for state-owned buildings include damage to structures from resulting wildfires, loss of landscaping, and impacts to correctional facilities and correctional industry programs.
- Critical infrastructure like dams and ditches can be damaged by low water levels and debris flows resulting from wildfires.
- State agencies like Colorado Parks and Wildlife (CPW) (formerly the Division of Wildlife (DOW) and State Parks) and the State Land Board have increased management requirements during drought and may also see decreases in revenue. Since the 2013 update to the Drought Mitigation and Response Plan and the 2011-2013 drought, these agencies have responded by implementing strategies such as using structural and non-structural measures to ensure water-based recreation can continue as long as possible despite drought conditions, and coordinating amongst stakeholders and interested parties to manage water resources for recreational purposes and habitat enhancement. It may be difficult to maintain instream flow rights during low flow periods. However, there are cases where senior calls downstream may inadvertently maintain flows during drought.
- Although systematic documentation is lacking, the impacts to protected areas and ecosystems can be severe and in some cases irreversible. This section addresses impacts as they relate to state assets. Broader analysis can be found in the Environmental sector.
- The 2011-2013 drought was, at the time of the 2013 Plan update, ongoing. As a result, comprehensive data related to State Assets were not yet available because they were still being collected. By the 2018 update, impacts related to the drought could be assessed and vulnerability of state assets further evaluated against the 2010 datasets.

Key Recommendations

The following key recommendations were originally developed in 2010, relevant in 2013, and reaffirmed during the 2018 update.

- Increased drought awareness and planning could benefit all of the state assets discussed in this section. Every agency should have a drought plan that addresses the vulnerabilities noted in this report.
- Agencies should be aware of their specific vulnerabilities and start developing policies to provide additional response and flexibility during drought.
- Lack of coordinated media outreach is often cited as a shortcoming during the 2002 drought. Since that time, efforts have been made to improve the situation. For example, in 2012 and 2013, the Public Information Officers of the Front Range Water Council collaborated and communicated on media and messaging campaigns. Nonetheless, additional media plans and coordination should be developed now to avoid confusion when a drought does occur.

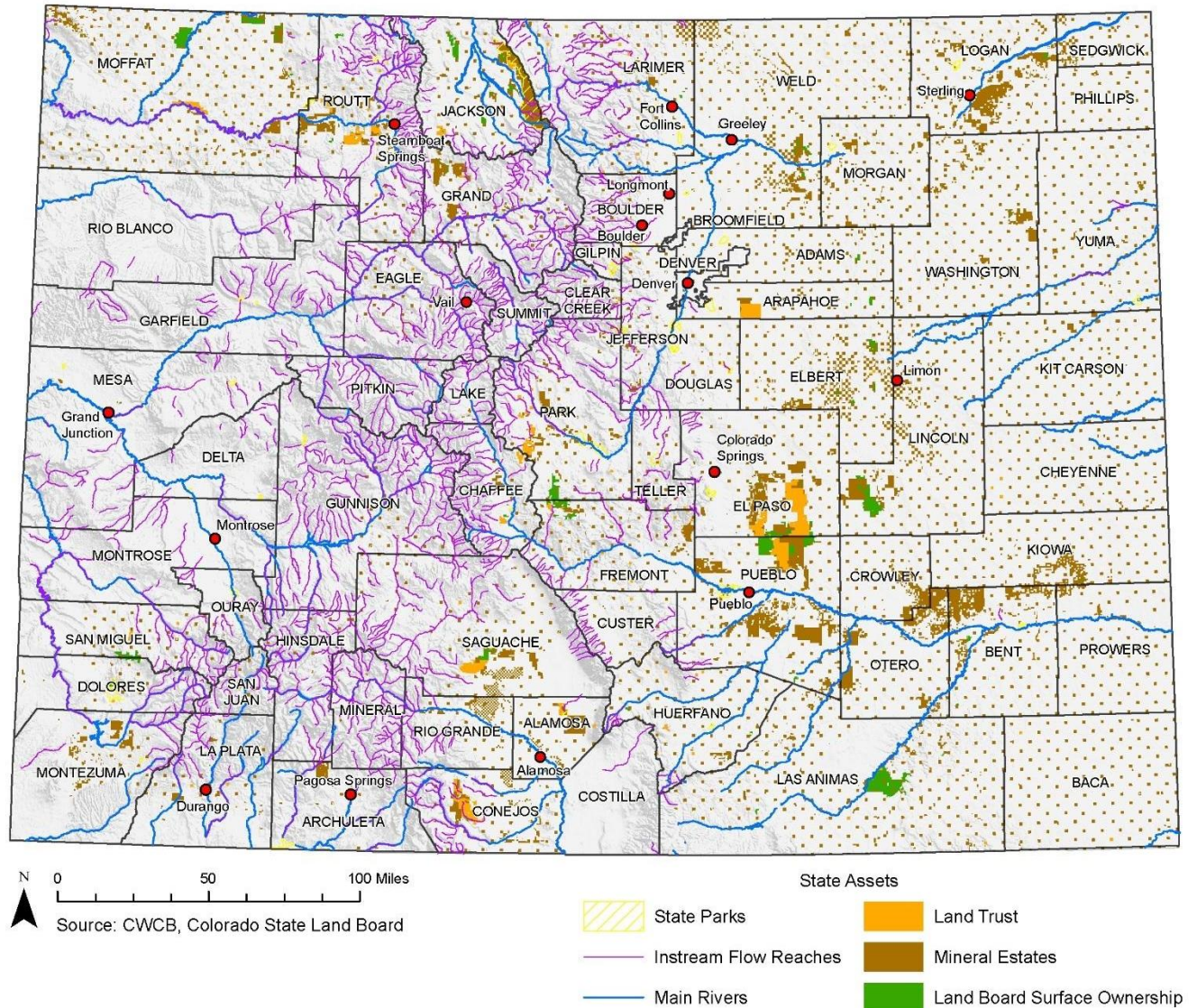
- In many cases vulnerability data are not available consistently statewide. Section 5.6.2 outlines future data gathering tasks for each impact category.

5.1 Introduction to Sector

The State of Colorado owns and/or operates numerous assets, which for the purposes of this report include: buildings, critical infrastructure, state lands, instream flows, and state fisheries. Drought vulnerable critical infrastructure includes: dams, transmountain ditches, and irrigation ditches. Instream flow rights are non-consumptive “in-channel” or “in-lake” water rights that can only be held by the Colorado Water Conservation Board (CWCB). These rights designate minimum flows between specific points on a stream, or water levels in natural lakes. Figure 5.1 shows the major state-owned lands and instream flow reaches.

The primary agencies responsible for drought-vulnerable assets are the State Land Board (Land Board) and CPW. The intent of this section is not to exhaustively cover the impacts of drought on all state agencies; rather, the focus is placed on the agencies that control the majority of the physical assets within Colorado that are vulnerable to drought. Given the wide variety of state asset types and their spatial distribution, vulnerability to drought is highly variable. It should also be noted that many of the state assets discussed in this section are natural resources. As such, there is significant overlap between this sector and the Environmental sector. The analysis of state asset vulnerability focuses on drought impacts as they relate to state operations and management practices. For a broader analysis of ecosystem vulnerability refer to the Environmental sector. For a general description of the vulnerability assessment approach refer to Chapter 2 (Annex B).

Figure 5.1 Distribution of State Assets



Source: State Land Board and CWCB. Data current as of 2018; Figure revised 2018

Many state assets are conservation areas or protected wildlife that cannot be adequately evaluated based on the revenue they generate. Colorado is renowned for its wilderness areas and outdoor recreation opportunities. The value of these areas goes far beyond any land value or revenue stream. Still, economic considerations are important because the revenues generated by state assets help to maintain protected areas. In fiscal year 2014-2015, State Land Board trust assets generated \$186 million in revenues. Recent increases in revenue is attributed largely to increased mineral development. The initial \$11 million of trust land revenues support the operations and investments of the State Land Board. The agency's operating budget comes directly from revenues earned from the lands and not from taxpayer dollars. Remaining funds are invested into the Public School Permanent Fund, the School Finance Act, and the BEST (Building Excellent Schools Today) Capital Construction Program. In the following year Colorado state parks had total visitation of

over 12 million people. From this CPW generated over \$114 million in revenue from licenses, passes, fees and permits, which is approximately 54% of its funding (CPW, 2017). This revenue helps fund conservation efforts by the division. While it is inaccurate to value state assets based on these revenues, it is important to note revenue sources and assess their drought vulnerabilities.

State assets have significant overlap with the Environmental, Recreation, and Municipal and Industrial sectors. The State owns or operates vast areas across the State, much of which is protected from development. State agencies like the CPW and the Colorado State Forest Service (CSFS) are responsible for much of the environmental and species management across the State. These agencies are important resources for the Environmental sector as a whole. The State is also an important investor in critical infrastructure, such as dams which provide important storage for municipal water providers. Revenue from the Land Board provides funding for public schools and other public amenities. As a whole, state assets contribute immeasurably to the value and quality of life of the State. This in turn impacts population growth, real estate value and the economic vitality of the State as a whole. Conversely, state agencies are dependent on tax revenue, thus impacts to other sectors can directly impact operating budgets.

5.2 Vulnerability of State Asset Sector to Drought

5.2.1 Aspects of Vulnerability

The diversity of state assets is reflected in their wide range of drought vulnerabilities. Specific impacts and adaptive capacities will be covered in more detail by asset in Section 5.3.

Table 5.1 outlines the impacts and adaptive capacities for state assets. Environmental assets such as instream flows and protected areas can be detrimentally impacted by drought. Decreased streamflows threaten instream flow rights and aquatic habitat. Low flows can also result in higher water temperatures that change water chemistry, harming some aquatic species. State-owned fish hatcheries may experience decreased water supply that could threaten their operations. Terrestrial habitat is also impacted by drought. Plants become stressed and are more susceptible to disease and infestation. Beetle kill and increased occurrence of wildfire are often cited as secondary drought impacts. Plant stress and decreased forage translate directly to animal stress. In times of drought there are often increased incidents of crop damage by animals.

Drought can also impact vital revenue streams. As reservoir levels decline so does visitation to water-based state parks. Wildfires and fire restrictions can also impact visitation numbers. In 2002, forage production on state-owned lands was so severely impacted that the Land Board issued countywide lease discounts to encourage responsible management practices.

Buildings and critical infrastructure such as dams and ditches are usually omitted from drought vulnerability assessments despite potential costly impacts. For example, building foundations can be damaged if they are on expansive soil that dries out. Landscaping can be damaged or lost if municipal water restrictions are imposed or water rights are out of priority. Wildfire resulting from

drought conditions can destroy buildings in its path and create air quality issues that affect a much larger radius. Decreased pore water pressure can cause structural damage to dams. Water supply ditches that remain dry for extended periods of time are prone to animal damage and overgrowth.

Adaptive capacities for state assets vary as much or more than vulnerabilities. As noted above they are discussed in more detail in Section 5.3. Most agencies could benefit from additional drought planning and awareness of possible drought impacts. Coordination between agencies and media relations is key during drought and these protocols should be established in advance. In the case of CPW, additional monitoring is needed during periods of drought to assess and prioritize direct impacts to priority species and habitats and identify particularly vulnerable species and habitats. Additional instream flow and natural lake rights will also help preserve aquatic environments in times of drought.

Table 5.1 Key Impacts and Adaptive Capacities of Drought Vulnerable Assets

State Asset	Key Impacts	Key Adaptive Capacities
State Buildings	<ul style="list-style-type: none"> ● Damage due to wildfires ● Loss of landscaping ● Damage to structure as a result of soil drying 	<ul style="list-style-type: none"> ● Invest in less water intensive landscaping ● Make a drought plan
Critical Infrastructure	<ul style="list-style-type: none"> ● Structural damage to dams and ditches resulting from low water levels ● Damage caused by high sediment loads when pulling water from the bottom of reservoirs ● Damage caused by debris flows and flooding from wildfires 	<ul style="list-style-type: none"> ● Budget for additional maintenance and oversight during and following a drought ● Take advantage of low water levels to maintain and repair structures
Land Board	<ul style="list-style-type: none"> ● Damage to rangeland and agricultural areas ● Loss of agricultural lease revenue 	<ul style="list-style-type: none"> ● Offer lease discounts in return for less intensive land use
Parks and Wildlife	<ul style="list-style-type: none"> ● Decrease in water-based recreation resulting from low water levels and degraded water quality ● Decrease in recreation resulting from wildfires or fire restrictions ● Damage to protected habitat and possible loss of protected species ● Increased management requirements ● Loss of licensing revenue for CPW 	<ul style="list-style-type: none"> ● Increased press relations coordination ● Decrease operating costs by cutting seasonal staff ● Land and angling closures ● Change the number of licensees released ● Increased monitoring efforts and drought planning during non-drought times
Instream Flows	<ul style="list-style-type: none"> ● Inability to maintain instream flow rights resulting in impacts to fisheries and aquatic habitat 	<ul style="list-style-type: none"> ● Increase water rights portfolio ● Obtain conditional lease agreements for drought conditions

5.2.2 Previous Work

The 2010 update to the Colorado Drought Mitigation and Response Plan (Plan) was the first time a quantitative vulnerability assessment was conducted for state assets. At the time of the 2013 Plan update, the 2011-2013 drought was ongoing and therefore the full extent of the drought was unknown in terms of reliable, measured data. During the 2018 update of this plan, new data was available to evaluate the aftermath of the 2011-2013 drought.

In the past, drought mitigation plans have assessed vulnerability only on a cursory level. For example, the CWCB conducted a Drought Water Supply Assessment (DWSA) in 2004 to determine the State's preparedness for drought and identify limitations to better prepare for future droughts. The details of this work are discussed in Section 4.1.1. It entailed a survey, or opinion instrument, where 537 responses were received statewide on specific impacts experienced during the dry period of 1999-2003. Various entity types were surveyed including power, industry, agriculture, municipal, state, federal, water conservancy and conservation districts, and tribes and counties.

The results of the DWSA survey are helpful in understanding the opinions of Colorado's water users statewide and on a basin-wide scale in terms of existing and future water conditions. However, responses were not received from everyone in the state and coverage is not sufficient to examine results on a county level. These spatial limitations, along with uncertainty in the interpretation of specific survey questions by the respondents, make it impossible to incorporate DWSA results into the vulnerability methodology developed for this study. However, there is pertinent information that should be analyzed in a qualitative way to inform and verify vulnerability findings.

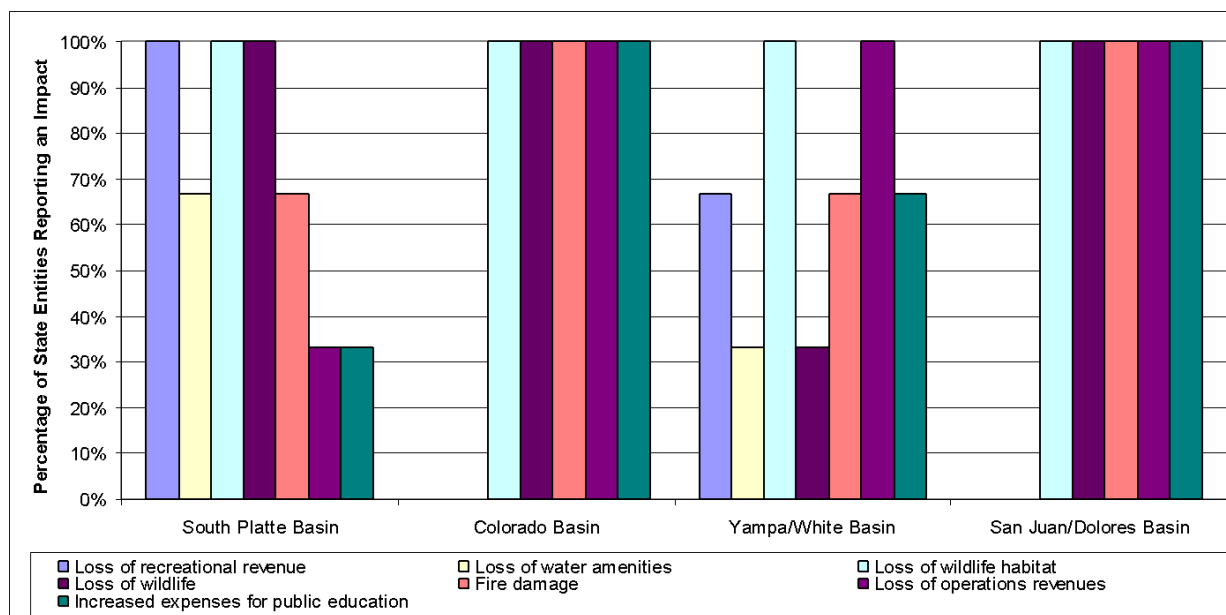
Figure 5.2 provides the percentage of surveyed State entities that experienced the impacts listed at the bottom of the figure. State entities surveyed included the Division of Water Resources (DWR), Colorado State University (CSU) Cooperative Extension, CSFS, Land Board, Steamboat Lake State Park, Department of Corrections, CPW¹, and the CWCB. It is important to note that only those categories that are applicable to the State Assets sector are shown in the figure. For example, results from loss of crop yield or loss of livestock are not shown. Additionally, only state entities within the South Platte, Colorado, Yampa/White, and San Juan/Dolores Basins responded to the survey with impacts and therefore only their results are shown. Of the eight state entities surveyed, impacts were reported in the following categories during the 1999-2003 drought period:

- Loss of recreational revenue
- Loss of water amenities
- Loss of wildlife habitat
- Loss of wildlife

¹ At the time the DWSA survey was conducted, Colorado State Parks and the Division of Wildlife were separate agencies. They are referred to herein as CPW, due to their merger in 2012.

- Fire damage
- Loss of operations revenue
- Increased expenses for public education

Figure 5.2 1999 - 2003 Drought Impacts to State Assets



Note: Despite a comprehensive review and internal testing process of the survey tool, these DWSA 2004 surveyed impact results are subjective. The impacts in the figure above are a reflection of the surveyed individuals' interpretation of the listed impacts.

All state entities within each of these four basins reported impacts due to loss of wildlife habitat. Nearly all of the entities experienced loss of wildlife and loss of operations revenue. Fire damage and increases for public education were also categories that impacted state entities. Loss of recreational revenue and loss of water amenities were only reported in the South Platte and the Yampa Basins.

In general, the impact categories identified in the DWSA findings are well aligned with the impacts covered in this vulnerability assessment. It is difficult to compare results spatially because many of the agencies surveyed have activities across the State (e.g., DWR, Land Board, etc.), but they only provided a single set of responses. Further surveying is needed to determine spatial extent. The CWCB has not conducted a study similar to the DWSA since 2004.

Another relevant previous study that has been conducted in Colorado is the Statewide Water Supply Initiative (SWSI), and the 2010 update (SWSI 2010 update). Although it did not specifically focus on drought as the DWSA did, the SWSI process was another important initiative undertaken and directed by the CWCB to understand existing and future water supply needs, and how those needs might be met through various water projects and water management techniques. SWSI used a statewide and basin-level view of the water supply conditions in Colorado. In 2010 the CWCB completed a Non-Consumptive Needs Assessment (NCNA) Focus Mapping Report

(CWCB 2010b). The NCNA expands upon the existing set of environmental and recreational attribute maps that were developed through the SWSI 2010 update process and develops aggregated maps of Colorado’s critical waters based on the concentration of environmental and recreational qualities. The maps are intended to be a guide for water supply planning, so that future conflicts over environmental and recreational water needs can be avoided.

Many of the in-channel, flow-based, and non-consumptive uses discussed in SWSI and NCNA are completely or partially state assets. For example, instream flows and CPW coverages such as critical habitat areas were analyzed throughout the State in light of how they can affect water supply planning and management. Although these assets are not traditionally used in water planning, they were used in SWSI and further investigated in NCNA to highlight the increased importance that stakeholders feel they are playing in enhancing recreational and environmental uses of water. In the NCNA, instream flows were used as one measure in determining the initial basis for estimating future uses for recreation and environment. Providing instream flows for recreational activities, such as rafting and kayaking, and maintaining minimum instream flows to protect critical habitat areas are seen as important aspects to consider in the planning process. Data on instream flows and critical habitat were gathered and are available as geographical coverages in Section 4 of the SWSI 2010 update and in the NCNA (CWCB, 2010; CWCB, 2010b). NCNA results and their applicability to this vulnerability assessment are discussed in more detail in the Recreation and Environment sectors.

Municipal water suppliers and agriculture are usually considered to be the most drought vulnerable and therefore drought planning efforts often focus on these groups. This drought vulnerability assessment goes further by specifically considering environmental, recreational, state asset, and general socioeconomic drought vulnerabilities. The emphasis placed on these groups in SWSI planning efforts supports the approach taken here and corroborates the interconnectivity of these groups.

5.3 Assessment of Impacts and Adaptive Capacities

In the following section, potential impacts and adaptive capacities for state assets are discussed in detail. The discussion is organized around the following sub-sectors: buildings, critical infrastructure, Land Board, CPW, and instream flow rights. There is significant overlap between the State Assets and the Environmental sector. The discussion in this section is directed toward vulnerabilities as they impact state assets specifically. For more detailed information on drought impacts to the environment refer to the Environmental sector.

5.3.1 State-Owned Buildings

The State of Colorado owns thousands of buildings through a myriad of state agencies and programs. Figure 5.3 shows the total building value (as of 2018, based on Office of Risk Management Data) by county for all state-owned buildings. There are state-owned buildings in every single county, with the highest concentration of assets located along the Front Range.

Figure 5.3 Total State-Owned Building Value by County, in Millions

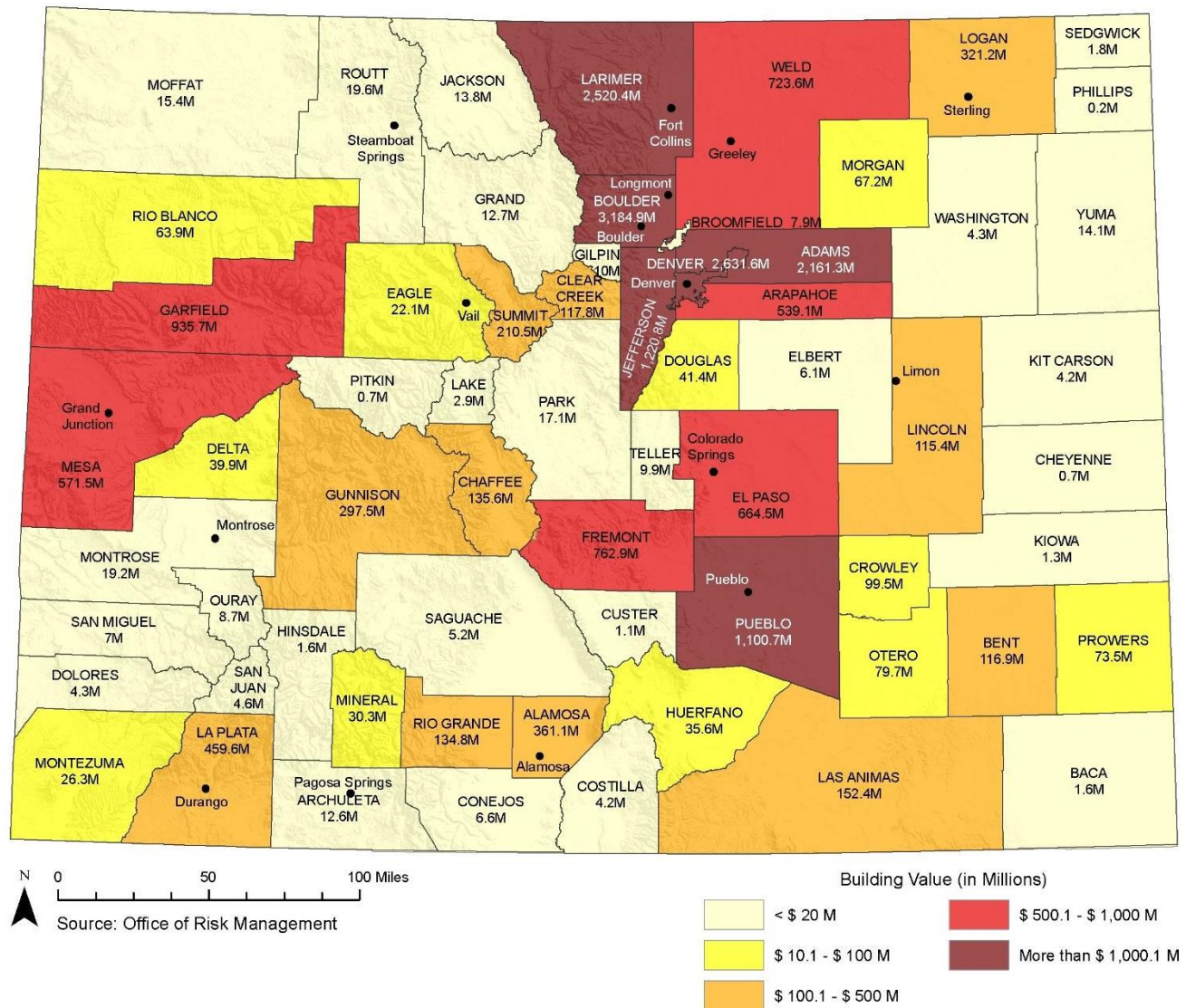


Figure revised 2018

Drought impacts to buildings are rarely mentioned because they are not as dramatic as the impacts from other hazards. However, there are several drought-related damages that should be considered. Table 5.2 outlines the main impacts and adaptive capacities identified for this asset.

If the building is located on expansive soils, foundation cracking can occur as soil moisture decreases and clay-based soils contract. While this is a well-known relationship, no work has been done to directly relate drought and structural degradation.

Buildings may also be forced to change operations and maintenance procedures during drought. As with the structural issues identified above, no work has been done to directly analyze these impacts. Most state buildings rely on the municipal supplier for water, so they will be impacted in similar ways to residential and industrial water purchasers. They will be subject to whatever watering restrictions or surcharges their water providers impose.² Water restrictions can impact landscaping and damage lawns. The same impacts, or greater, may be seen for properties with their own water rights. If these water rights are junior, watering could be completely cut off. Similarly, properties using groundwater may be impacted by declining water tables or augmentation plans that are difficult to fulfill during drought.

One of the biggest threats to state-owned buildings during drought is from increased occurrence of wildfire. Buildings located in high wildfire hazard areas are more vulnerable to catastrophic losses as a result of drought-induced wildfires. Wildfire hazard areas are discussed in more detail in the Environmental sector. In addition to fire damage to buildings, smoke and ash in the air can harm heating, ventilating, and air conditioning (HVAC) systems in affected areas. Ash can also cause extra wear and tear on building exteriors.

The Colorado Department of Corrections (CDOC) has 20 state-owned facilities in 11 counties and private prison contracts in four more. Three facilities are solely dependent on their own public water supply systems for potable and fire protection water. Several others depend on municipalities without sufficient senior water rights or are basin-dependent on water. Both situations increase water supply vulnerability during times of drought. For particularly vulnerable facilities, an extended drought could result in significant operational impacts like interim facility closures or extensive trucking operations to supply potable and fire protection water. Additionally, the Division of Correctional Industries has several programs in its agricultural sector which are directly vulnerable to drought (e.g., crops, greenhouses, hatcheries, etc.). If these programs are damaged by drought, population management concerns can result from idleness.

During the 2011-2013 drought, CDOC was concerned about those facilities located in the Arkansas basin, due to the conditions that exist there. Level II drought restrictions were implemented and directly impacted facility landscaping. An indirect impact of the watering restrictions can be higher local temperatures. Irrigation increases the amount of water available for plants to release into the air through evapotranspiration. When the soil is wet, part of the sun's

² Refer to the Municipal and Industrial sector for information on drought vulnerabilities of water providers

energy is diverted from warming the soil to vaporizing its moisture, creating a cooling effect. Watering restrictions can thus have the indirect impact of local warming as well as increasing dust in the air as soils become dry. Costs are associated with both impacts, including greater use of air conditioning and increased housekeeping and equipment maintenance to contend with dust. There are no concerns for CDOC facilities on the western slope and in the metropolitan Denver area (CDOC, 2013a). The CDOC does not anticipate serious water shortages for their agriculture program, as it is supported by relatively senior water rights. Their other specialty programs, such as the aquaculture, wild horse, and fisheries programs are on potable water systems and providers do not anticipate significant shortages in 2013 (CDOC, 2013b).

Table 5.2 State Buildings Impacts and Adaptive Capacities

Key Impacts to State Buildings	Key Adaptive Capacities or Mitigation Strategies
Increased exposure to wildfires	<ul style="list-style-type: none"> ● Coordinate with local officials ● Create a fire barrier (defensible space) and do additional pruning
Increased wear and tear on building exterior and HVAC systems due to air pollution	<ul style="list-style-type: none"> ● Identify which buildings are in high-risk areas and plan to replace or upgrade exteriors and HVAC systems as part of Operations and Management budget
Water shortages due to out-of-priority rights or restrictions imposed by municipality	<ul style="list-style-type: none"> ● Plan landscaping to incorporate drought-resistant or native plant species that are capable of surviving on reduced water. ● Limit access to stressed lawns during drought
Possible water shortages for correctional facilities and industry programs	<ul style="list-style-type: none"> ● Secure back up water supplies for facilities identified as highly vulnerable. ● Make sure drought plans are in place to react efficiently if water shortages do occur

5.3.2 Critical Infrastructure

Critical infrastructure refers to state-owned or operated infrastructure that could be impacted by drought. For this assessment, this covers water storage and delivery infrastructure such as: dams, transmountain ditches, and irrigation ditches. This does not cover all state-owned critical infrastructures, but focuses on those assets that could be directly impacted by drought.

The highest value critical infrastructure for the State is dams. Figure 5.4 shows the state-owned dams and water facilities. Transmountain diversions are vital conveyance infrastructure used to move water from one basin to another. In general, water is transferred from the western slope to the Front Range. Figure 5.5 outlines the major transmountain diversions in the State. It is important to note that these are not all state-owned projects.

Figure 5.4 State-Owned Dams as of 2015

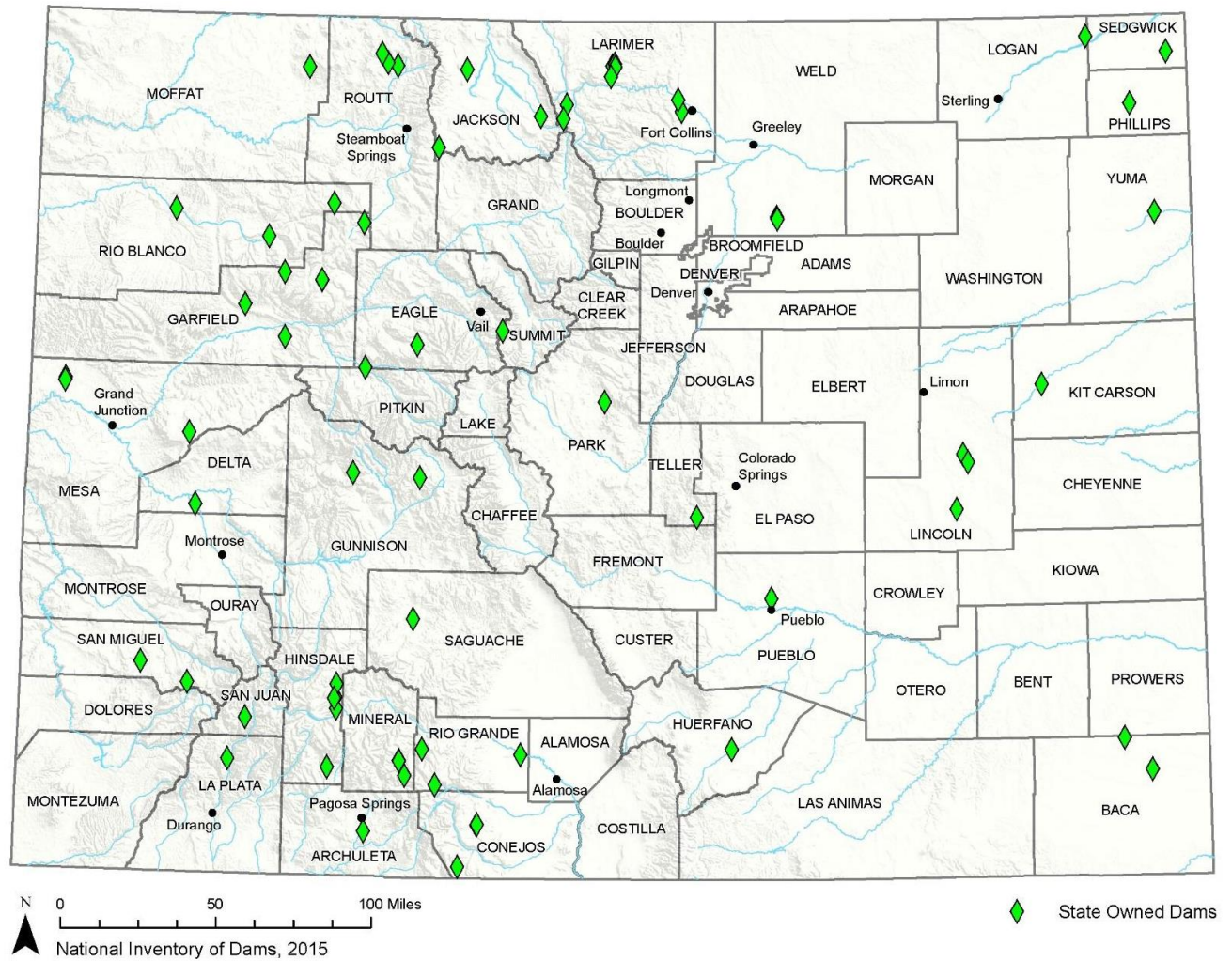
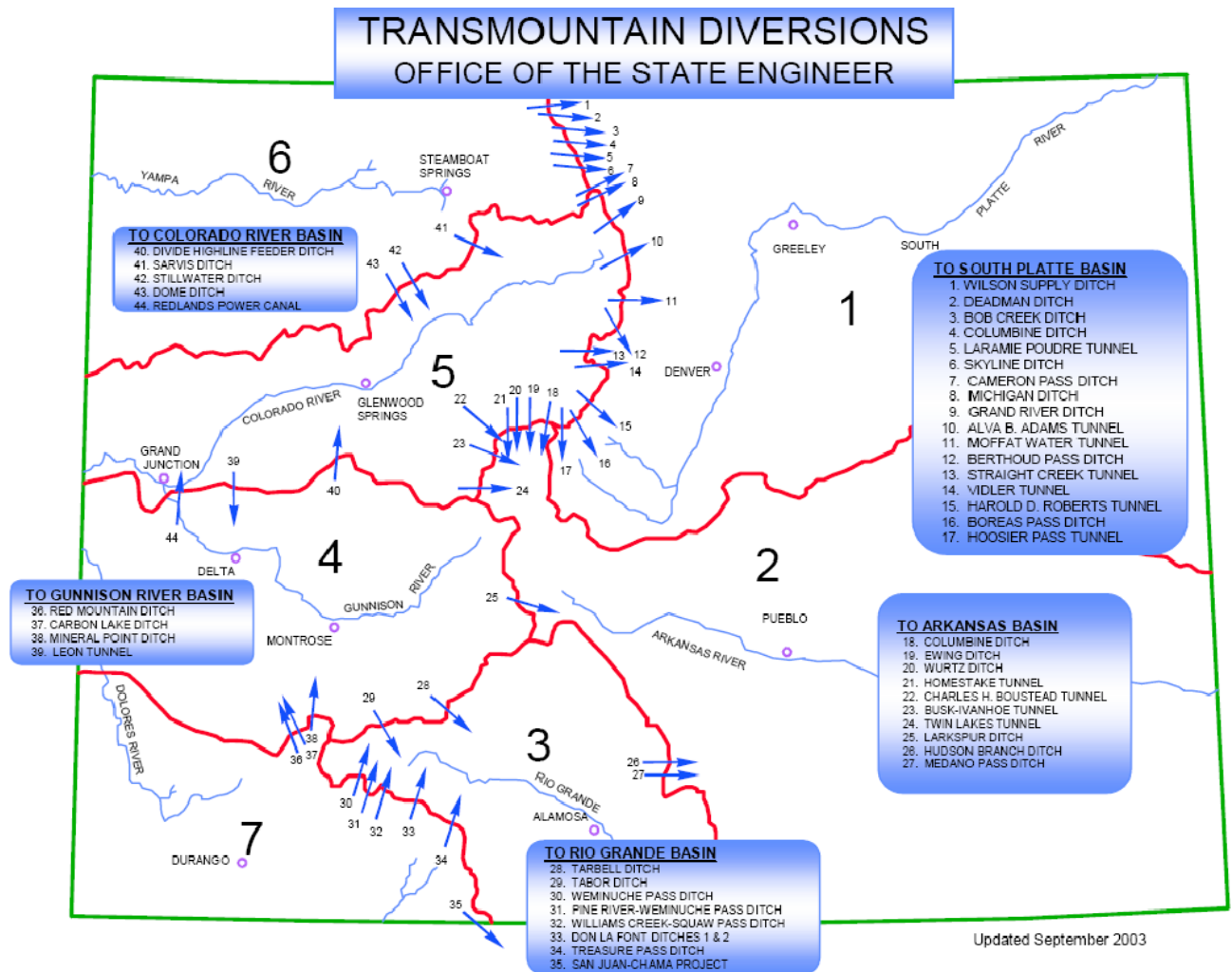


Figure revised 2018

Figure 5.5 Transmountain Diversions



Source: Byers and Wolfe, 2003

Drought has several primary and secondary impacts to critical infrastructure. Decreased water levels in dams and ditches can lead to structural damage as pore water pressure decreases. In personal communications with water commissioners, increased animal holes and overgrowth of ditches that remained dry for extended periods of time were cited. In general, increased maintenance and oversight are required for these structures during drought. In some cases, decreased water levels can be taken advantage of to perform maintenance on areas that would normally be submerged.

As reservoir water levels decline the sediment load increases. In severe cases this can cause damage to outlet structures and water treatment facilities. Water quality can also be impacted by drought induced wildfires which lead to debris flows and flooding. This can significantly impact structures, including potentially catastrophic damage to dams.

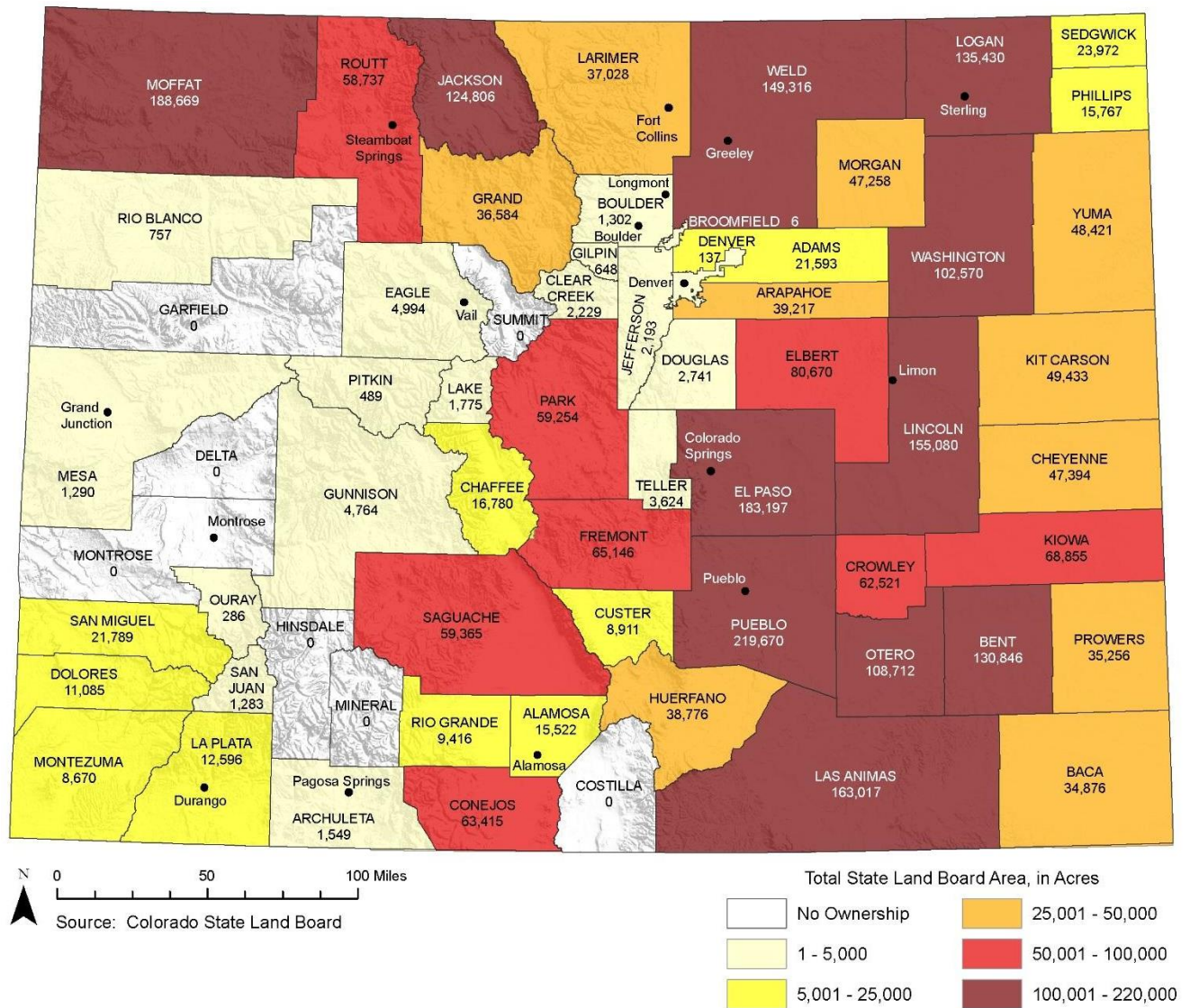
Table 5.3 Critical Infrastructure Impacts and Adaptive Capacities

Key Impacts to State Buildings	Key Adaptive Capacities or Mitigation Strategies
Decreased water levels in dams can cause structural damage	<ul style="list-style-type: none"> ● Take advantage of low water levels to conduct maintenance
Dry ditches can be damaged by animal holes and increased vegetative growth	<ul style="list-style-type: none"> ● Budget for additional ditch maintenance following drought
High sediment loading resulting from low reservoir levels or wildfires can damage structures.	<ul style="list-style-type: none"> ● Pre-emptive fire management in key supply basins ● Focused beetle kill management in key supply basins
Flash flooding following wildfires can damage structures	<ul style="list-style-type: none"> ● Pre-emptive fire management in key supply basins ● Focused beetle kill management in key supply basins

5.3.3 Land Board

The Land Board is responsible for managing more than three million acres of land and four million acres of mineral rights given to the State by the federal government in 1876. Figure 5.6 and Figure 5.7 show the total Land Board ownership by county for both surface and mineral rights respectively. As can be seen from these maps, distribution of state-owned land is greatest in the eastern half of the State. The State does, however, own surface and/or mineral rights in nearly every county in Colorado.

Figure 5.6 Land Board Area Ownership, in Acres



Source: Colorado State Land Board, data current as of 2018. Figure revised 2018

Figure 5.7 Land Board Mineral Rights, in Acres

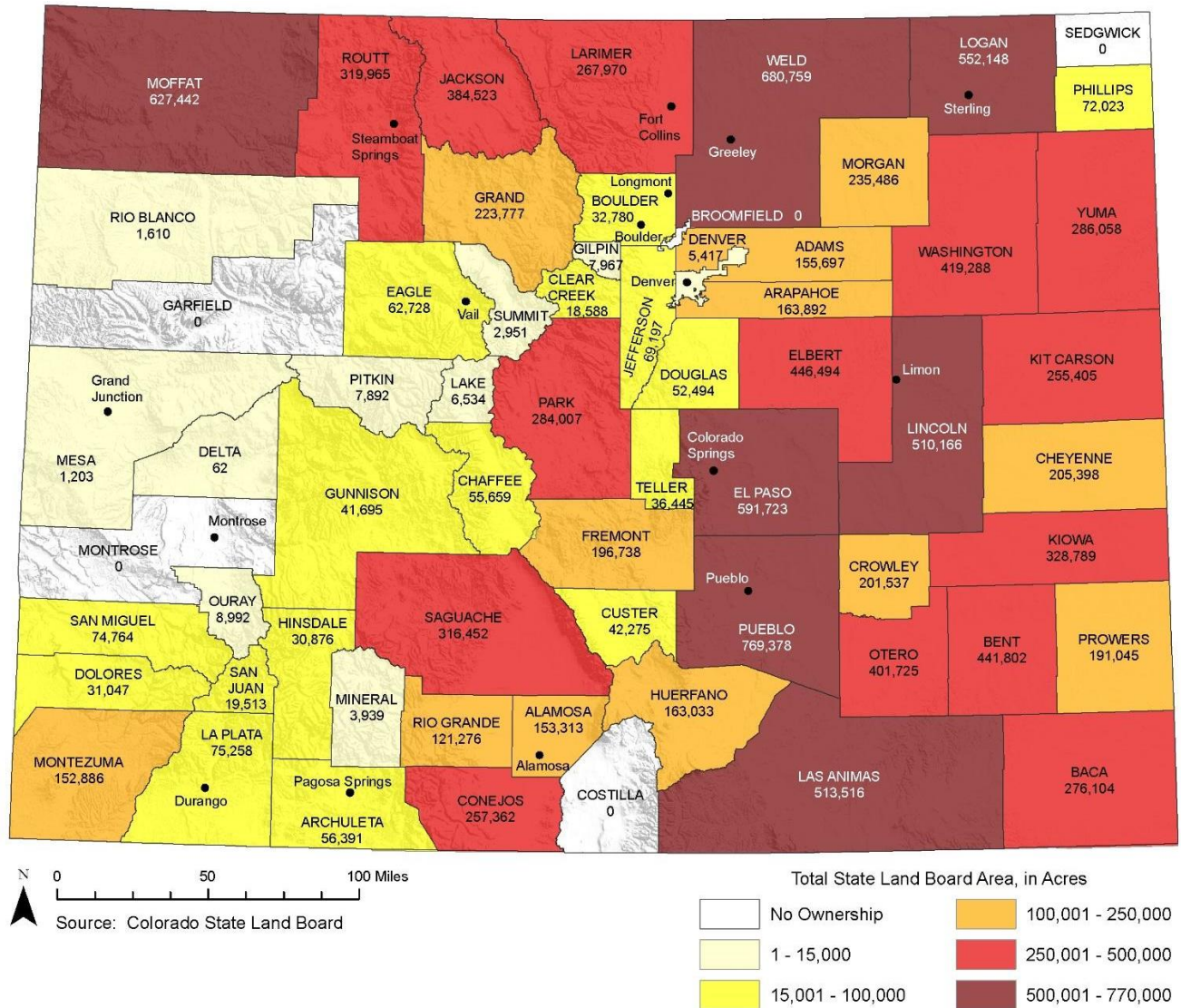


Figure revised 2018

The Land Board generates revenue by leasing land for agricultural and industrial activities. They also lease mineral rights and receive a significant portion of their revenue from mineral royalties. Revenue generated by the Land Board goes to public schools, parks, prisons, and other public buildings. In 2016 the State Land Board had 8,098 active leases covering 2.8 million in managed acres and 4 million acres of sub-surface land managed. Table 5.4 lists the eight trusts that receive Land Board funding and the total revenue generated for each in fiscal year 2016-2017. Public schools are by far the largest beneficiary. Table 5.5 gives the leasing revenue by source for fiscal year 2016-2017. Agricultural leases account for most of the land leases, but they do not generate as much revenue as the mineral assets and the oil/gas/coal royalties.

Table 5.4 Land Board Trust Recipients, FY16-17

Trust	Revenues	Percent of Total
School	\$118,356,860	99.12%
Colorado State University	\$721,346	0.60%
University of Colorado	\$46,584	0.04%
Internal Improvements (Parks)	\$144,427	0.12%
Saline Trust (Parks)	\$36,687	0.03%
Penitentiary	\$18,100	0.02%
Public Buildings	\$38,361	0.03%
Hesperus (Fort Lewis)	\$4,036	0.00%
Forest /Other	\$33,934	0.03%
Total	\$119,402,334	100%

Source: Board of Land Commissioners 2017

Table 5.5 Land Board Leasing Revenue, FY16-17

Gross Revenue Dollars by Source	
Agricultural Rental Income	\$3,908,112
Commercial Revenue	\$5,303,349
Gas Royalty	\$20,714,628
Oil Royalty	\$44,023,788
Coal, Limestone, Sand, Gravel, Water Royalty	\$8,942,276
Bonus Income	\$20,292,014
Net Operating Income	\$113,007,722
Total	\$134,267,740

Source: Board of Land Commissioners 2017

Table 5.6 outlines the key impacts and adaptive capacities of the Land Board during drought. Based on conversations with Land Board employees, mineral asset revenue is relatively drought tolerant. While it is likely that mineral producers may incur extra operating costs in a drought, it

is unlikely that the producing companies would actually stop operations or postpone planned expansion. However, most mining activities do require water. It is possible that in a severe drought, mining operations would be unable to purchase the water they need for production.³ Given the importance of mining revenue to the Land Board this possibility should be taken seriously in any planning efforts.

The most vulnerable revenue stream for the Land Board is the agricultural lease revenue. Under drought conditions the impacts to rangeland and resulting carrying capacity reduction can lead to serious overgrazing concerns and financial hardship for the agricultural lessees. Similarly crop yields on agricultural leases may be significantly decreased or, in extreme cases, crop failure may occur. Agricultural leases through the Land Board are issued on a 10-year basis making it difficult for farmers and ranchers to increase or decrease leased area in response to drought. However, the Land Board has a vested interest in the responsible stewardship of the land and may be willing to offer lease discounts during drought. The intent of such discounts would be to give land managers financial incentive to decrease land use intensity.

In the 2002 drought the Land Board found that forage production on some of their lands was down as much as 90-100% (Board of Land Commissioners, 2002). Given the severity of the drought and the widespread impact, the Land Board issued blanket agricultural lease reductions based on county-scale drought indices developed from the Standard Precipitation Index. Figure 5.8 shows the lease discount percentage per county that was applied between September 2002 and August 2003. This program was not offered during the 2011-2013 drought because it was discontinued in 2012.

³ Refer to the Energy sector for more information on mining

Figure 5.8 Land Board Agricultural Lease Discounts in 2002

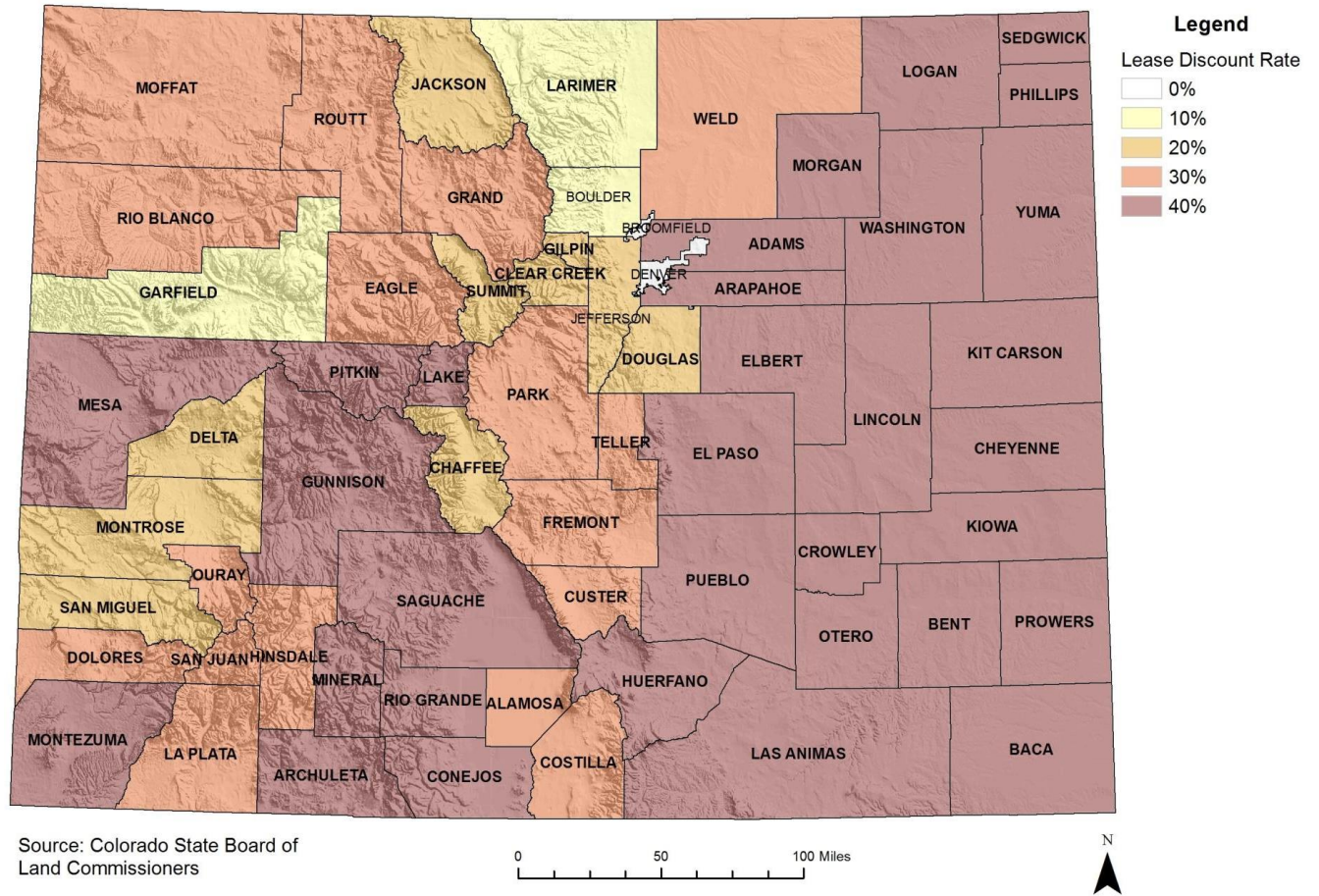


Figure from 2013

The total cost of the 2002 lease discounts was estimated by Land Board staff to be just over \$1.9 million (Board of Land Commissioners, 2002). Unfortunately, these discounts did not have the intended mitigating impact because many lessees continued to manage the land as usual despite the discount, and did not decrease grazing intensity. As a result of this experience, during future droughts the Land Board was intending to only offer lease discounts when applied for on a case-by-case basis because past experience had shown that lessees are personally involved in applying for a discount and negotiating terms with the Land Board. Unilateral discounts do not require communication on the part of the operator and are too extensive to be sufficiently monitored by the Land Board. However, this program was discontinued in 2012 and will not be available for use in future droughts. Given the nature of most lands owned by the Land Board, there is little that they can do to mitigate against dry land crop yield and forage decreases in drought.

This is a good example of the interconnectedness of the State Assets Sector with the other sectors. From the viewpoint of the Land Board, possible decreases in lease revenue represent drought vulnerability. This, in turn, is a vulnerability to all of the trusts receiving funding from the Board. However, from the viewpoint of agricultural lessees, the ability to negotiate lease terms in times of drought is an important adaptive capacity.

Table 5.6 Land Board Impacts and Adaptive Capacities

Key Impacts to State Trust Land	Key Adaptive Capacities or Mitigation Strategies
Decreased forage and crop yields on leased lands – negative impacts to lands if lessees don't appropriately adjust grazing management	<ul style="list-style-type: none"> ● Offer agricultural leases at discounted rates in return for decreased intensity of land use.
Decreased mining activity if water is not available for production	<ul style="list-style-type: none"> ● Increased drought planning by mining companies

5.3.4 Colorado Parks and Wildlife

CPW manages state parks, wildlife areas, 15 state fish hatcheries, and all species of Colorado wildlife (CPW, 2013). CPW also works to protect and recover threatened and endangered species, and conducts research to provide wildlife management and species protection information to the public and other land management agencies.

Figure 5.9 shows the location of all the state parks, colored according to the activities available. River corridor parks were designated as “River”, any park with fishing or boating activities listed was designated “Water” and parks without any boating or fishing activities were designated “Land.” Figure 5.10 shows the average annual visitation for each of the state parks. This map is instructive from a statewide perspective and shows that the most popular parks are located in urban areas. However, it is important to note that smaller parks in less developed areas often contribute proportionally to the local economy. Further discussion on the impacts to areas surrounding state parks is included in the Socioeconomic Sector. Figure 5.10 highlights the fact that visitation can vary by orders of magnitude from park to park. Revenue is also generated by river outfitter

licensing and rafting trips. CPW gets a portion of all rafting trip revenue for trips that go through state parks.

CPW's influence is primarily focused in the western half of Colorado, but the CPW also has important lands in the Northeast and Southeast of the State. The land within CPW is owned by multiple entities/agencies divided into: Land Board, CPW, US Army Corps of Engineers, US Bureau of Reclamation, local government/other, irrigation companies, and US Forest Service/Bureau of Land Management (CPW 2013). In addition to land management and ownership, CPW owns the facilities within state park boundaries (e.g., visitor centers and restrooms) and two marinas. CPW also holds numerous construction easements on lands.

The CPW operating budget comes mainly from licenses, passes, fees and permits; lottery and Great Outdoors Colorado (GOCO) funds; and Federal and State grants. Table 5.7 shows the contribution of various revenue sources to CPW for fiscal year 2016-2017.

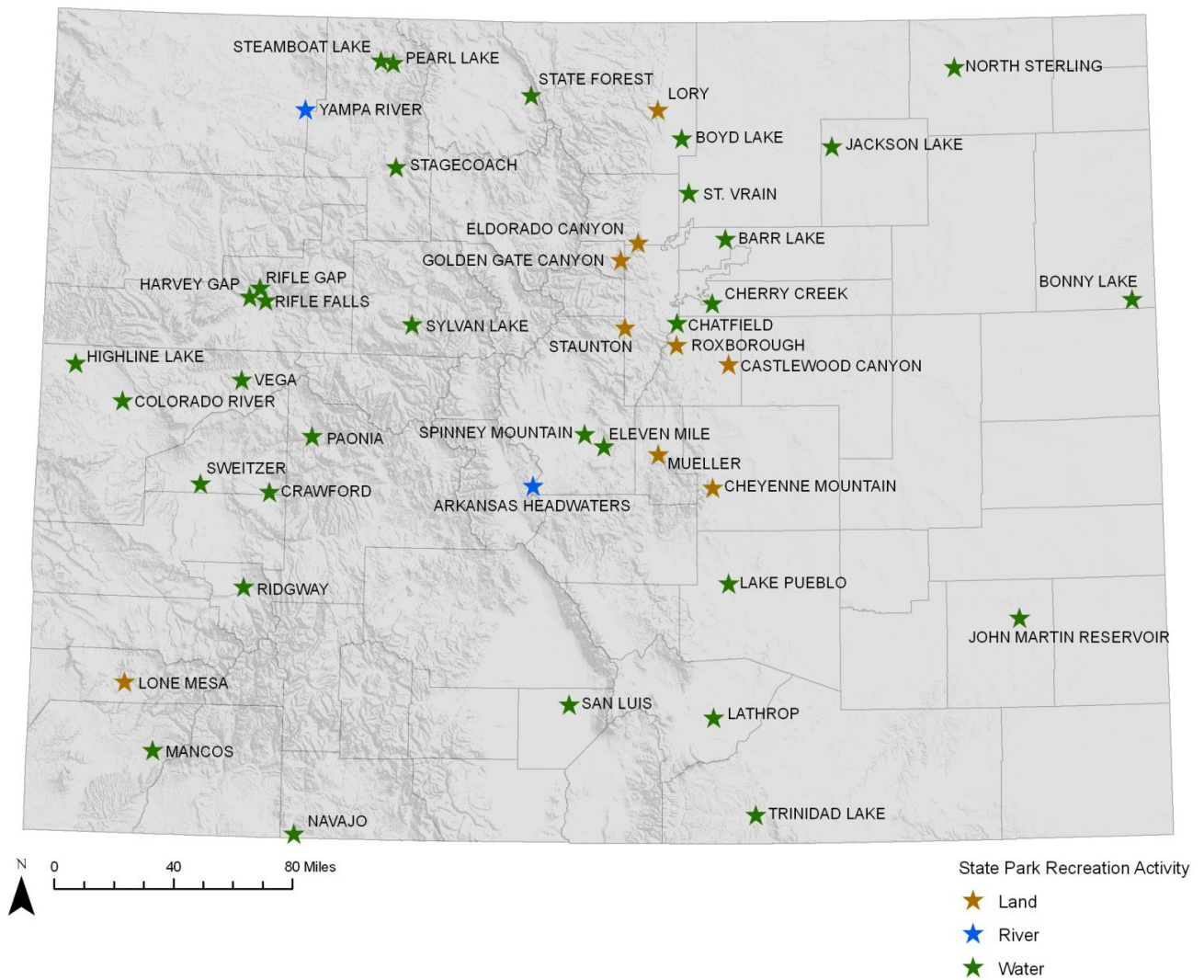
Table 5.7 CPW Funding 2016-2017

Source of Revenue	FY 16-17 (\$millions)	% of Total
Licenses, Passes, Fees and Permits	\$114.0	54%
Lottery and Great Outdoors Colorado	\$39.6	19%
Federal and State Grants	\$30.8	15%
Registrations	\$9.3	5%
Sales, Donations, Interest, and Other	\$9.7	4%
General Fund and Severance Tax	\$9.0	4%
Total	\$212.4	

Source: CPW 2017
Figures shown in millions

The CPW construction budget, which is different than the operating budget, is funded primarily by lottery money and by the GOCO fund. These funds are less variable and not reliant on visitation numbers. Based on conversations with CPW employees, the operating budget is much more drought vulnerable than the construction budget. This study did not specifically investigate the impacts of drought on lottery and Great Outdoors Colorado. Further work is needed to understand drought impacts on these funds and how such impacts can translate into changes in funding for CPW. It is also important to note that even if funding stays constant, drought conditions may put a strain on the construction budget. This could occur if drought-related facility modifications (e.g., extending boat ramps) or repairs are required.

Figure 5.9 State Parks Locations and Activity Types



Source: CPW website 2010

Figure 5.10 Total Annual Visitation to State Parks, 2017

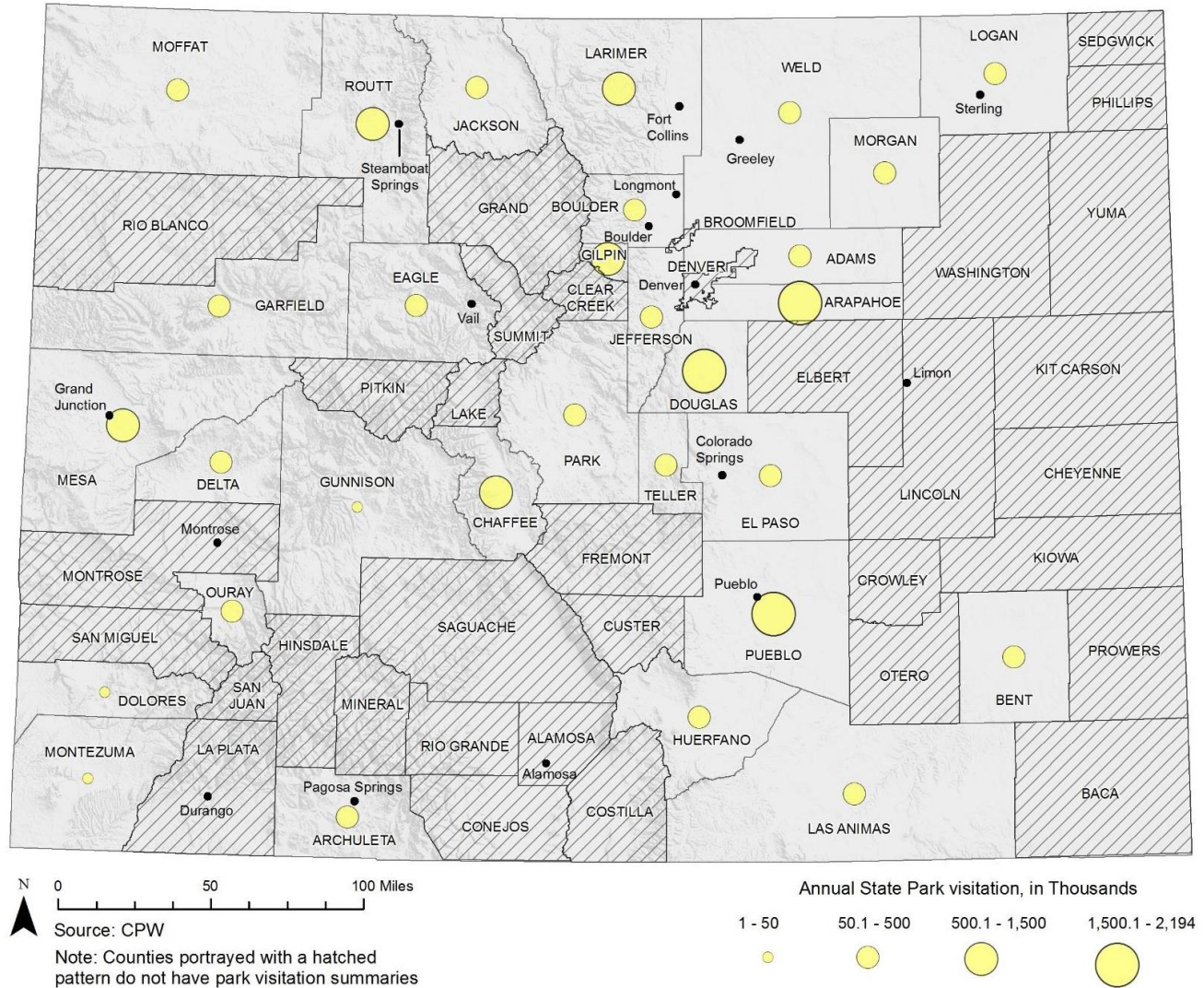
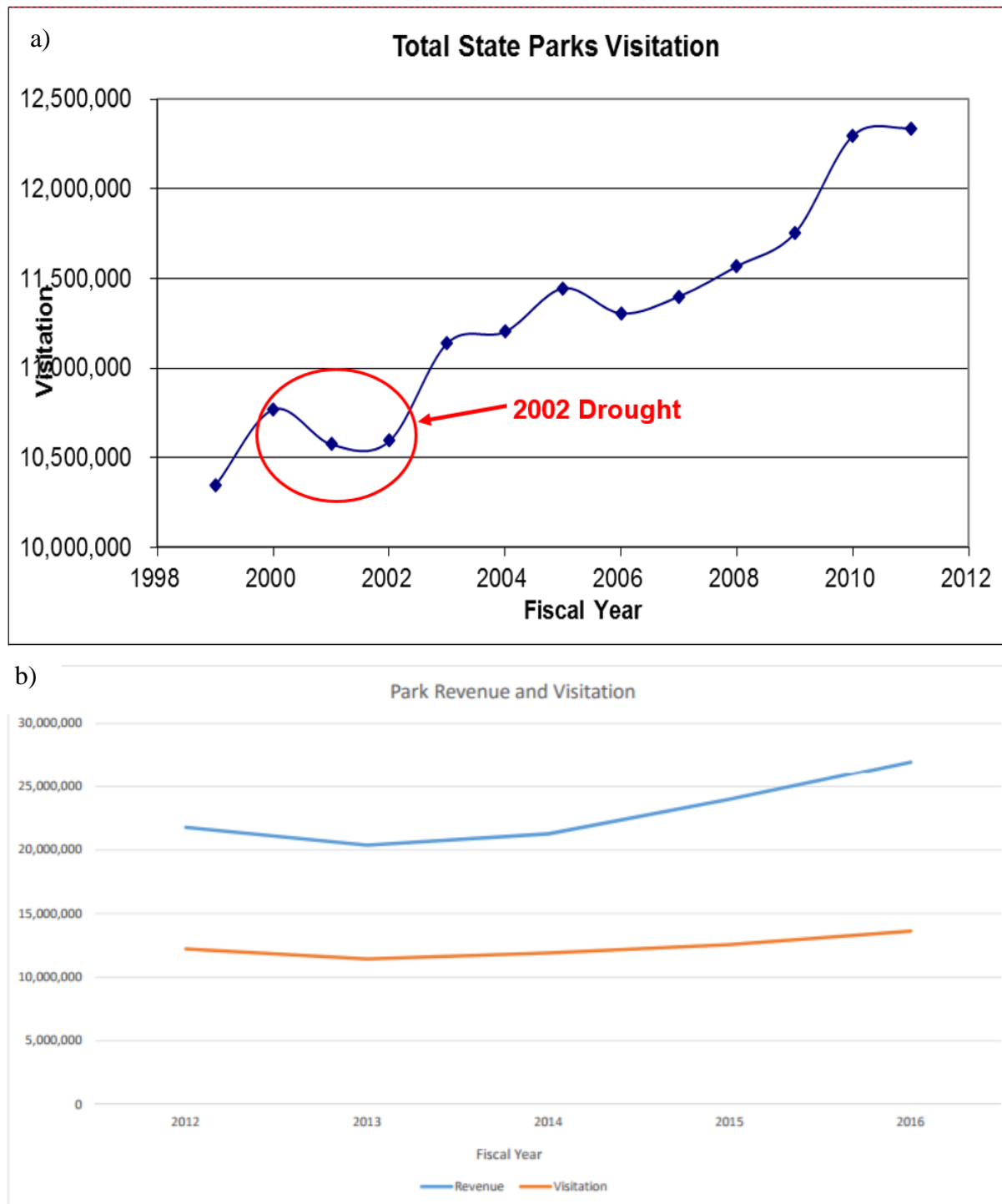


Figure revised 2018

In the past, CPW has been impacted by drought in various manners. One manifests itself in reduced visitation numbers. Boating and fishing are two of the biggest activities in the State parks and are directly impacted by lower reservoir levels. Boat ramps can become unusable if reservoir levels drop below a certain point. Camping at water-based parks can decline as a result. Because CPW operating revenue is so dependent on park pass sales, this impact is felt almost immediately. Parks with water-based activities are most vulnerable to this initial impact because of the direct drought vulnerabilities of these facilities. However, land based parks are not immune to initial drought impacts. Hiking and wildlife viewing experiences may be compromised as a result of drought-related environmental degradation. Access may be restricted to sensitive areas to protect stressed ecosystems.

Around the time of the 2011-2013 drought, several state parks experienced significant decreases in visitation, including: Castlewood Canyon, James R Robb Colorado River, Pearl Lake, and North Sterling. Figure 5.11 summarizes park visitation from 1998 to 2016, split amongst two graphs based on time periods. Figure 5.11 a) shows a clear decrease in state park visitation during the 2002 drought, while Figure 5.11 b) highlights stalling/slight negative change during the 2011-2013 drought event. It is estimated that state park visitation was down about 5% overall in the summer of 2002, which equates to a total loss of about 1 million visitors (Luecke et al., 2003). However, it should be noted that this loss is most likely not fully attributable to drought. For example, it is unclear how to separate potential visitors whose recreational budgets were impacted for various reasons from those who could not recreate because of drought affecting those recreational activities. Other factors such as decreased travel following September 11, 2001 could also have contributed to the 2002 visitor decline. Similar statements could be made about much of the drought impact data used throughout all sectors of the vulnerability assessment. Careful interpretation of data is required to determine if impacts are actually drought related or just coincidental. While it is impossible to completely separate drought-related impacts from other factors, by interviewing knowledgeable people, for example, a sufficient degree of accuracy can be achieved. In the case of visitor decline to State Parks in 2002, employees confirmed that the visitor decline was mostly drought related, but there were other factors involved as well.

Figure 5.11 Annual State Park Visitation



Source: CPW, 2017

Another impact involves the increased risk of forest fires due to drought. This impacts CPW in several ways. As wildfire risk increases, fire bans may be necessary which can negatively impact camping. If a forest fire actually reaches a state park, the park will be closed and all visitor revenue

will stop for the duration of the wildfire event. Even after a fire is extinguished visitation may be slow to return to normal levels as a result of public perception. Even when state parks are not in direct danger of wildfire, they can be impacted by public perception that the parks are closed. In the 2002 drought, national forests in Colorado were closed. State parks remained open, but the public was not aware of this distinction and assumed state parks were also closed. Visitation numbers also dropped sharply after Governor Owens' comment that "all of Colorado is burning" (June 9, 2002). During the 2012 wildfires, particularly the High Park, Flagstaff, Springer and Waldo Canyon fires, smoke and road closures nearby resulted in numerous reservation cancellations for campgrounds and day-use areas (CPW, 2012). Though there have not been any national forest closures of the same magnitude as the 2012 forest closures, fires in 2016 and 2017 prompted numerous trail and road closures. In the summer of 2017, the 412 Fire in San Juan National Forest closed a portion of the Colorado Trail. In 2013, Highway 160 over Wolf Creek Pass was closed during the West Fork Fire Complex. Additionally, the Beaver Creek Fire in 2016 prohibited access to hunting roads northwest of Walden. These are just a few examples of significant national forest restrictions caused by wildfire.

Beetle kill can also impact state park campgrounds and hiking trails by forcing them to close during tree removal, which can be a safety hazard. Forests, such as White River and Rocky Mountain National Forests, are being heavily impacted by beetle infestation, and portions of numerous parks throughout Colorado were closed for dead tree removal (Hartman, 2009).⁴ Refer to the environmental sector for additional information on forest health.

Species and habitat managed by CPW are also affected by drought. During the 2002 drought, the Wildlife Impact Task Force chaired by the CPW (then the DOW) set the following priorities to protect and conserve: 1) threatened or endangered wildlife populations such as greenback cutthroat trout or Colorado River native fishes; 2) wildlife populations that are at risk of being listed as threatened or endangered such as Rio Grande cutthroat trout, eastern plains minnows; and 3) recreationally significant wildlife populations such as tail-water trout fisheries. Although the Wildlife Impact Task Force was not activated in 2012, these priorities are expected to remain the same during future droughts. However, the specific species of priority to fit these criteria will need to be revisited at the onset of future drought events.

Long term drought impacts to wildlife and their habitats are complex and often not well documented, while short-term direct impacts to species and habitats are easier to detect. For example, increases in the presence and spread of noxious or pest weed infestations in priority habitats during drought may be difficult to quantify because of a lack of baseline data to compare to.

Aquatic species are especially vulnerable to drought. They are impacted by low water levels, increased water temperatures, and decreased water quality. During the 2002 drought, streams throughout the State were identified and prioritized so that CPW could rescue critical species at

⁴ For more information on beetle kill and drought refer to the Environmental Sector

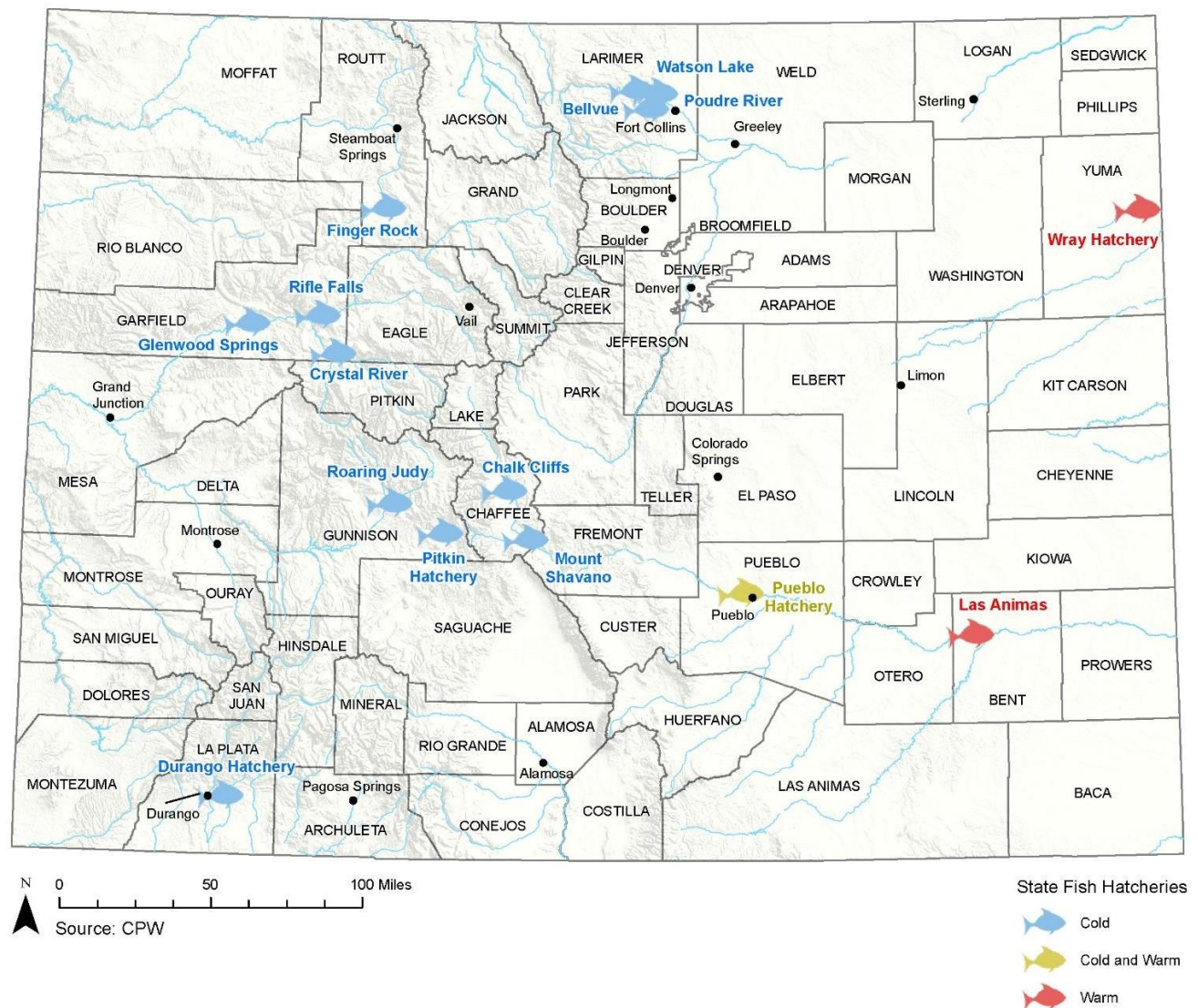
risk, such as genetically pure strains of cutthroat trout. Brood source cutthroat trout were captured from pools within various, at-risk headwater streams and transported manually to the Pitkin Fish Hatchery. The Pitkin Fish Hatchery has a quarantine facility which allowed for rescued wild cutthroat trout to be held temporarily while not compromising the health of existing hatchery fish at the facility. Several other fish populations had to be salvaged from areas no longer providing suitable habitat. For example, the Greenback Cutthroat trout population was salvaged from Como Creek and transferred to a nearby lake environment. Similarly, Roundtail Chub were moved from La Plata and Mancos Creeks to the Mumma Native Aquatic Species facility. Other populations were destroyed, as was the case with several Cutthroat Trout populations in the Rio Grande and the trout fishery in Antero Reservoir (DOW Staff, 2009; Luecke et al., 2003). It is important to note that over 94% of the lakes, reservoirs, and pond acreage in the South Platte River basin are man-made, which means that CPW does not control the water interests and that fisheries are secondary to the primary use of the water, typically municipal/industrial or agricultural. As a result, these water impoundments have to be managed from a recreational fishing perspective. Finally, streams that are designated to be “gold medal” fisheries, due to their large fish size and biomass characteristics, are typically streams that are in good ecological condition and better able to resist the impacts of drought. Accordingly, these streams were not considered to be as vulnerable to the impacts of the 2002 drought as streams containing populations of genetically pure wild cutthroat trout.

As shown in Figure 5.12 there are a total of 15 hatcheries in the CPW, state-owned system that breed, hatch, rear, and stock over 90 million fish per year. The vulnerability of a specific hatchery depends upon its water sources and operating procedures. Of all the hatcheries, most are groundwater-fed, relying on a groundwater well as the primary water supply, while only two rely on surface water for their primary water supply. The hatcheries that rely on surface water are the Chalk Cliff Hatchery drawing water from Chalk Creek, and the Watson Lake Hatchery drawing water from the Poudre River. There are two fish hatcheries in Colorado that are included on the list of National Fish Hatcheries owned by the U.S. Fish and Wildlife Service: Hotchkiss National Fish Hatchery in Delta County, and the Leadville National Fish Hatchery in Lake County. Finally, Las Animas Hatchery and Wray Fish Hatchery are two warm water hatcheries, producing brood fish such as channel catfish and largemouth bass. The Pueblo Hatchery is the only cold water and warm water facility in Colorado.

During the 2002 drought, all hatchery fish from the Watson Hatchery had to be rescued and relocated to a hatchery with isolation and quarantine facilities. In 2012, CPW experienced a loss of water supply for several hatcheries. Additionally, wildfires have impacted hatcheries, as debris flows have increased sedimentation, reducing viable habitat and food sources for hatchery fish. Catchable sized trout were removed from the Watson Hatchery, located on the Poudre River, in order to prevent fish kills. These fish were relocated to areas with improved water quality, e.g., Horsetooth and Carter Reservoirs. A large portion of CPW’s capital construction budget is targeted at maintaining and/or improving our hatchery facilities and the water supplies that support them. For example, CPW has been diligent since the latest drought event in looking for opportunities to

improve recovery systems, aeration systems, and operating efficiencies that will allow the hatcheries to function at lower flows. In addition, CPW is also diligent in searching for new sites for eastern plains hatcheries that have the potential for both warm water and cold-water facilities. This process involves evaluation and acquisition of water rights, land, and infrastructure, and the potential to improve CPW's capacity to protect and maintain eastern plains fisheries.

Figure 5.12 State Fish Hatcheries as of 2017



Source: CPW website. Figure updated 2018

Aquatic species, especially fish, may be very sensitive to municipal and industrial wastewater effluent, particularly during low flow times when waters have diminished volume or flow with which to dilute pollutants. This can have detrimental effects on native fish species as well as lucrative sport species. The 2002 drought illuminated the inability of water quality and water quantity legislation to respond to drought coherently because they are managed in two separate arenas. For example, wastewater treatment operators were legally allowed to continue discharges into state waters experiencing very low flows even though discharge calculations were completed for flow levels higher than the flow levels at the time. When and where these situations actually occurred and whether such conditions impacted aquatic life was difficult to assess in real time, making monitoring a difficult and reactive task. Many new water transactions and management plans have been developed since 2002 and impacts from future droughts will probably not parallel past experience. Colorado's water quality regulations do not provide a framework for overall review of water-quantity projects nor can they inhibit the exercise of water rights. Similarly, water-quantity regulations cannot incorporate literal water-quality considerations. As such, future planning and education efforts are needed to reduce the potential for water-quality impacts and conflicts.

In 2007, the Colorado Water Quality Control Commission adopted revised water-quality standards for protection of aquatic life. The standards include an acute standard (a 2-hr daily maximum) for protection from lethal effects of elevated temperature and a chronic standard (a maximum weekly average temperature) for protection against sub-lethal effects on behavior. The standards also include seasonal adjustment for protection of spawning, and they include a narrative requiring that temperature maintain a normal pattern of daily and seasonal fluctuations and spatial diversity with no abrupt changes. Colorado's revised water-quality standards for temperature did not exist during the 2002 drought. Further, a low-flow exclusion allows for temperature exceedances when the daily streamflow falls below an acute low flow or when the monthly average streamflow falls below a chronic critical low flow. The basis of Colorado's temperature standards in species-specific physiological tolerances to elevated temperature suggests that the standards will provide a useful benchmark against which to evaluate whether elevated temperatures resulting from drought conditions are likely to contribute to deleterious effects on fish communities. The implementation of the temperature standards has prompted an increase in temperature monitoring, which will likely facilitate better evaluation of the influence of drought-associated flows and elevated temperature on fisheries during future drought conditions.

In addition to temperature monitoring, CPW staff have been intensively monitoring flow and dissolved oxygen levels at many rivers and streams throughout the State in response to the 2011-2013 drought. With this increased effort, they are able to proactively implement fishing restrictions and/or closures, thus reducing fishing pressure on already stressed fish. CPW continues to remind anglers to fish early in the day, and to monitor water temperatures throughout the day, moving on when temperatures rise above 68 degrees Fahrenheit (CPW, 2012).

In responding to the 2002 drought, CPW learned that instream flows were not as adversely affected as one might expect, since low water supplied during the extreme drought resulted in a shift in

typical water right administration and water use patterns. In 2002, there were significantly fewer depletions from junior water rights, and the calling senior water rights were farther downstream, thus having the effect of pulling water downstream through the watershed; the junior intervening in-stream flow water right became the unintended beneficiary of this pattern of water right administration. As a result, a number of higher order streams (first, second, and third order streams) experienced water levels greater than or equal to what is typically experienced under normal water supply conditions. Further, the 2002 experience highlighted the need for CPW and CWCB to increase their cooperative efforts regarding management of CPW's water right portfolio. In particular, communications should address the use of reservoirs and storage water rights to examine the feasibility of releasing water to protect instream flows.

For the 2011-2013 drought, CWCB's instream flow program, DWR and CPW helped mitigate low stream conditions on the White River. In June of 2012, CPW was approved by the DWR to perform an emergency release into the White River from Lake Avery to support the White River Fishery and to maintain instream flow levels. Ultimately, the release was not needed due to cooperation between local landowners and beneficial rains that followed in July and August, but the approved lease agreement is in place if needed in the future (CPW, 2012). In addition, Steamboat Lake released to the Elk River to help protect Mountain Whitefish spawning in late 2012.

With regard to drought vulnerability and impacts on terrestrial ecosystem, many land-based animals are impacted by food supply reductions during drought. This can lead to greater susceptibility to disease, expansion into areas of human development, and decreased birth rates. Little is known about the impacts to specific species during the 2002 and 2011-2013 droughts. In general, the droughts had limited impact on big game populations; however, it did have consequences for bird production including pheasants, quail, and waterfowl species. CPW was insufficiently staffed to monitor conditions and could only conduct follow-up reconnaissance during scheduled monitoring the following year (CPW Staff, 2009). Unfortunately, when personnel effort is most needed to understand impacts of drought, CPW staff often have other, more pressing responsibilities. Coordinating efforts with other conservation agencies can help minimize staff requirements for the CPW. For 2011 and 2012, CPW observed a number of drought impacts to terrestrial species. Generally, reductions in food and habitat have weakened and/or altered the behavior of many species. Black bears are emerging earlier from their dens, and bear-human conflicts slightly increased in 2012 (CPW, 2012).

Birds from several different ecosystems have been impacted by the drought. In 2012, Lesser Prairie Chicken numbers decreased by 35% from 2011, partially due to the lack of recruitment into the population. Emergency grazing on Conservation Reserve Program lands has also contributed to the loss and degradation of habitat, including the ability to provide cover, nesting habitat or feeding. In 2013, the *Ag Journal* reported a reduction in the population of ground-nesting birds. Due to the drought, the government released Conservation Reserve (CRP) acreage in 22 counties land to be hayed and grazed by farmers and ranchers, which led to the destruction of the nesting grounds of several birds that live in the CRP land. Pheasants and quail populations declined 70%

(Krebs, 2013). Habitat for upland game birds was severely diminished, as the 2011-2013 drought affected their food, water, and cover. While waterfowl breeding was poor in many areas of the State such as North Park, the San Luis Valley and the Yampa/White River area, the largest impacts to waterfowl are expected to result from changes in migration, e.g., birds are traveling farther north instead of wintering in Colorado because the habitat conditions required to attract them are deteriorating due to drought (CPW, 2012). An option to mitigate this is to develop ways to keep some stock water tanks filled even when ranchers de-stock cattle and to provide wildlife ladders so wildlife species have access to water during drought conditions.

From 2011 to 2013, pronghorn antelope herds in southeastern Colorado experienced reduced recruitment, as well as changes in their spatial distribution. In this case, the drought helped to bring large populations of pronghorn antelope in this area of the State to more sustainable levels (CPW, 2012).

Operational procedures also impact CPW drought vulnerability. Previously, annual passes to state parks were sold based on a calendar year, regardless of when the pass was purchased. As a result of this policy, annual passes were generally purchased early in the year. By the time the 2002 drought became big news, a large number of annual passes had already been sold. In recent years, the park pass policy has changed so that annual passes are good for 12 months from the date of purchase. This policy could result in more people buying passes later in the year. If this is the case, annual pass revenue may be more vulnerable to drought than previously noted, as a majority of passes are likely to get sold at the start of summer, at which time possible park pass buyers may have been alerted to drought conditions and hence not purchase a pass.

Past reactions from CPW management included laying off or not hiring temporary workers and stopping any irrigation to park lands. When reservoir recreation is threatened, CPW can lengthen boat ramps to allow reservoirs to remain open under lower water levels. During the 2002 and 2011-2013 drought periods, state parks experienced increased camping reservation cancellations. In previous years there were no cancellation fees and therefore cancellations would have been a 100% loss. However, in January of 2002, the department enacted cancellation fees. As a result, CPW was able to generate some revenue from cancellations.

One key mitigation strategy for future droughts is effective public relations to ensure the public receives correct information. In the past, CPW did not employ a full-time public relations person to control the message sent out to the public. However, communications improved between agencies after the 2002 drought, as well as during the latest drought in 2011-2013. Development of a formal communication plan for drought may be considered by the CWP in the future.

During drought, there are opportunities to expand the CPW system. In times of stress, land values are often reduced. National parks and forests may consider selling some land. If prepared, CPW can capitalize on these scenarios to expand. It is possible that acquisitions may also increase adaptive capacity by increasing recreational areas (i.e., revenue sources) and expanding habitat.

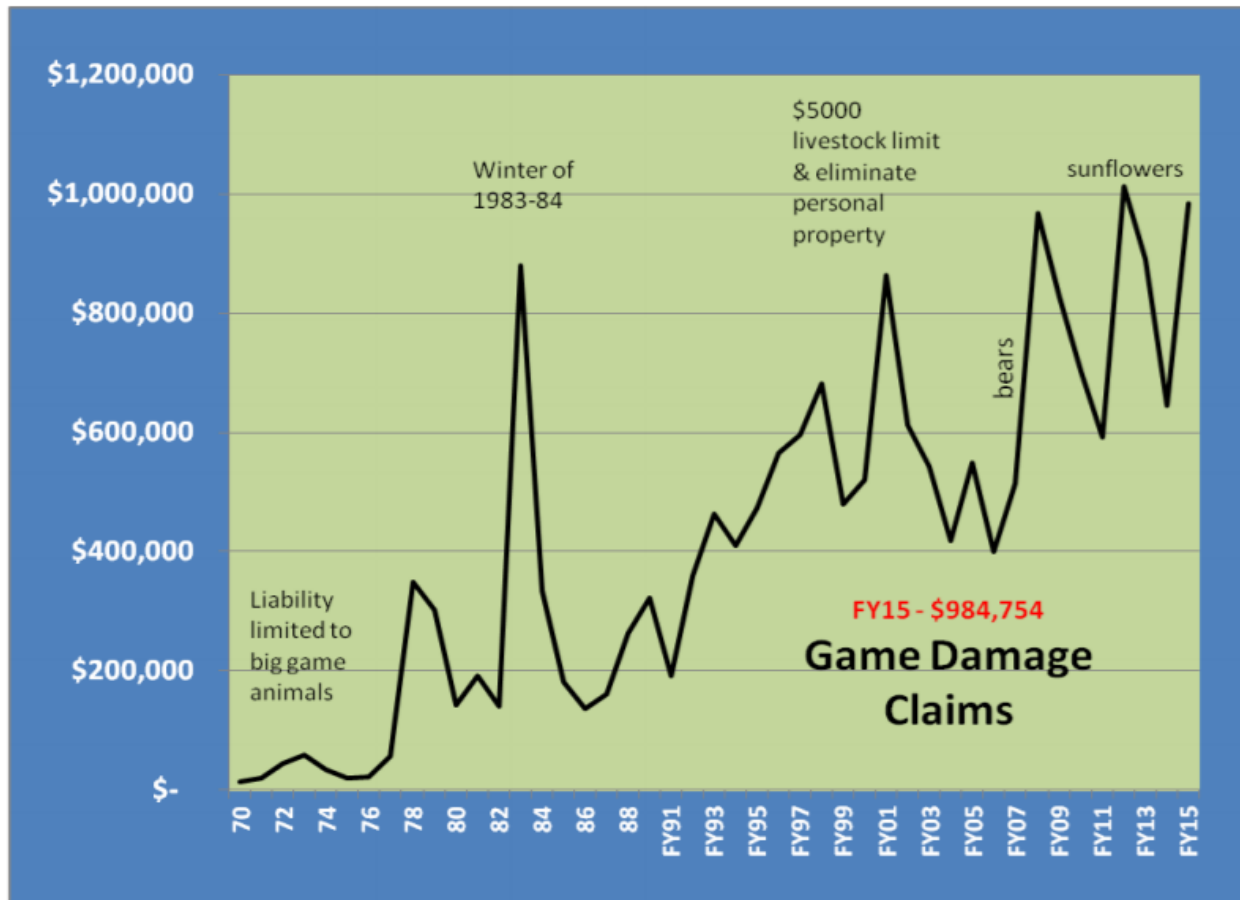
The potential impact of any land acquisition would be highly dependent on the planned land use and its location.

The adaptive capacity of CPW is not static and is in many ways dependent on economic conditions. As discussed above, if operating budgets are decreased, either for drought or non- drought related reasons, CPW may decrease staff. Decreased operating budget decreases options for responding to drought. Furthermore, without adequate staff the ability to react efficiently is impaired.

However, during a drought, management demands on the CPW are high. Staff stated that during the 2002 drought many individuals went months without any days off (DOW Staff, 2009). Manpower was needed across the State to respond to bear conflicts and species in distress. For vulnerable native fish populations, the time between identification of severe stress and salvage/rescue is very short thus mandating quick action and on the fly responses (DOW Staff 2009).

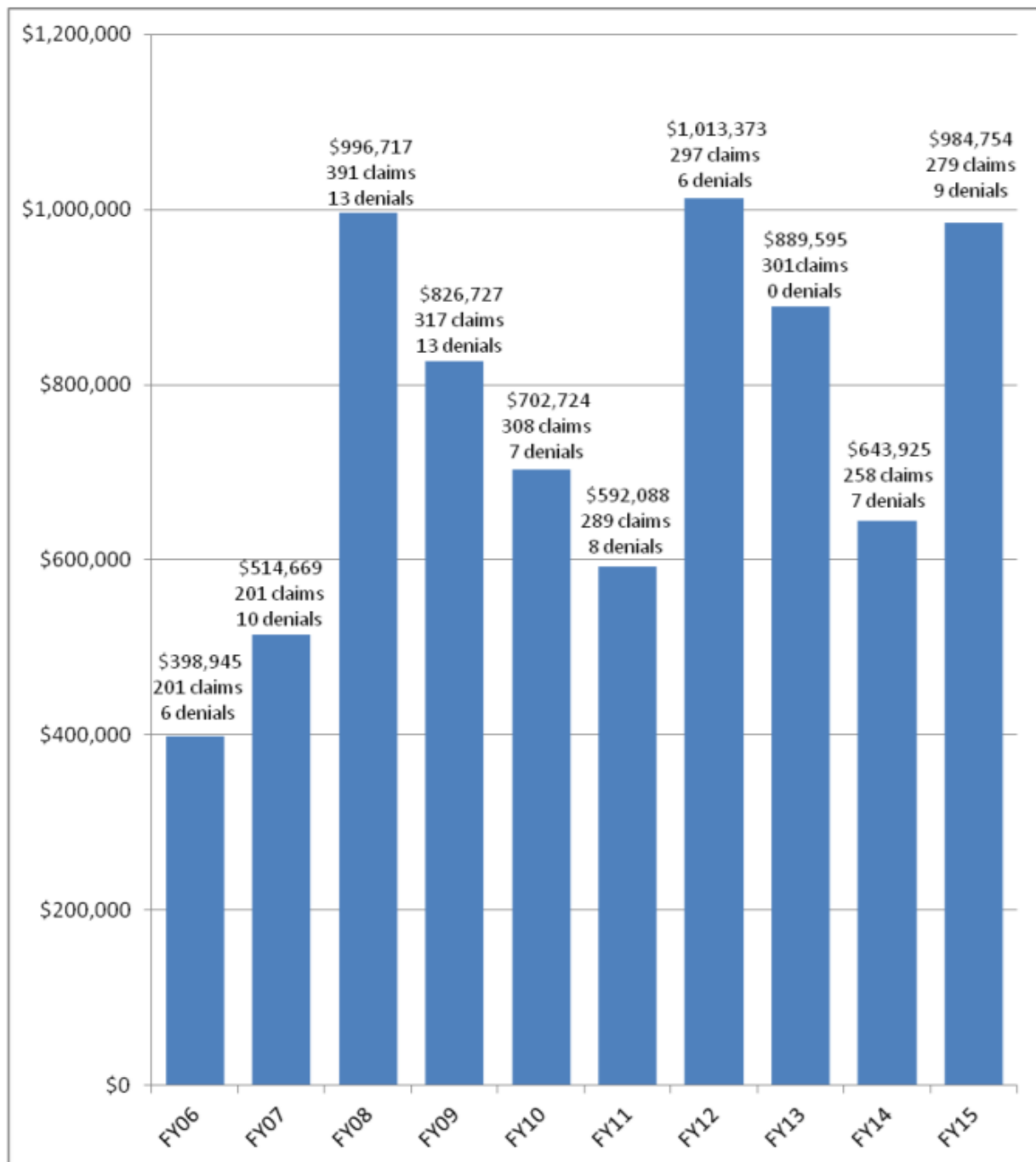
CPW pays damage claims when big game animals (e.g., elk, deer, bear, mountain lion, pronghorn antelope, moose and bighorn sheep) damage private property. Figure 5.14 shows the total annual big game damage claims from 1970 to 2015. Figure 5.14 summarizes the 2006-2015 years with specific claim totals as well as number of cases denied. There was a clear spike in damage claims around the time of the 2002 drought, and an even larger increase around 2012. For the four years prior to fiscal year 2011 to 2012, the average game damages paid by CPW was \$769,459 to pay 304 annual claims. In 2011 to 2012, that number increased to \$1,013,373 on 297 game damage claims (CPW, 2012b). Comparing these figures to a non-drought year, in FY15, the number decreased slightly to \$984,754 in settlement of 279 claims (CPW, 2015). While it is reasonable to attribute the 2011-2012 claim increases to drought, due to dry conditions potentially disrupting the animals' habitat, water, resources, and food, causing them to migrate and damage human property, further verification is needed to more accurately determine if there are additional causes for this change in statistics. No quantitative estimates are available for the past or future costs of restocking destroyed fisheries and re-establishing rescued populations. It is recommended that CPW create a monitoring plan to better quantify species impacts in future droughts. As part of these efforts they should track costs associated with species preservation both during a drought and for reclamation efforts following a drought.

Figure 5.13 Annual Game Damage Claims



Source: CPW 2015

Figure 5.14 Annual Game Damage Claims 2006 - 2015



Dollar amounts do not include operating/administrative costs

Source: CPW 2015

There is little evidence that CPW experienced large drought-related decreases in licensing revenue in 2002. Fishing license sales remained constant and hunting license sales actually increased in 2002. Fearing that many elk would not survive the winter after being seriously stressed by drought

conditions, CPW released 16,000 extra cow elk hunting licenses in September (Luecke et al., 2003). Bear licenses were reduced due to concerns about the low vigor of female bears going into hibernation. Several voluntary angling closures were instituted to minimize impact to stressed salmonids. For more information on the economic impacts of hunting and fishing, see the Recreation Annex.

Controlling license sales does impact revenue, but it allows for adaptation to changes in animal populations. Fish losses can be offset by relocating populations and stocking other areas or restocking damaged areas after the drought (State of Colorado Water Availability Task Force, 2002). CPW also has an emergency process that allows the director to close areas to activity in times of stress (DOW Staff, 2009). Many of the adaptive measures taken during previous droughts were responsive in nature. In the future, adaptive capacity could be increased by focusing efforts between droughts on making habitats more drought resistant.

In 2008 the Colorado Division of Wildlife partnered with the New Mexico Game and Fish Department to determine areas of crucial wildlife habitat. To avoid population declines, these habitats have been identified as areas that provide connections among different habitat areas used by fish and wildlife. The Colorado-New Mexico Border Region Decision Support System Pilot Project provides information on crucial habitats and wildlife movement corridors along the border region. The development of this tool represents an important shift in regional planning and provides access to data and planning that can help inform adaptive measures or can be utilized in a drought as a way to prioritize response strategies.

Also, looking for opportunities to increase the capacity for monitoring during non-drought years will provide a better understanding of baseline conditions and allow for better quantification of impacts in the future. Monitoring the wide range of habitats and species CPW manages is no small task and was probably an unrealistic goal given 2013 resources. However, there are other groups like the Nature Conservancy and Colorado State University that do similar work and could provide mutually beneficial collaboration. Effective collaboration will require increased communication and planning efforts to ensure consistent methods and compatible data.

In order to mitigate impacts to terrestrial species, CPW has implemented annual monitoring of a number of key species. These efforts have been further supplemented with aerial surveys in 2012 of pronghorn antelope as this species is suspected to be particularly affected by drought. CPW is also actively managing herds with careful thought and flexibility built in to population objectives. For example, in 2012 additional antelope doe licenses were made available for southeastern Colorado to assist in reducing population levels in that area. CPW, recognizing the importance of habitat enhancement during drought as well as non-drought conditions, also participates in programs designed to protect and conserve habitat for all species (e.g., Wetland Wildlife Conservation Program, Colorado Wildlife Habitat Protection Program) (CPW, 2012).

Table 5.8 summarizes the key impacts to CPW discussed above and adaptive capacities or mitigation strategies that can be employed for future droughts.

Table 5.8 CPW Impacts and Adaptive Capacities

Key Impacts to CPW	Key Adaptive Capacities or Mitigation Strategies
Lower reservoir and stream levels can impact water based recreation	<ul style="list-style-type: none"> ● Lengthen boat ramps to accommodate lower water levels ● PR campaign to educate the public about alternative activities to boating/fishing ● Implement monitoring programs, voluntary closures, and emergency fish salvages that can help identify those aquatic resources exposed to the most risk. ● Increase collaboration with water users to develop and maintain flow levels that can sustain aquatic life and the rafting industry.
Impacts from wildfires, including park closures and campfire restrictions	<ul style="list-style-type: none"> ● Communicate with media to emphasize which state parks are still open and which counties don't have campfire restrictions
Negative media portrayal	<ul style="list-style-type: none"> ● Maintain communication with other state agencies and the governor ● PR campaign to educate the public about state parks activities in times of drought
Decreased operating budget as a result of visitation decline	<ul style="list-style-type: none"> ● Cut operating costs by decreasing seasonal staff
Lower (surrounding) land values	<ul style="list-style-type: none"> ● Opportunities for expansion and to acquire more habitat for protected species
Impacts to fish populations	<ul style="list-style-type: none"> ● Relocate populations ● Restock impacted areas after drought ● Voluntary angling closures ● Better monitoring of baseline conditions ● Establish more drought resilient habitats ● Work with other entities to maintain water quality and quantity
Impacts to terrestrial species	<ul style="list-style-type: none"> ● Change the number of hunting licenses released ● Restrict access to sensitive areas ● Establish more drought resistant habitats ● Better monitoring of baseline conditions
Increased management requirements	<ul style="list-style-type: none"> ● Hire additional staff ● Develop collaborative relationships with other researchers (e.g., share data, develop consistent approaches, share analytical burden)

5.3.5 Instream Flow and Natural Lake Rights

The instream flow program began in 1973 when the Colorado State Legislature recognized the need to preserve the natural environment and gave the CWCB authority to appropriate and acquire water for instream flows. An instream flow is a non-consumptive, “in-channel” or “in-lake” use of water. The rights designate minimum flows between specific points on a stream, or water levels in natural lakes. The instream flow program protects habitats such as: cold and warm water

fisheries (various streams and lakes); waterfowl habitat; unique glacial ponds and habitat for neotenic salamanders; unique hydrologic and geologic features; and critical habitat for endangered, native, warm-water fish. Since 1973, the CWCB has appropriated instream flow water rights on 1,718 stream segments covering 10,550 miles of stream combined, and 494 natural lakes (CWCB, 2017). Since the 2013 update of this plan, there were over 50 new water rights appropriated. Appropriated rights are new, junior rights that have an upper and a lower terminus, usually identified as the confluence with another stream. Water acquisitions involve permanent transfers of water rights, or long-term leases or contracts for water. These acquisitions are generally more senior than the appropriated rights since they consist of previously-existing water rights that have been purchased by CWCB for instream use. Figure 5.15 shows the stream reaches in the state with instream flow rights.

Instream flow rights are considered assets, not only in an environmental sense but as real property. However, the water rights market is highly variable and not well documented. Therefore, tabulating the existing value of CWCB water rights would not be practical from a logistical as well as a value-added perspective. Figure 5.15 shows the total number of instream flow rights per county. As can be seen from this map, water rights tend to be concentrated in the western half of the State especially in mountainous areas.

Figure 5.15 Instream Flow Reaches

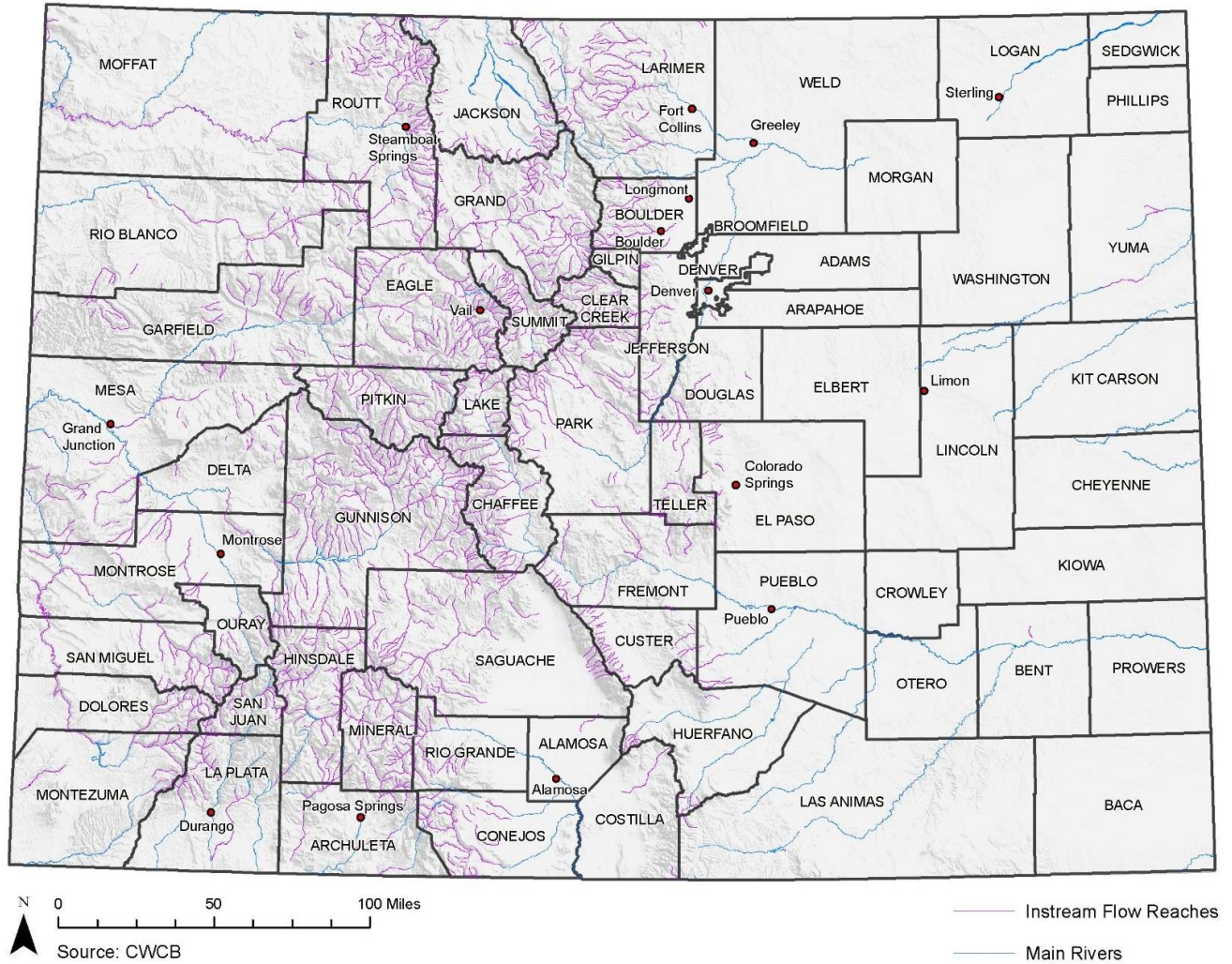
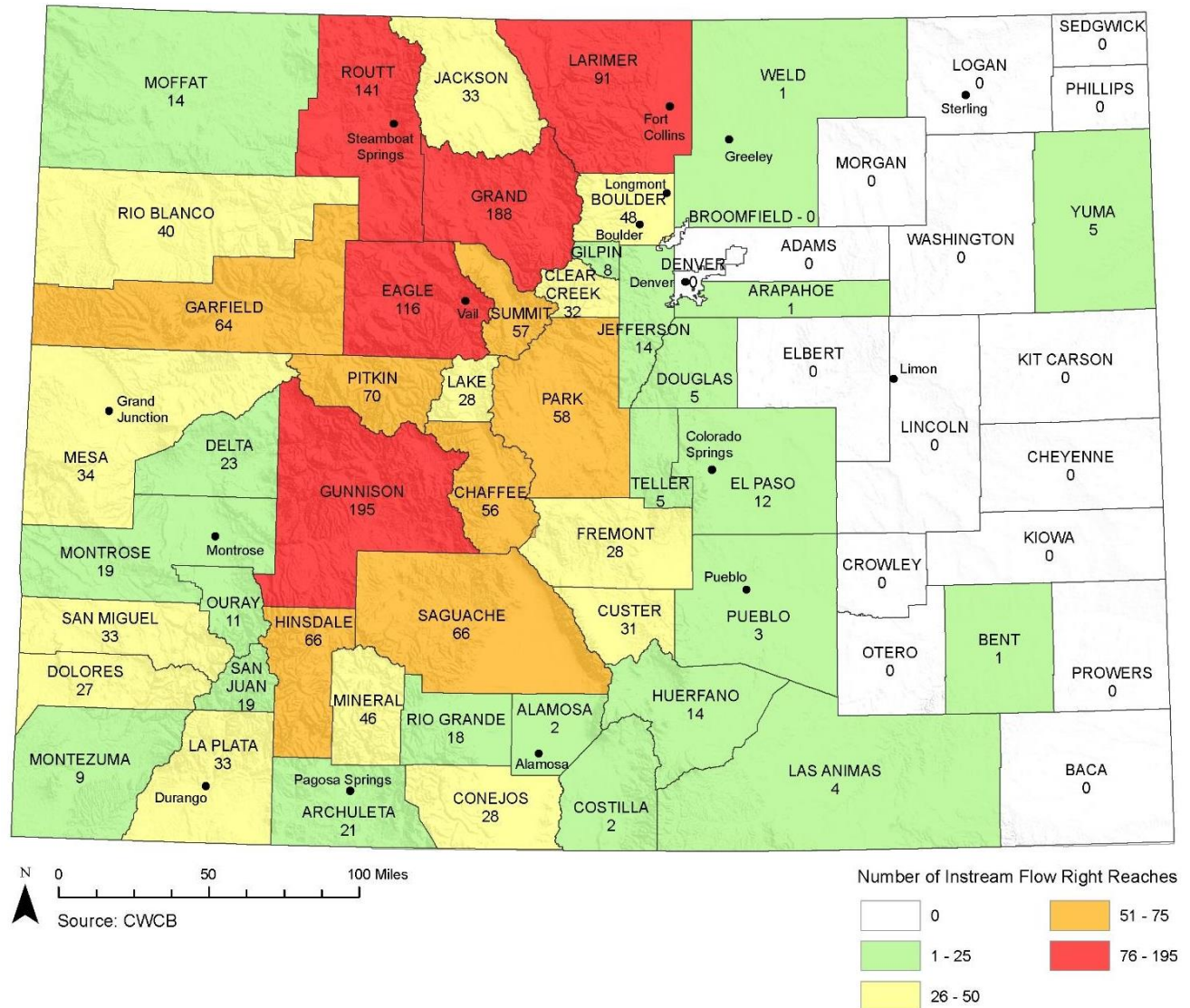


Figure 5.16 Number of Instream Flow Rights by County



Data current as of 2018. Counts do not include pending rights.

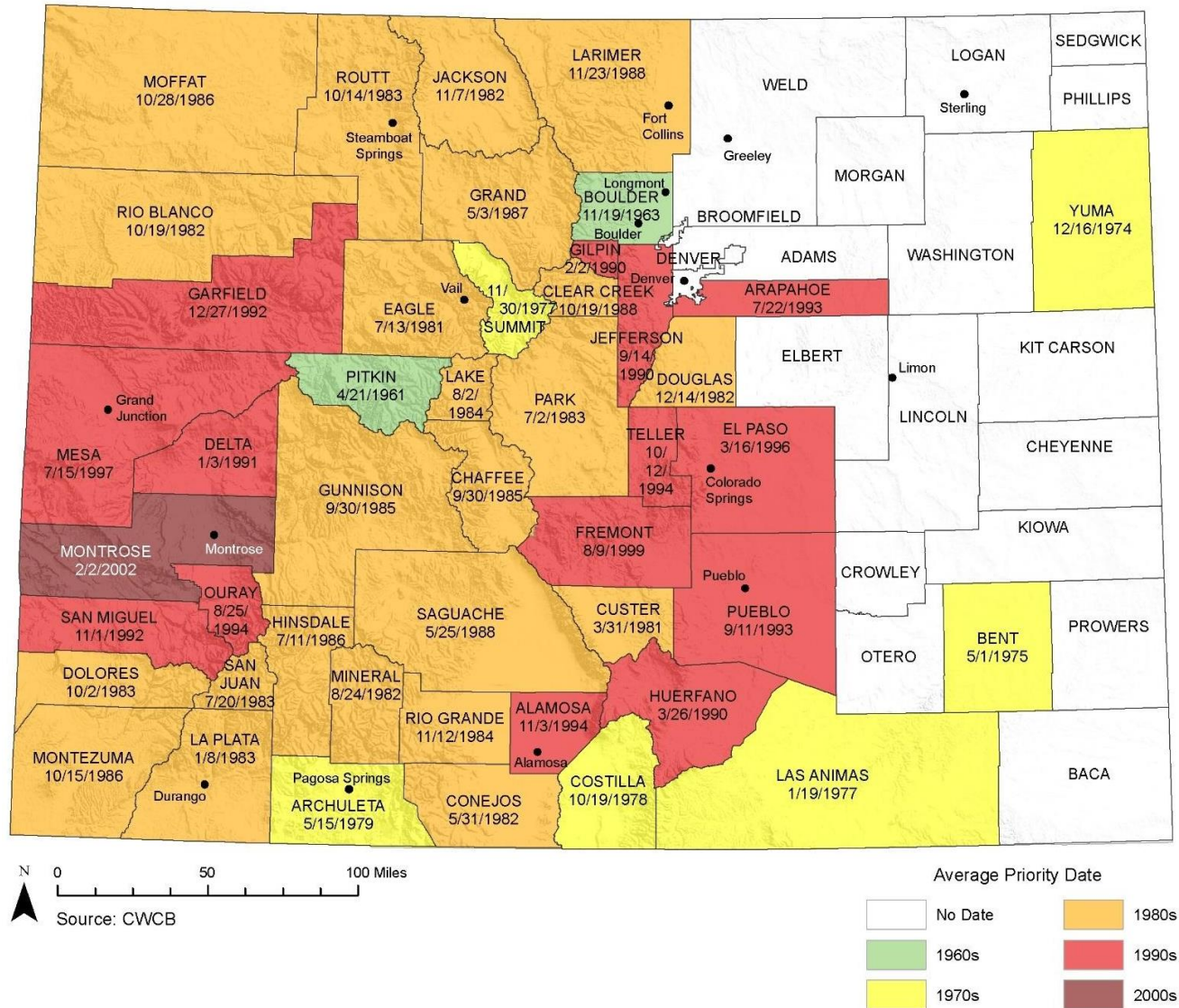
Instream flows are administered as any other water right in Colorado according to the Doctrine of Prior Appropriations. During a drought, it is possible that instream flow rights would be out of priority and therefore non-functioning. This could potentially leave habitat unprotected in the most stressful (drought) situation. Given that instream flow rights are created for environmental protection purposes, any vulnerability of the water right is actually a vulnerability of the environment.⁵ In the 2002 drought, there was no systematic analysis done to measure losses and relate them directly to decreased flows.

Vulnerability of instream flow rights can be considered from two angles: the sensitivity of a reach to change; and the probability that an instream flow will not be maintained. The sensitivity of protected reaches to small environmental changes can provide information on likely losses if an instream flow is not in priority. However, this analysis would be a significant undertaking given the number of variables to consider (e.g., water quality, disease, and invasive species). Future work should assess the feasibility of such analysis and gather data where applicable.

Priority dates provide information on the likelihood that a given right will be out of priority. Dates for all instream flow rights are publicly available. Figure 5.17 shows the average priority date for instream flow rights by county. However, the date alone does not provide enough information to conduct this assessment. Accurate analysis will need to consider the instream flow appropriation date relative to other calls on the water body. As previously noted, it is beyond the scope of this vulnerability assessment to complete a detailed water rights assessment. Future water rights analysis will also need to consider situations where instream flow rights are satisfied by coincidence even when their calls are out of priority. In the 2002 drought, there were actually several instream flow reaches that experienced greater flow even when their rights were out of priority. This is because the drought caused senior downstream users to make calls earlier in the summer. This curtailed upstream users, keeping more water in the stream longer. Also, many users requested that contract water be released from federal reservoirs earlier in the season (Merriman, 2002).

⁵ Refer to the Environmental sector for additional information on the environmental impacts of decreased stream flow.

Figure 5.17 Average Instream Flow Priority Dates



Source: CWCB, data current as of 2018.

While it is true that several instream flows were inadvertently protected even when they were out of priority, this is not a reliable mitigation strategy. The CWCB is constantly working to acquire additional instream flow rights and these efforts should continue. Establishing good relations with watershed groups can also aid cooperation during drought. Conditional agreements can be made where individuals are compensated for loaning water to the CWCB or exchanging water to downstream users to keep a specific stretch wet (State of Colorado Water Availability Task Force, 2002).

Table 5.9 Instream Flow and Natural Lake Rights and Impacts and Adaptive Capacities

Key Impacts to Instream Flows	Key Adaptive Capacities or Mitigation Strategies
Instream flow or natural lake rights are out of priority and required levels are not maintained resulting in environmental damages	<ul style="list-style-type: none"> ● Continue increasing natural flow rights portfolio especially with respect to senior rights, as this adaptive capacity has been shown to decrease some vulnerability to overall risk to drought ● Cooperate with watershed groups ● Obtain conditional agreements for drought conditions ● Cooperative effort with CPW on use of CPW water rights, reservoirs, etc. to maintain instream flow levels

5.4 Measurement of Vulnerability

For the purposes of the following numerical analysis, state assets were divided into five impact categories: structures, Land Board revenue, recreational activity, aquatic habitat and species, and protected areas. For each impact group, one or more inventory datasets were defined to serve as spatial density metrics, along with impact metrics to portray vulnerability. Scores were derived from the spatial density and impact metrics by county. Each metric is described in detail below. Refer to Section 3.1 of Chapter 3 (Annex B) for a general description of the vulnerability assessment numerical methodology. For the aquatic habitat and protected areas categories, impact data was not available. This is a data gap that is identified for future work. Because impacts could not be calculated for two key categories, vulnerability results are presented for the available subcategories but an overall state asset vulnerability score is not calculated.

5.5 Vulnerability Metrics

5.5.1 Structures

Spatial Density Metrics

There are two metrics for the spatial density of state-owned structure: 1) total state-owned building value, and 2) total storage volume for state-owned dams. The final spatial density score is the average of the individual density scores of the two variables.

State-owned facilities

State-owned building value was provided by the Office of Risk Management. Values for all facilities were summed by county using the provided information for the location of the facilities.

State-owned dams

Storage in state-owned dams was calculated using the Homeland Security Infrastructure Program database from 2013. Nearly one-third of all counties do not contain state-owned storage. This makes the typical percentile thresholds invalid. Therefore, thresholds were adjusted to create equal bins for the non-zero dataset. The adjusted percentile thresholds used were: 72%, 81% and 91%.

Impact Metrics

There are two metrics for structural vulnerability: relative importance of dams versus buildings, and the percentage of county area in a wildfire hazard area. To calculate overall structural impact, relative importance of dams was weighted 70% and wildfire hazard was weighted 30%.

Relative importance of dam storage

The purpose of this variable is to reflect the fact that dams are more likely to be impacted by drought than other state-owned buildings/facilities. The relative importance of dams versus buildings was calculated using the spatial density scores (1 through 4) previously calculated. The dam storage score was divided by the sum of all the dam storage plus the building value score. Counties where the relative importance of dam storage is less than 50% were given a score of 2. Counties with values greater than 50% were given a score of 3.

Wildfire hazard area

The Colorado State Forest Service maintains an online data portal that contains a number of wildfire specific datasets.⁶ Wildfire threat is defined as the annual probability of a wildfire occurring. Threats were divided into six main categories: very low, low, moderate, high, very high and none. For the purposes of this analysis, the percentage area by county with a risk level of moderate or above was calculated by county. Counties were then ranked according to the percentage of area with moderate or higher wildfire risk.

⁶ <http://www.coloradowildfirerisk.com/>

5.5.2 Land Board Revenue

Spatial Density Metrics

Total surface ownership

Surface ownership by county was obtained from the Colorado State Land Board website (Land Board, 2018). The Land Board owns property in nearly every county, so the normal 25%, 50% and 75% thresholds could be used. Ideally, areas leased for specific purposes (e.g., agricultural, mineral) would be considered independently. However, this data would be difficult to process in the context of this vulnerability assessment. As such, using total surface ownership fits the need of this numerical calculation, given most of the other land leases cover very small areas relative to the total extents anyway.

Impact Metrics

Historical lease discounts offered in 2002

Since the lease discount program was discontinued in 2012, the percentage discount for agricultural leases offered in 2002 was used. Information was provided by county in an internal Land Board memo (Board of Land Commissioners, 2002). The Land Board offered 10%, 20%, 30%, and 40% discounts depending on the drought monitor status. Impact scores of 1, 2, 3, or 4 were assigned to each discount respectively. While it should be noted that future droughts may look different and that the Land Board will not be offering across-the-board discounts, this still serves a historic measure of what counties may be seeking larger discounts in the future.

5.5.3 Recreation

Spatial Density Metrics

Annual state park visitation

State park visitation data was provided by CPW, and serves as an impact metric to summarize spatial density/coverage of parks' influence across the State. Annual visitation totals from 2017 were broken up by county. Nearly all state parks fall within a single county. Visitation for parks that straddle county lines were assigned to the county covering the majority of their area. Yampa River State Park was assigned to Routt County, the Arkansas Headwaters Park was assigned to Chaffee County, Chatfield Park was assigned to Douglas County, Eldorado Canyon went to Boulder, Elkhead Reservoir to Moffat, Golden Gate Canyon to Gilpin, Navajo Park to Archuleta, and Staunton State Park to Jefferson County. While this is a good marker for revenue for state departments such as CPW, this data does not directly refer to fishing and hunting activity, for example. Hunting and fishing data by county was not available. Ideally, these data could be combined with the state parks visitation numbers in future assessments. However, from the

perspective of general state assets, these data are not required because the CPW does not sell licenses for specific areas of the State.

Impact Metrics

There are two impact metrics for recreation: the relative importance of water-based recreation, and the percentage of counties' extents found within wildfire hazard areas. To calculate overall structural impact, relative importance of water based recreation weighted 75%, and wildfire hazard weighted 25%. Wildfire hazard was assigned a lower weight because of the uncertainty that wildfire would occur in recreation areas even if the county hazard score is high.

Relative importance of water based recreation

This variable reflects the fact that water-based activities are generally more vulnerable to drought than land-based ones. The two major river corridor parks (Arkansas Headwaters and Yampa) were assigned the highest impact rating of 4. All parks with boating or fishing on their listed activities were assigned impact ratings of 3. All parks with no boating or fishing were assigned impact ratings of 2. Overall county ratings were calculated using a weighted average of impact ratings based on park visitation. Park visitation numbers were assigned to counties using the same guidelines outlined for the inventory (spatial density) metric. Counties with no state parks were assigned an impact rating of zero.

Wildfire hazard area

As noted in Section 5.5.1, wildfire threats were divided into six main categories: very low, low, moderate, high, very high and none. For the purposes of this analysis, the percentage area by county with a risk level of moderate or above was calculated by county. Counties were then ranked according to the percentage of area with moderate or higher wildfire risk.

5.5.4 Aquatic Species and Habitat

Spatial Density Metrics

Two metrics were used to spatially characterize the State's investment in and protection of aquatic habitat and species. These metrics are instream flow reaches (totals by county) and number of state fish hatcheries per county. Other aquatic areas owned by the State are covered in the protected areas category.

While fish hatchery totals are included as a spatial density metric, this information could not be utilized in the vulnerability calculation because direct quantitative impacts associated with these data was not available or easy to manipulate into metrics broken up by county. Future work should analyze the vulnerability of fish hatchery water supplies, in particular, and incorporate this information as an impact metric.

Instream flow rights

The number of instream flow reaches per county was calculated using the primary county designation from the CWCB instream flow reaches dataset, current as of October 2017. Over one fourth of the counties (17 of the 64) had zero instream flow rights. Therefore, thresholds were adjusted to create equal bins for the non-zero data set. The adjusted percentile thresholds used were: 52%, 68%, and 84%.

State fish hatcheries

The number of state fish hatcheries was summarized per county, using data available on the CPW website brochures that discuss State Fishing Units. There are 15 state-owned fishing units/hatcheries as of 2017. Counties with one fish hatchery were assigned a score of 2, those with two hatcheries a score of 3, and those with three hatcheries received a score of 4.

Impact Metrics

As of the writing of this Plan, there is currently only one impact metric for aquatic resources. This is the average priority date for introducing instream flows, and the results are broken up by county.

Average instream flow stream priority date

The average priority date of instream flow rights was calculated using the primary county designation from the latest (as of October 2017) CWCB instream flow rights database. Reaches covering more than one county were assigned to their primary county designation. Nearly one third of counties have zero instream flow rights. Therefore, thresholds were adjusted to create equal bins for the non-zero data set. Instream flow rights historically have not been focused on protecting habitat; rather, they ensure a minimum flow in a given stream (so that enough water is distributed along the stream for various purposes). As such, future studies could be carried to assess the effectiveness of instream flows at protecting species and habitat that would otherwise be at risk. In addition, average priority dates should be considered relative to surrounding water rights. However, because instream flows often result in water being retained in a stream that may otherwise have been diverted, this metric is considered an appropriate impact capacity and is treated as such in the Vulnerability Assessment Tool.

5.5.5 Protected Areas

Spatial Density Metric

Protected area

The total state-owned protected area by county was calculated based on the Colorado State Land Board's stewardship trust dataset (current as of January 2018). Since there are 30 counties without

any protected land, adjustments were made to the baseline thresholds to account only for non-zero values.

Impact Metrics

As of the writing of this plan, there are currently no quantitative impact metrics for state-owned protected areas. As noted in Section 5.3, there has not been adequate monitoring of drought-related impacts on these lands, so direct metrics that determine vulnerability are not clear. Refer to the Environmental Sector (Annex B, Chapter 8) for a greater analysis of statewide environmental vulnerability. Future work should improve monitoring efforts and identify specific drought vulnerable attributes related to state assets.

5.5.6 Results

Figure 5.18 through Figure 5.23 show the impact scores and spatial density metrics for the five subcategories assessed in this state assets sector. Figure 5.23 displays the overall vulnerability ranking for the entire State Assets sector. The red shades on the maps represent impact ratings, while the size of the grey circles indicate how small or large the respective sub-sector is within a given county. As noted in Section 5.5 there were no impact metrics available for state-owned protected areas. Therefore, Figure 5.22 shows spatial density of the inventory metric but no impact results. For the aquatic habitat and structures sub-sectors there were multiple spatial density metrics, which were averaged to obtain the final inventory/spatial density results. Discussion of the vulnerability assessment is included in the following section.

Figure 5.18 Structures Impacts and Spatial Density Metrics by County

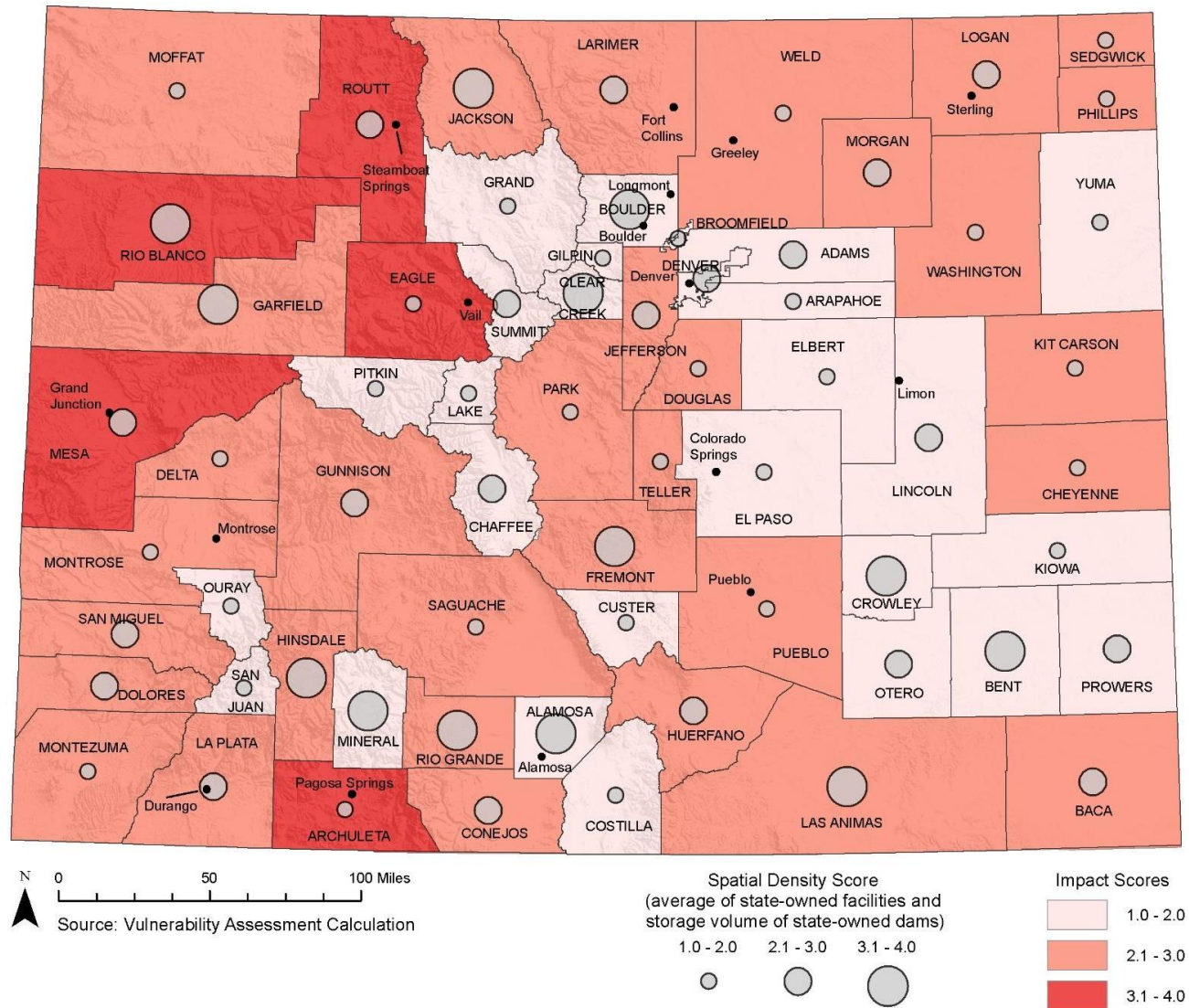
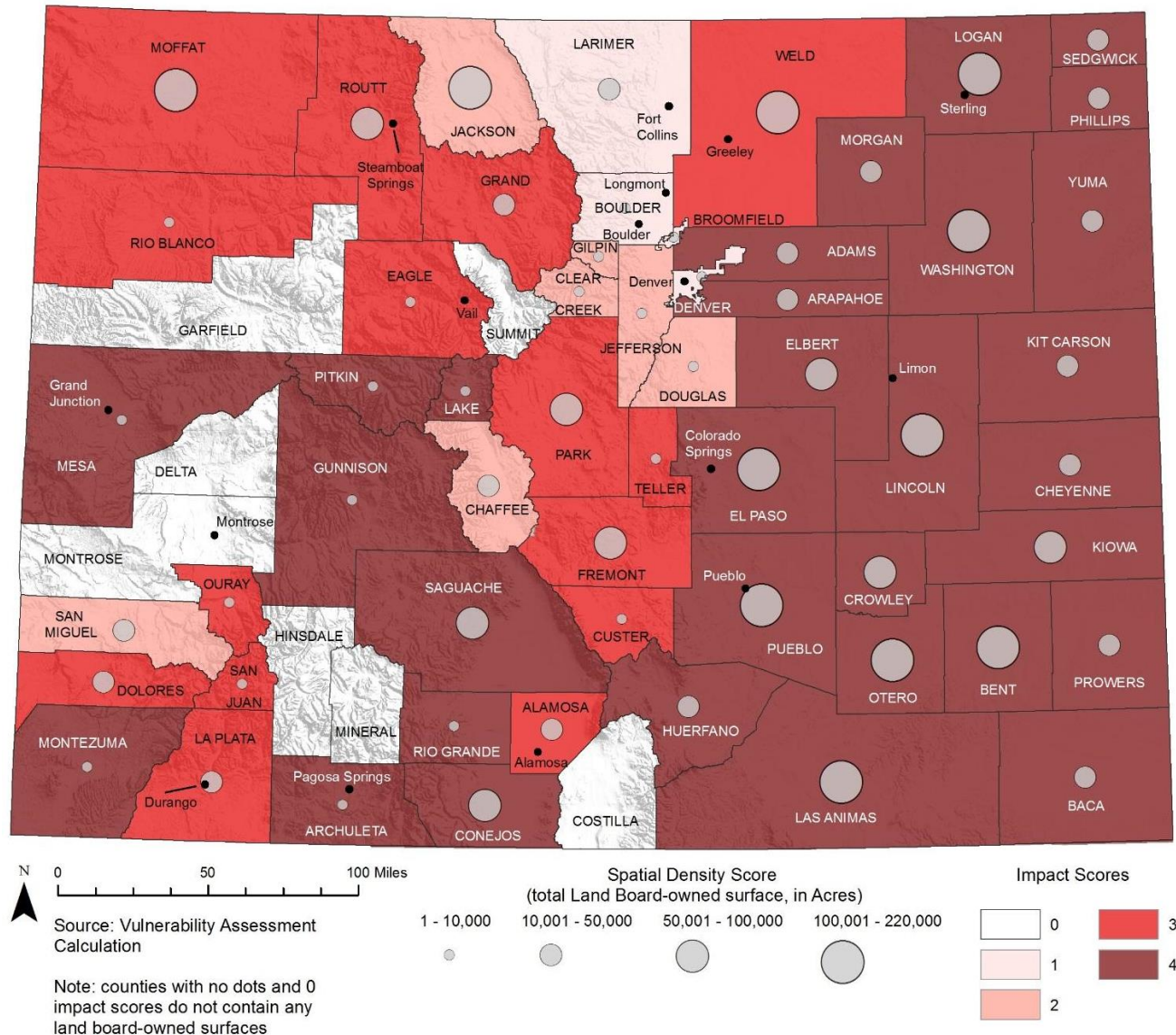


Figure 5.19 Land Board Impacts and Spatial Density Metrics by County



Both Figure 5.19 and Figure 5.20 show some noticeable changes in the impact scores obtained in the 2018 vulnerability assessment update, when compared with the 2013 results. A reason for these stark changes has to do with the way in which the impact scores were categorized (i.e. classified) for the rankings, and how they are represented visually in the end.

Figure 5.20 State Parks Recreation Impacts and Spatial Density Metrics by County

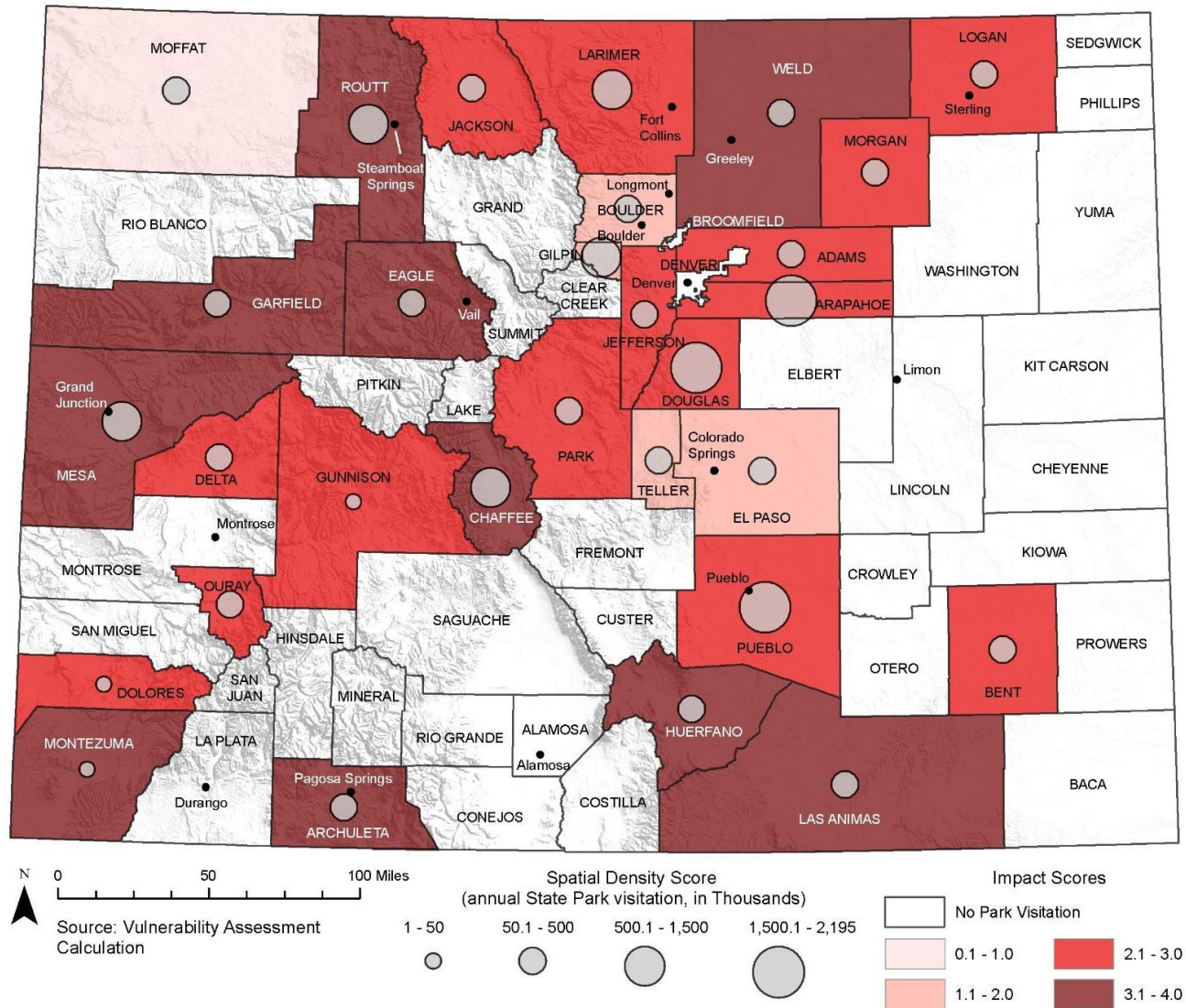


Figure 5.21 Impacts to State Fisheries, with Spatial Density Metrics by County

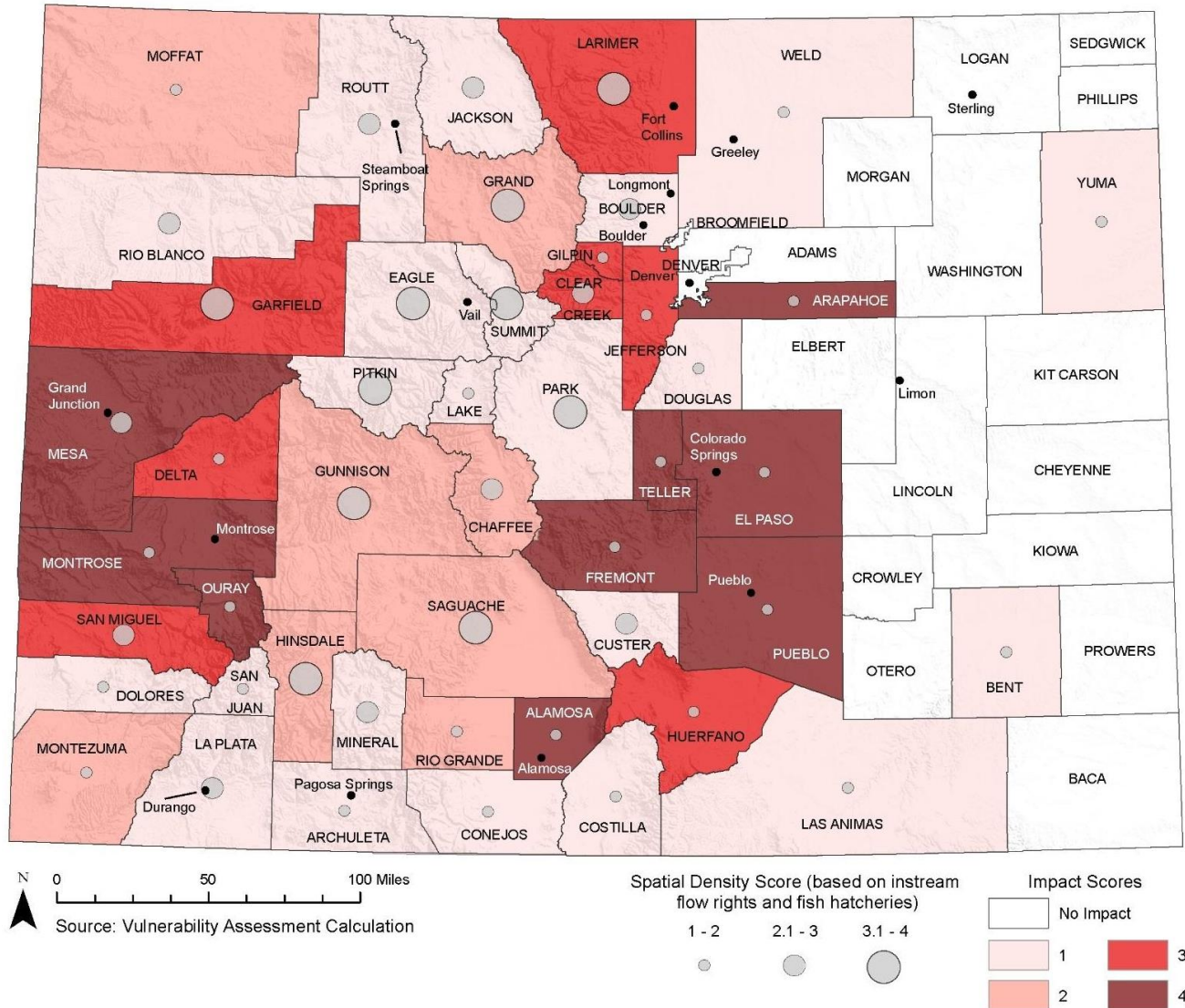


Figure 5.22 State-Owned Protected Areas by County

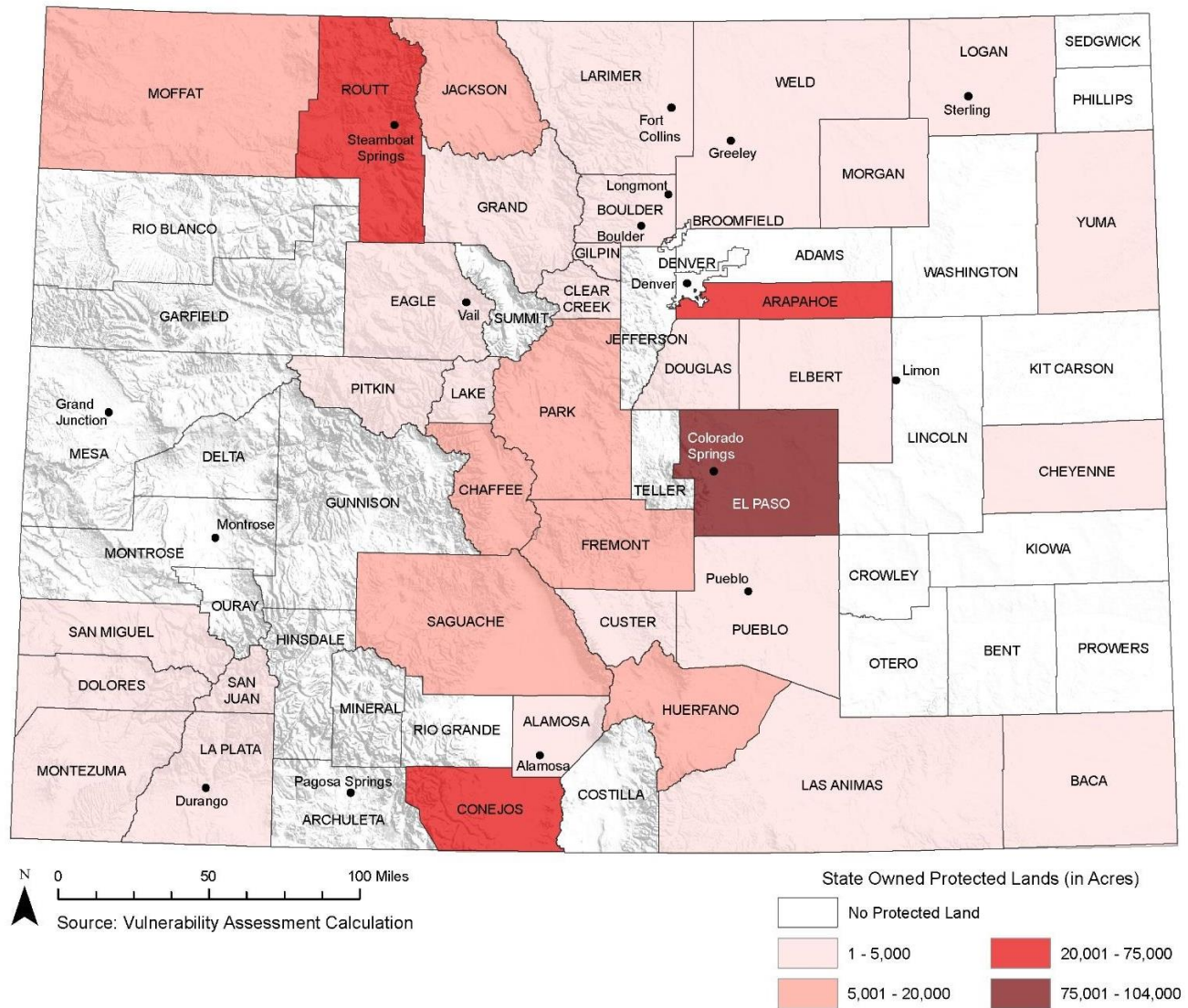
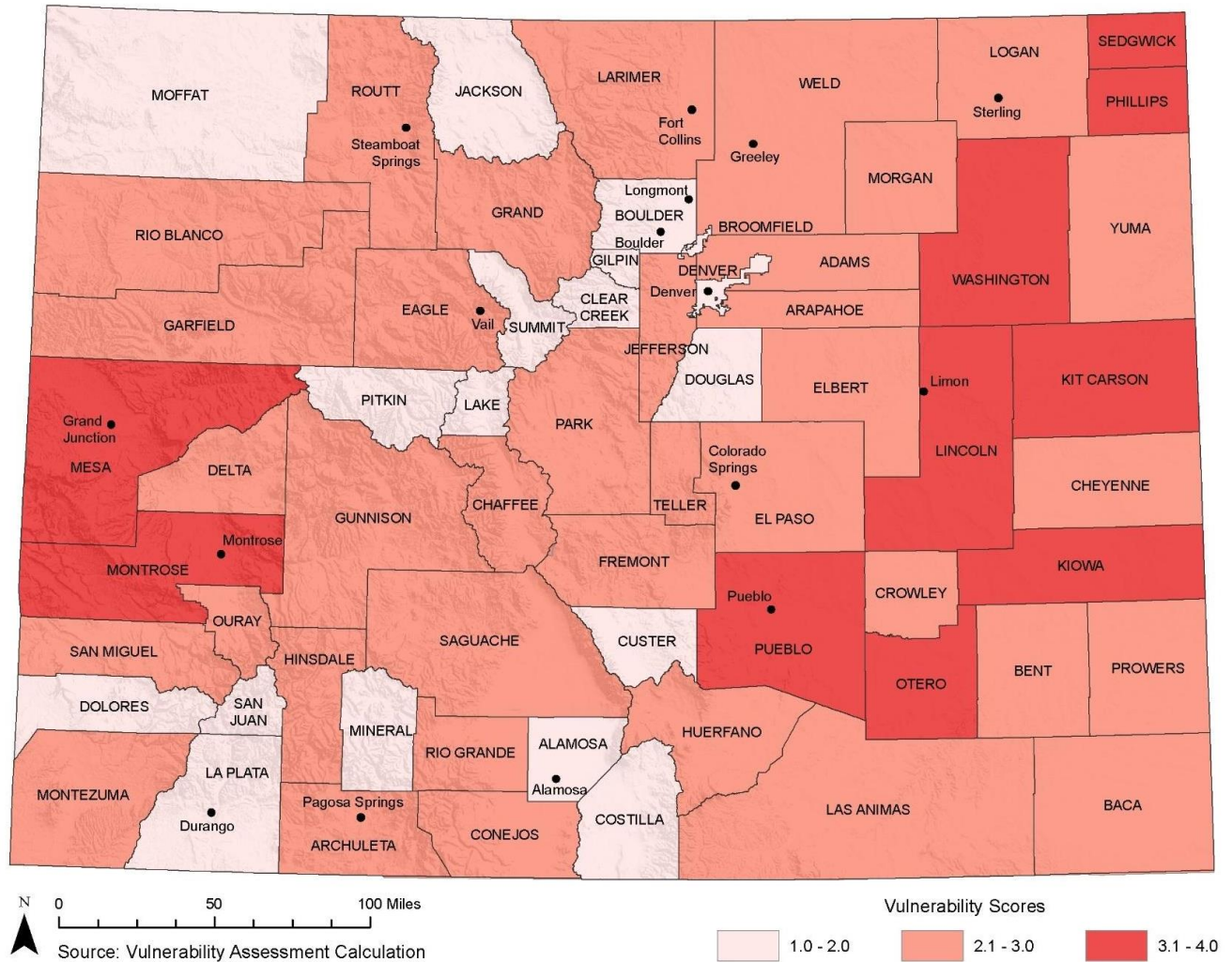


Figure 5.23 Overall Vulnerability Rankings in the State Assets Sector, by County



5.5.7 Spatial Analysis

The State owns structures in every county. As seen in Figure 5.19, vulnerability for these structures is relatively distributed over the State. A few more vulnerable counties are seen in the west, a result of higher wildfire hazard and due to the presence of a majority of state-owned dams. On the eastern plains, more counties have seen increases in their vulnerability rating, primarily due to the improved available wildfire data.

Vulnerability scores for Land Board revenue are completely dependent on the metric summarizing discounts issued in 2002. Figure 5.23 shows that the eastern half of the State is more highly vulnerable. Furthermore, many of the counties with high impact ratings in eastern Colorado also fall in the largest category for surface ownership by the Land Board. The Land Board currently does not own any land in several counties towards the southwest and central-west, including Costilla, Mineral, Hinsdale, Garfield, Delta, Montrose, and Summit.

Spatial vulnerability of recreation revenue is highly dependent on the location of water-based state parks. Counties such as Eagle, Routt, and Chaffe (among others) have the highest impact scores due to the presence of river-based parks, coupled with high wildfire hazard rankings (especially if they are located close to forested areas). Counties in eastern Colorado do not have any State parks that bring in revenue. As such, they do not account for any impacts to this sub-sector.

Impacts to State-owned aquatic habitat are defined by the average instream flow right priority dates. The spatial density/inventory metrics combine the number State Fishery Units with the number of instream flow rights reaches, per county. The highly impacted counties are generally concentrated in the western half and centrally located areas (e.g., Fremont, Pueblo, Teller, El Paso). Alamosa and Arapahoe counties also have high vulnerability based on their impact scores, and so do counties in the Front Range, west, and south (with impact scores of 3). Those counties with the highest impact ratings have the most junior priority dates for their instream flow rights. Relatively few instream flow rights have been acquired since 2010, but many are pending and will be incorporated into future analysis. Additionally, while there are only 15 State-owned fisheries, more information on how those aquatic habitats are preserved or contribute to the adaptive capacity of counties should be explored in the future.

State-owned protected areas are distributed across the State, but many counties in the eastern plains and western edge do not contain any State-owned protected acres (as defined by the Land Board stewardship trust lands dataset) (Figure 5.22). Ownership of protected lands is highest in El Paso county, followed by Routt, Arapahoe, and Conejos counties. This may seem counterintuitive given all the natural and seemingly protected areas in western Colorado. However, it is important to note that this map is only representing state-owned areas which are largely dominated by the Land Board. Other protected areas owned by federal agencies such as the Bureau of Land Management and the US Forest Service are not included in this analysis.

Overall, there is some degree of vulnerability for the State assets sector across most of Colorado. The more highly impacted counties are found on the eastern plains, southeast, and west. There are 10 counties receiving vulnerability scores of 3 and above, though the majority of the counties in the State score anywhere between 2 and 3 in vulnerability. The 16 lowest ranked counties (receiving scores of 2 or below) are found in the Front Range, mountain areas, northwest, southwest, and south. A possible reason for low scores is that many of those counties are largely populated, and may not rely heavily on park visitation or even possess protected lands, due to the lack of natural spaces. Because of the few natural areas in the more urban settings, wildfire hazards are also low, contributing to their overall low vulnerability scoring.

5.5.8 Compound Impacts

Taken as a group, state assets overlap considerably with other sectors assessed in this vulnerability study (e.g., Recreation and Tourism). The potential for overlapping and often compounding impacts is thus important to consider. The work done by the CPW helps preserve Colorado's natural environment and promote public use of this valuable resource. Tourism in Colorado is a major industry⁷ strengthened by the protected areas owned and managed by the State. Drought impacts to these assets directly translate to declines in tourism and related industries. Furthermore, decreased revenues for state agencies resulting from drought can impact management budgets and further negatively affect assets. Budget reductions may occur when tax bases are impacted. In years of drought such as 2002, state revenue was lower than during non-drought years, likely due to a lack of water resources to sustain water-based recreation, coupled with the negative perception of the State assets' conditions, among other factors. The importance of Colorado's environment to the quality of life and identity of the State cannot be underestimated. Degradation of natural areas can also have compound effects on society as a whole⁸, impacting more than just one segment of the economy in the State.

The Land Board is closely connected to agriculture as well. Decreased production on their lands directly impacts yields of farmers and ranchers. However, this can be a cooperative relationship because the Land Board is willing to negotiate lease discounts during drought. This may actually increase the adaptive capacity for farmers and ranchers leasing Land Board land versus those with mortgages. While this is a good thing for agriculture, lease discounts create compound impacts for public schools and other trust beneficiaries of Land Board funds.

5.6 Recommendations

5.6.1 Adaptation to Drought

One clear theme that emerged from interviews with state employees is that, in the 2002 drought, actions and efforts were generally not well coordinated and media communications were unclear.

⁷ Refer to the Recreation Sector for additional information

⁸ Refer to the Socioeconomic Sector for additional information

More efforts were made during the 2011-2013 drought to enhance coordination and messaging across agencies and governments, such as with the Front Range Water Council. Although some steps have been taken in response to the 2011-2013 and 2002 droughts by some agencies to better prepare them for dry conditions, all the state assets discussed in this section could benefit from greater drought awareness and planning. Every agency should have a drought plan that addresses vulnerabilities such as those noted in this report, including a communication plan. It is important for all state agencies to identify opportunities for cooperation and coordinated media communication before drought occurs. Taking the time to be aware of existing support systems and existing vulnerabilities will greatly increase the relevance of planning efforts, further enhancing actual messaging and coordination endeavors. Management strains on many agencies, especially CPW, was significant during the 2002 drought. Where possible, agencies should set up emergency funds to be used during drought events. Having the ability to hire additional staff during drought would significantly increase the adaptive capacity of the CPW and other management agencies, and as such, appropriate planning and mitigation efforts are key before a drought occurs.

In Section 5.3, specific adaptation opportunities were discussed for each asset group individually. In addition to increased awareness and planning efforts, agencies can start developing policies to provide additional flexibility and resources during times of drought. For example, the CPW has the ability to close access to stressed areas, while the Land Board can negotiate lease prices in response to decreased yields. In many cases, statewide action will not be effective because of the wide spatial dispersion of state assets and the number of agencies involved in sustaining or managing those. Thus, mitigation planning has to be flexible. In addition to coordinated efforts, individual state parks and buildings will need to assess operations and determine response. Individual stream reaches and wildlife resources such as fish hatcheries should be assessed for specific vulnerabilities applicable to their own distinctive qualities. As noted in Section 5.3.5, impacts can vary greatly depending on water sources, sensitivity of species, and water rights in the basin. To adapt appropriately, these variables will need to be considered and planned for on a case-by-case basis.

5.6.2 Improving Vulnerability Assessment

The vulnerability assessment conducted for state assets in this study is the first of its kind. While most assets have been quantitatively evaluated, there are several data gaps that could further improve results if filled. Future work should focus on gathering statewide data in a consistent manner to input into the framework developed here.

For the purposes of this analysis, the relative importance of dams versus buildings was used as a metric, assuming that dams are more likely to be impacted by drought. Future work should analyze the types of dams that are most likely to be damaged, for example, and the ditches that are most junior and hence likely to remain dry for extended periods of time.

The number of instream flow rights per county was used as an impact metric to estimate effects on protected state fisheries and aquatic habitats. Future work should develop other statewide

metrics to further classify this resource. Identification of those areas that are most sensitive could be completed with additional monitoring, to determine baseline conditions and the sensitivity of specific fish populations to various kinds of environmental perturbations. Using this information, instream flow reaches and natural lakes could be assigned sensitivity scores to be input into the vulnerability assessment. Since 2010, CPW has increased their monitoring efforts and begun assembling this kind of data.

Detailed water rights analyses could also inform on the likelihood of water levels not being maintained, or how low water levels during times of drought can more directly affect the different sectors. For example, modeling exercises could be completed to determine the minimum flow for which an instream flow level will likely be maintained, taking into account probable calls by other water rights. The resulting minimum flow numbers can be used as a vulnerability metric where those rights with the lowest minimum flows are the least vulnerable.

CPW provided helpful qualitative information on the impacts to several fish hatcheries during the 2002 and 2011-2013 droughts. However, systematic data on water sources and operations information were not readily available in an aggregated format, and it was beyond the scope of this project to investigate hatcheries on an individual basis. Future work is needed to investigate the potential drought impacts to individual fishery operations, and determine relative vulnerabilities. As with instream flows, it would be important to determine the minimum flow in the rivers affecting hatcheries, for example, to assess effective operation potential (once again taking the requirements of other water rights into consideration). Most hatcheries operate on wells or spring collection systems to handle disease mitigation. The number of state-owned hatcheries is small, and it could be feasible to survey hatcheries one by one to determine the relative impact of their efforts with regards to aquatic species and habitat preservation. Some modeling most likely also would be required. In addition to minimum flows, sedimentation resulting from wildfire damage and subsequent debris flows were reported several times as being particularly damaging to hatcheries. Information on debris flows and where they might occur could prove useful to future vulnerability calculations too.

The spatial extent of state-owned protected areas is well documented; however, detailed information on management practices and vulnerabilities specific to the type of protected area is not available. Furthermore, drought impacts have not been monitored in a consistent manner well suited for spatial analysis. Wildfire hazard and beetle kill can be used to measure secondary impacts, but this does not adequately define stress on the system as a whole. Refer to the Environmental Sector document for more detailed analysis on wildfire and beetle kill related vulnerability. Future monitoring efforts should focus on identifying specific drought vulnerable species and habitats.

Analysis similar to those described in the paragraph above for protected areas would be helpful for Land Board lands. In this case, there are impact data from 2002; however, changes in Land Board operations (i.e., changes in lease discount administration) indicate that future responses will be different. Spatial drought sensitivity information would be of great value.

In this methodology, outdoor recreation revenue was characterized by visitation to state parks. Hunting and fishing license sales are an important funding source for the CPW too. However, they were not included in this methodology, as the data did not have any spatial distribution component. Future work should analyze the types of hunting and fishing that are most vulnerable to drought. Cross referencing these vulnerabilities with the hunting areas for the respective activities would provide spatial information on revenue vulnerability. Coordination with the CPW is required to determine if spatial analysis and geographically localized vulnerabilities are relevant to their operations.

One aspect of state assets not specifically considered here are the administrative costs of drought. Employees at the CPW and the State Engineers Office specifically noted a significant increase in workload responding to drought-related issues. The State is responsible for many public service agencies which may also be in high demand when responding to drought impacts across all sectors. These agencies often provide important assistance and increase the adaptive capacities of the sectors they work with. In 2000, the Hi Meadow and Bobcat wildfires cost state and local governments about \$6.5 million (State of Colorado Water Availability Task Force, 2002). While management costs are not included as a state asset, future work should analyze the potential cost incurred by all state agencies in responding to drought. Appropriate preparation should be taken so that state agencies anticipate drought-related issues and are prepared to expand their services when they are needed the most.

Below is a summary of some possible key approaches that could enhance future work related to assessing vulnerability and adaptive capacity within the various State-owned assets (sub-sectors) discussed in this document:

Structures

- Identify other state-owned water infrastructure besides dams.
- Conduct a water rights analysis for state-owned ditches to determine the likelihood that they will be dry for extended periods during a drought.
- Conduct a vulnerability assessment for every state-owned dam considering the construction material and the possible low water levels during drought.
- Gather data on irrigation practices and their water sources for state-owned properties.

Land Board Revenue

- Determine spatial drought sensitivity information for Land Board properties, based on ecological conditions and land use.

Recreational Revenue

- Estimate costs of drought management for CPW.
- Determine the spatial distribution of CPW revenue sources, other than state park visitation.

- Understanding the patterns behind how animal populations respond to drought could offer additional information about which species, areas, and activities are most susceptible to drought.

Aquatic habitat

- Conduct a vulnerability assessment for state-owned aquatic habitat and managed species to determine sensitivity to environmental perturbations.
- Conduct water rights analysis for instream flow reaches and natural lakes to determine the minimum flow levels which can maintain required flows.
- Survey state-owned fish hatcheries and differentiate operational practices that increase vulnerability.

Protected areas

- Identify and map drought-vulnerable species and habitats. These efforts should be coordinated along with the Environmental Sector.

6 AGRICULTURE SECTOR

Key Findings

- Three key impact categories were identified for agriculture: crops, livestock, and the green industry.
- Key drought vulnerabilities for crops include crop loss from lack of precipitation (in the case of dryland crops) or insufficient irrigation, and/or damage to crops due to reduced quality of irrigation water.
- Grazing lands are vulnerable to drought, resulting in limited forage availability, discontinued recharge of groundwater stock wells, and disturbance of the managed ecosystem.
- The green industry (which consists of nursery, greenhouse, floriculture, and sod) is vulnerable to municipal water restrictions as well as water-availability reductions that could cause income and job loss.
- For the livestock subsector, the 2011-2013 drought event was a culmination of difficult circumstances. The widespread nature of the drought impacted local and regional rangelands limiting the abundance of healthy pasture and feed hay production. The drought also impacted the Midwestern corn feed crop, driving up the price of feed. Many ranchers were forced to sell breedstock leading to uncertainty regarding future business viability.

Key Recommendations

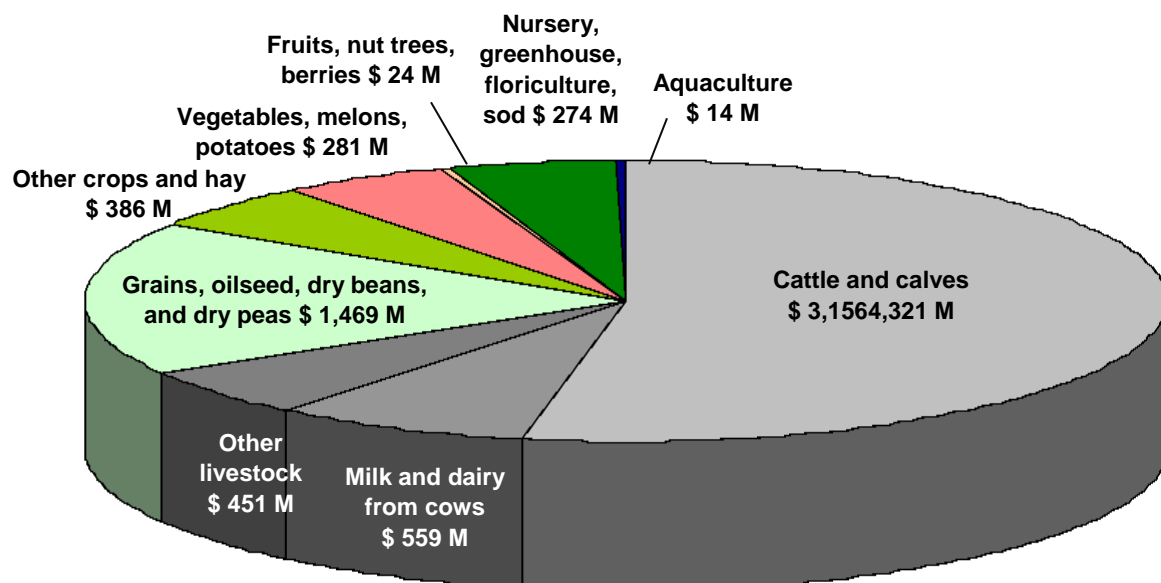
- Crop diversification and advanced planning for drought scenarios can benefit all sub-sectors within the Agriculture Sector.
- In this assessment, dryland crops were identified as the most vulnerable. In future studies, a specific analysis of irrigated crops and water availability is recommended.
- Best management practices developed by the green industry might have applications for irrigated crop producers.
- Due to the small sample size of green industry producers, public data on this sub-sector is not available. A survey instrument might be a valuable tool to collect information about the industry in the future.
- NASA's CASA (Carnegie-Ames-Stanford Approach) model provides a way for resource managers to measure drought impacts in Colorado at a synoptic scale.

6.1 Introduction to Sector

The Agriculture Sector is a key economic driver in Colorado, and some form of agriculture activity is found in nearly every county in the State. The Colorado Department of Agriculture (CDA) estimates that more than \$40 billion of economic activity is generated from Colorado's agriculture

sector¹ (CDA, 2013). The U.S. Census of Agriculture, which collects statistics on farms and producers throughout the country, reported that the total market value, before value-added processing, of agricultural products in Colorado in 2012 was \$7.8 billion. Figure 6.1, from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS), shows how that \$7.8 billion is broken down between different agricultural groupings. Unfortunately, the census is published every 5 years, with the 2017 update expected to be available in 2019. Figure 6.1, based on 2012 data, remains relevant as an overall representation of agricultural products in Colorado; however, it is important to note that in recent years the marijuana industry has become an important product for the Agricultural sector, contributing an estimated \$1.5 billion dollars in sales.

Figure 6.1 Market Value of Agricultural Products in Colorado, 2012



Source: USDA NASS, 2012

Cattle and calves constitute a large percentage of the overall agricultural products in Colorado. Along with dairy cows and other animals, the “livestock” sub-sector contributes over \$5.3 billion to the Sector. Other than livestock, sub-sectors identified for this study include crops (which consist of irrigated and non-irrigated) and the green industry (which consists of nursery, greenhouse, floriculture, and sod). The one sub-sector shown above that is not discussed in detail is aquaculture, due to its minor economic role in the overall sector. Discussion of and impacts to

¹<https://www.colorado.gov/pacific/sites/default/files/COLORADO%20AGRICULTURE--Learn%2C%20Speak%2C%20Share.pdf>

state-run fish hatcheries, which are expected to be similar to privately-owned hatcheries, are located in the State Assets and Recreation Sector.

For this assessment, the livestock sub-sector consists of cattle and calves, although livestock owners in Colorado do raise other animals (e.g., sheep, goats, horses, etc.). The focus on cattle is due to the nature of grazing. Drought can severely impact ranchers by limiting forage availability, thus reducing the carrying capacity of traditional grazing areas. In response local, state, and federal land-holders restrict the number of grazing leases issued in a drought year. Raising cattle for meat also depends on having adequate pasture and finishing feed sources (e.g., corn, hay, alfalfa, etc.) (Luecke et al., 2003). The herd is turned out to graze in the summer and brought back in the winter, where they are fed stored hay and grain. The stored feed is either grown by the rancher or purchased from an outside source, either an in-state farmer or an out-of-state one. This reliance on supplemental feed in the wintertime (generally hay, which can be both irrigated or dryland) means that cattle ranchers are vulnerable to drought impacting the crop sub-sectors as well.

Other animals that are housed in feedlots or on small farms generally consume hay and grains purchased from both in- and out-of-state growers and water from various sources such as municipalities, private wells, or surface water rights. These operations can be secondarily affected by drought in that feed may become more expensive or hard to obtain, and their water supply may become reduced or restricted. However, the value of the livestock is generally such that operators have invested in senior water rights or another secure supply of food and water (much like high-value irrigated crop farmers tend to invest in senior water rights to ensure the viability of their fields). Dairy production is mentioned here but not considered in this assessment because the dairy operations are accustomed to purchasing feed on a year-round basis, and thus are fairly insulated from localized droughts (communication with CDA, 2010). The map shown in Figure 6.2 is a head count of total cattle per county. The data comes from the 2017 NASS survey database and should be evaluated with the 2017 NASS census numbers when that dataset becomes available.

The crops sub-sector consists of irrigated and dryland (non-irrigated)² crops grown around the state. Major dryland crops are winter wheat (grown on the eastern side of the state), pastureland, and beans (McKee et al. 2000). Dryland millet production has increased substantially in the last decade. Roughly 90% of Colorado's wheat is grown under dryland conditions, while about 75% of corn grown for grain is irrigated (Situation Statement, Colorado State University [CSU], 2010).

Dryland crops, which are entirely dependent on precipitation, are distinguished from irrigated crop for this assessment because they are more susceptible to damage by droughts. Dryland crops are particularly vulnerable to severe, "single season" droughts that deplete soil moisture (McKee et al., 2000). Figure 6.8 shows the dryland cropland concentration as a ratio of total farmland for each Colorado county (NASS, 2012). Total dryland cropland area was calculated by subtracting the ag

² Dryland crops are crops that are not irrigated and are grown in a semiarid climate. In Colorado, non-irrigated crops are essentially dryland crops, although this may not hold true for other states and other climate regions.

land irrigated area from the total farm area (NASS, 2012 Census). Wheat is the dominant crop on Colorado's 8.9 million acres of non-irrigated cropland, and Figure 6.9 illustrates the harvested wheat coverage by county. Annually, it occupies about one quarter of these acres, which is more than the total of the next five most extensively grown dryland crops (e.g., corn, sorghum, hay, proso millet, and sunflowers). (Situation Statement – CSU, 2010). After winter wheat, other crops primarily found on the eastern plains include corn, sorghum, proso millet, sudex, and sunflowers. These crops are commonly rotated with wheat. Livestock producers, located throughout the state, often plant annual forage (dryland) to feed their herd in the winter months.

There is a wide range of irrigated crops grown in Colorado, such as irrigated hay on the western slope, irrigated vegetables located throughout the state; and fruit orchards and vineyards, which are concentrated mainly in Mesa County. Specific examples of irrigated crops in Colorado include corn, sorghum, dry beans, barley, potatoes, sugar beets, and vegetables (McKee et al., 2000). Due to the extensive variety of crops grown in Colorado, specific crop discussion is limited except as it relates to geographic areas of the state.

Geographic distribution of total crop acreage is shown in Figure 6.3, which illustrates that there is a higher percentage of land (as a percentage of county land area) in farms on the eastern plains than on the western slope (NASS, 2012). The 2012 estimated agricultural land area with irrigation application is provided in Figure 6.4 along with the Moderate Resolution Imaging Spectroradiometer (MODIS) Irrigated Agriculture Dataset for the United States (MIrAD-US) (Pervez & Brown, 2010). Figure 6.5 and Figure 6.6 illustrate the total agriculture area devoted to cropland and pastureland respectively (NASS, 2012). Figure 6.7 shows the distribution of some common crops as they are grown throughout Colorado. The image was created by classifying land cover types from a Landsat image with a ground sampling distance of 30 m. Some trends in cropping include fruit orchards and vineyards in Mesa County, oats and barley in the San Luis Valley, and the dominance of the eastern plains by pasture/grass (yellow-green) and winter wheat (brown).

The final sub-sector in the Agriculture Sector is the green industry, which contains a number of significant secondary sub-sectors such as landscape labor fields (e.g., landscaping companies and grounds maintenance) and landscape designers (e.g., landscape architects, etc.). These industries would be impacted by drought if the growers were unable to provide plants, or if the owners of the yards voluntarily chose or were mandated to reduce watering and/or stop new planting. However, the main focus of this report is on the primarily impacted areas - namely, the growers (e.g., nurseries, floriculture, sod, etc.). These producers within the green industry are impacted when drought impedes their ability to grow a product that can be sold to the consumer.

According to an independent study by CSU, the green industry in Colorado contributed approximately \$2.8 billion to the economy in 2015 (Bauman & McFadden, 2017). The direct market value of nursery, garden center and farm supply stores in 2015 was \$980 million. This illustrates the “value added” multiplier that green industry products (and other agricultural products) have as they are processed and sold to consumers. Colorado's green industry grew by

\$900 million (90%) during the 1999 to 2015 period although 2015 sales finally surpassed 2007 levels (pre-recession) by 2%. During the same 1999-2015 period green industry employment levels grew from 35,000 to 43,000 with 2015 employment yet to surpass the 2007 mark (Bauman & McFadden, 2017).

For USDA statistical purposes, the following “crops” or categories are considered part of the green industry in Colorado (as listed in the NASS CO Ag Census 2007):

- Aquatic plants
- Bulbs, corms, rhizomes, and tubers
- Cuttings, seedlings, liners, and plugs
- Floriculture crops - bedding/garden plants, cut flowers and cut florist greens, foliage plants, potted flowering plants, and floriculture and bedding crops
- Flower seeds
- Greenhouse fruits and berries
- Greenhouse vegetables and fresh cut herbs
- Mushrooms
- Nursery stock and crops
- Vegetable seeds and transplants
- Sod harvested
- Cut Christmas trees

With the emergence of the medical and recreational marijuana industry, it is recommended that future updates to the plan attempt to quantify the agricultural impact of this growing sector. Currently, a large majority of the marijuana industry grow operations take place indoors, meaning water demands are often met by municipal water providers.

As shown in Figure 6.10, green industry producers (e.g., greenhouses, nurseries, sod growers, etc.) are primarily located in Weld, Larimer, and Boulder Counties on the east slope and in Mesa and Delta Counties on the west slope. In general, the green industry producers are located near urban population centers. There are some producers throughout the west and the south, and there are very few on the eastern plains and near the southwestern part of the state (in the vicinity of San Juan, Hinsdale, Mineral, and Archuleta Counties).

Since the Agricultural Sector is quite large, different seasons of drought will impact different sub-sectors. Table 6.1, below, discusses water use and seasonality in the Agricultural Sector.

Table 6.1 Seasonality and Water Use in the Agricultural Sector

Sub-sector	Season	Water Use
Crops: dryland	<ul style="list-style-type: none">• Successful crop depends on precipitation in the fall to start plant germination, and in the spring to develop the grain (McKee et al., 2000).	<ul style="list-style-type: none">• Water is required for adequate soil moisture to germinate and grow.

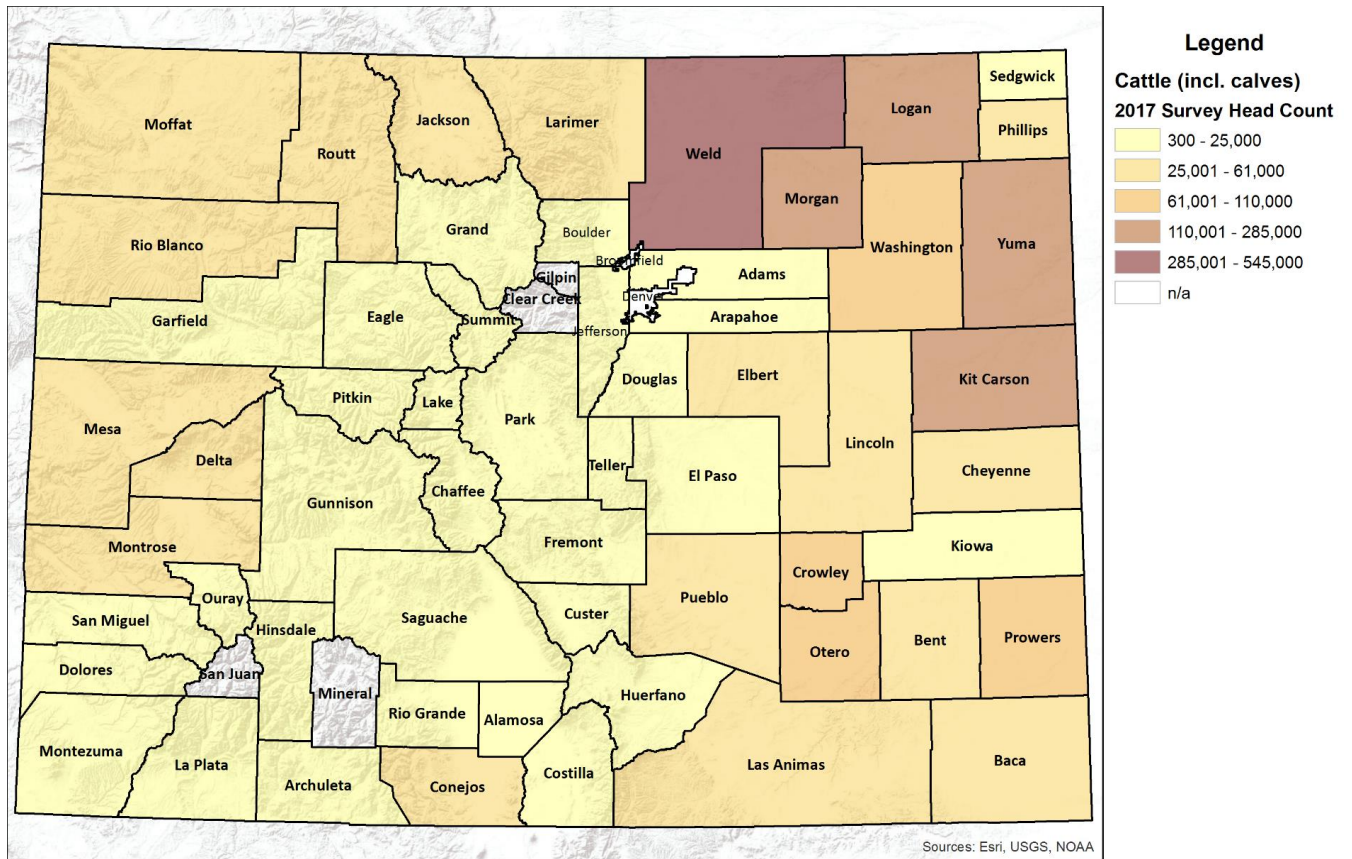
Sub-sector	Season	Water Use
	<ul style="list-style-type: none"> Winter wheat, the prominent dryland crop in Colorado, is generally planted on a 2-year rotating basis to allow the soil to accumulate enough moisture to support it. 	<ul style="list-style-type: none"> These crops are entirely dependent on precipitation.
Crops: irrigated	<ul style="list-style-type: none"> Water demands for most irrigated crops begin increasing in late April, peak in early July, and drop off into late October (McKee et al., 2000). 	<ul style="list-style-type: none"> Irrigation water is used to supplement natural precipitation and ensure the crop has adequate moisture to grow and produce the desired yield.
Livestock	<ul style="list-style-type: none"> Cattle released to grazing pasture in early summer, return around the time of the first snowfall. 	<ul style="list-style-type: none"> Animals need clean drinking water and plenty of forage land or pasture. Most cattle ranchers grow their own forage, either with irrigation water or through dryland practices.
Green Industry	<ul style="list-style-type: none"> Year-round production for greenhouses. Some greenhouses ship their plants to “winter” in the southeast part of the U.S. (communication with CSU economist, 5/26/10). 	<ul style="list-style-type: none"> Water is required to grow and maintain plants, trees, and sod. Source water is diverse - some growers have water rights, some have ditch rights, and some buy from municipalities.

Table 6.1 demonstrates that impacts from drought are not confined to a single growing season. In addition to being a year-round industry, the Agriculture Sector influences a number of other sectors of the economy and state, namely municipal and socioeconomic. The sub-sectors described above were chosen based on their economic impact to the overall agricultural industry and their immediately recognizable vulnerability to drought. Other sub-sectors that are not covered in this report but worth mentioning include:

- Livestock other than cattle, such as sheep, goats, chickens, pigs, etc. These animals would be impacted by drought but are much smaller in numbers than cattle.
- “Agri-tourism,” which is tourism centered on agricultural attractions (e.g., wineries), is a growing sub-sector within agriculture. Not only do these farms produce and sell fruit, but a growing tourism industry is developing around wine-based activity in Colorado. A report was conducted by CSU in 2013 on the economic contribution of the wine industry in Colorado. Among their findings: Colorado wineries reported approximately \$24.8 million in wine sales. Considering both Colorado wine-based events and visits to wineries by in and out-of-state visitors, the industry contributed about \$144 million in total effects to the Colorado economy in 2012 (Thilmany & Costanigro, 2013).

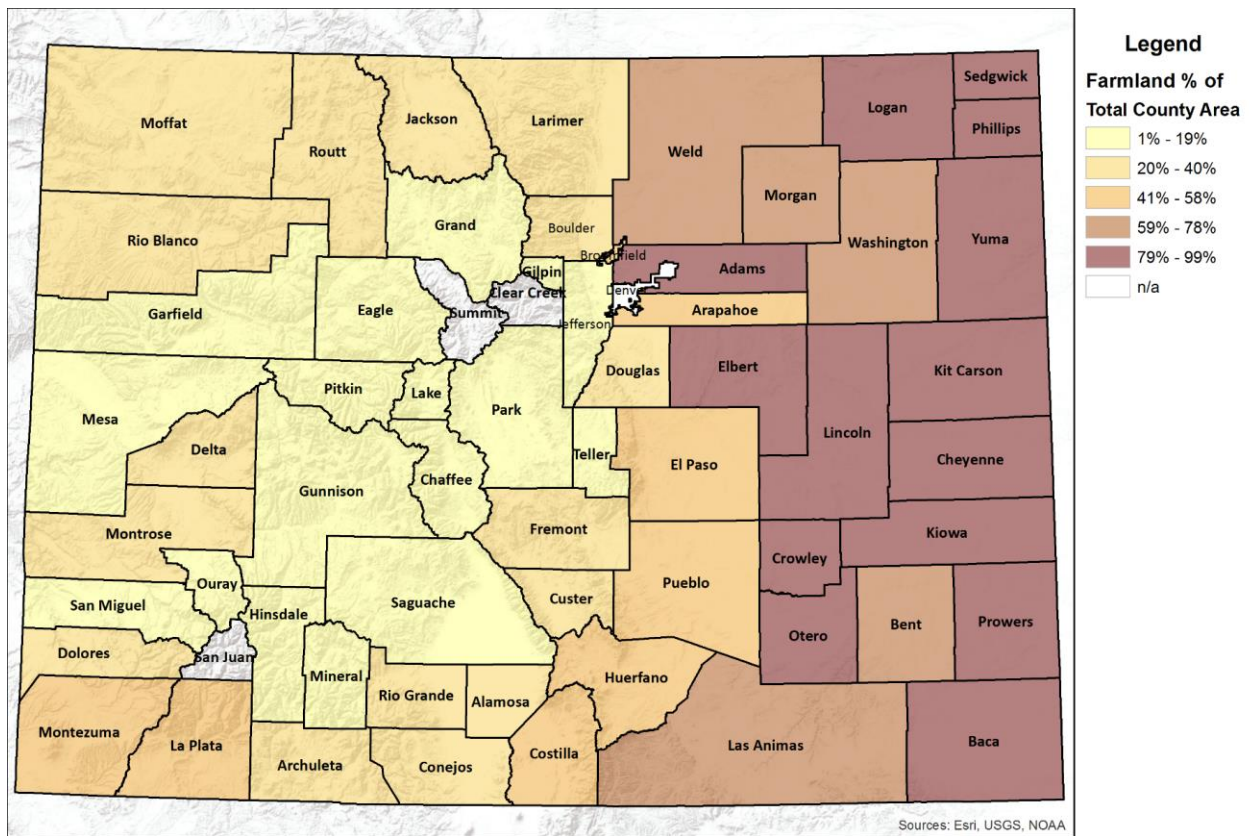
The following sections discuss aspects of vulnerability to drought in the Agriculture Sector, and cover adaptive capacities used to mitigate the impacts. For a general description of the vulnerability assessment approach refer to Chapter 2 of Annex B.

Figure 6.2 Cattle Head Count per County



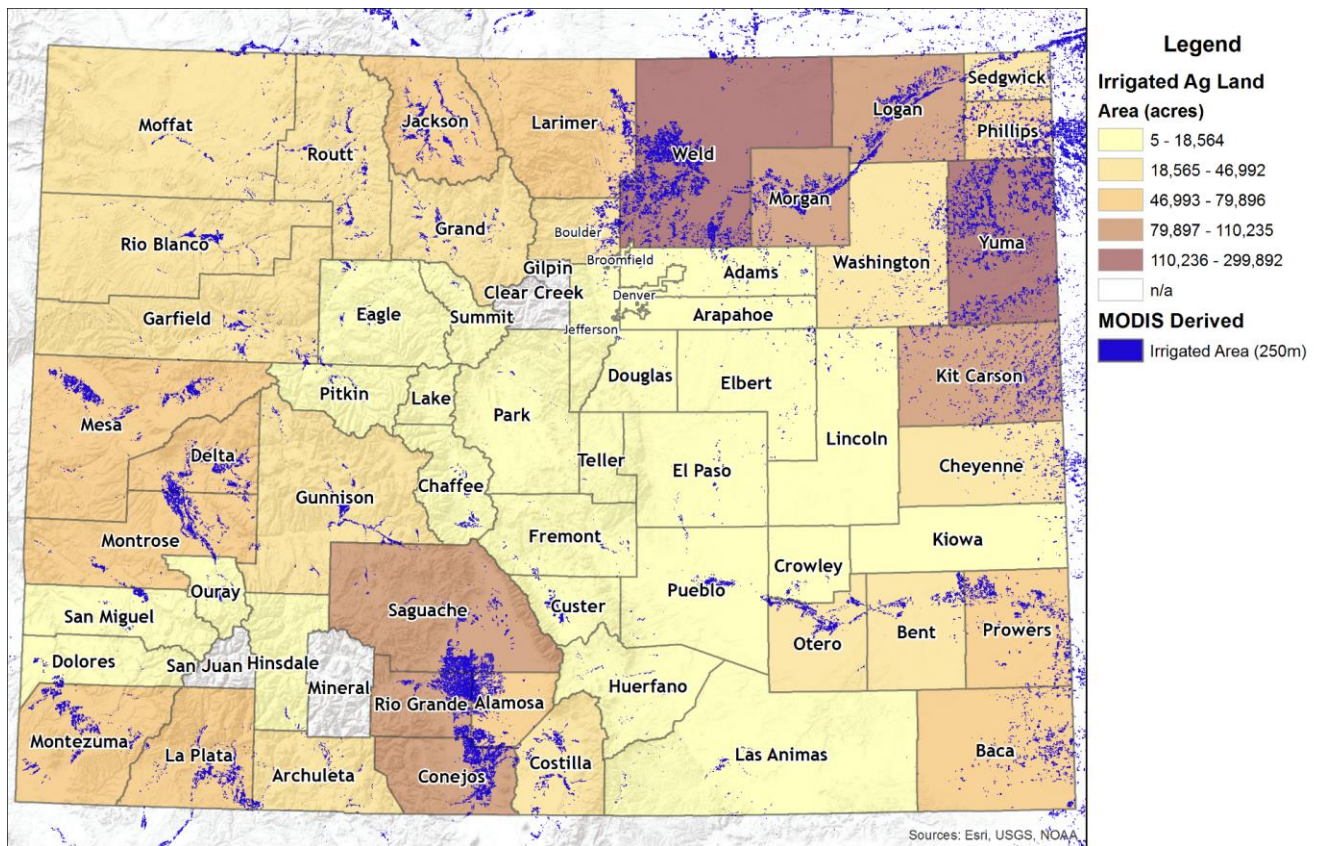
Data Source: NASS, 2017

Figure 6.3 Percentage of Total County Area Dedicated to Farmland



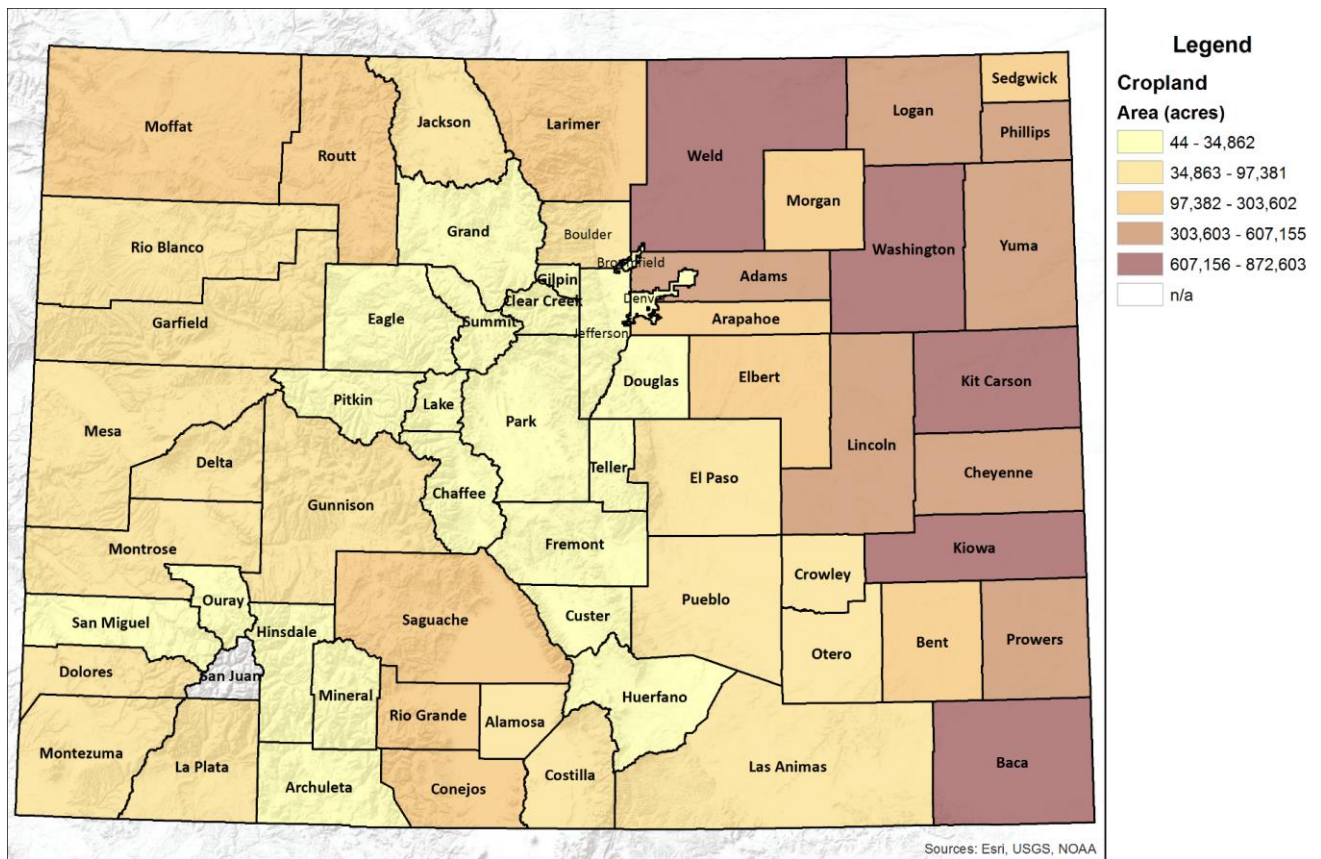
Data Source: NASS, 2012

Figure 6.4 Total Agricultural Land Area with Irrigation



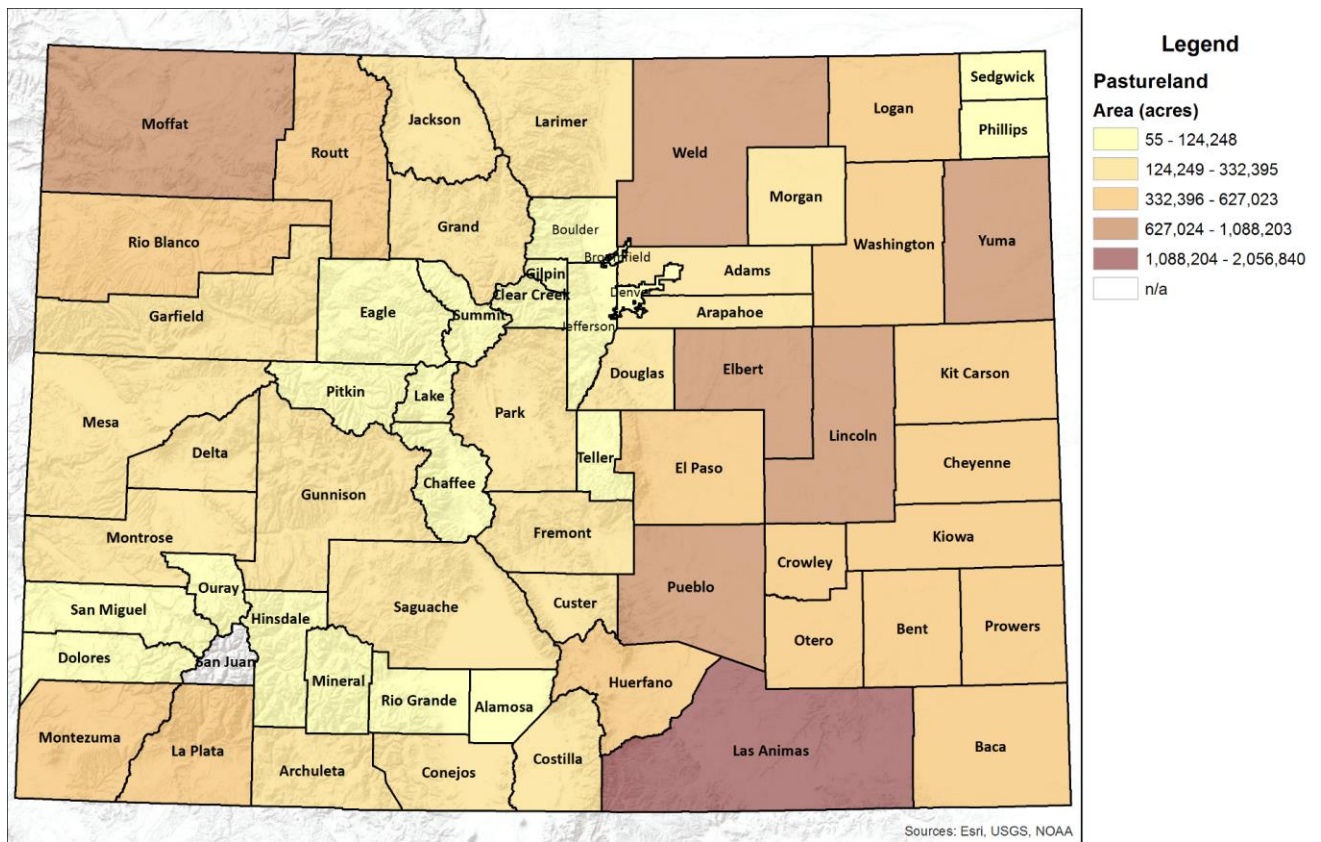
Data Source: NASS, 2012

Figure 6.5 Total Area Dedicated to Cropland Agriculture



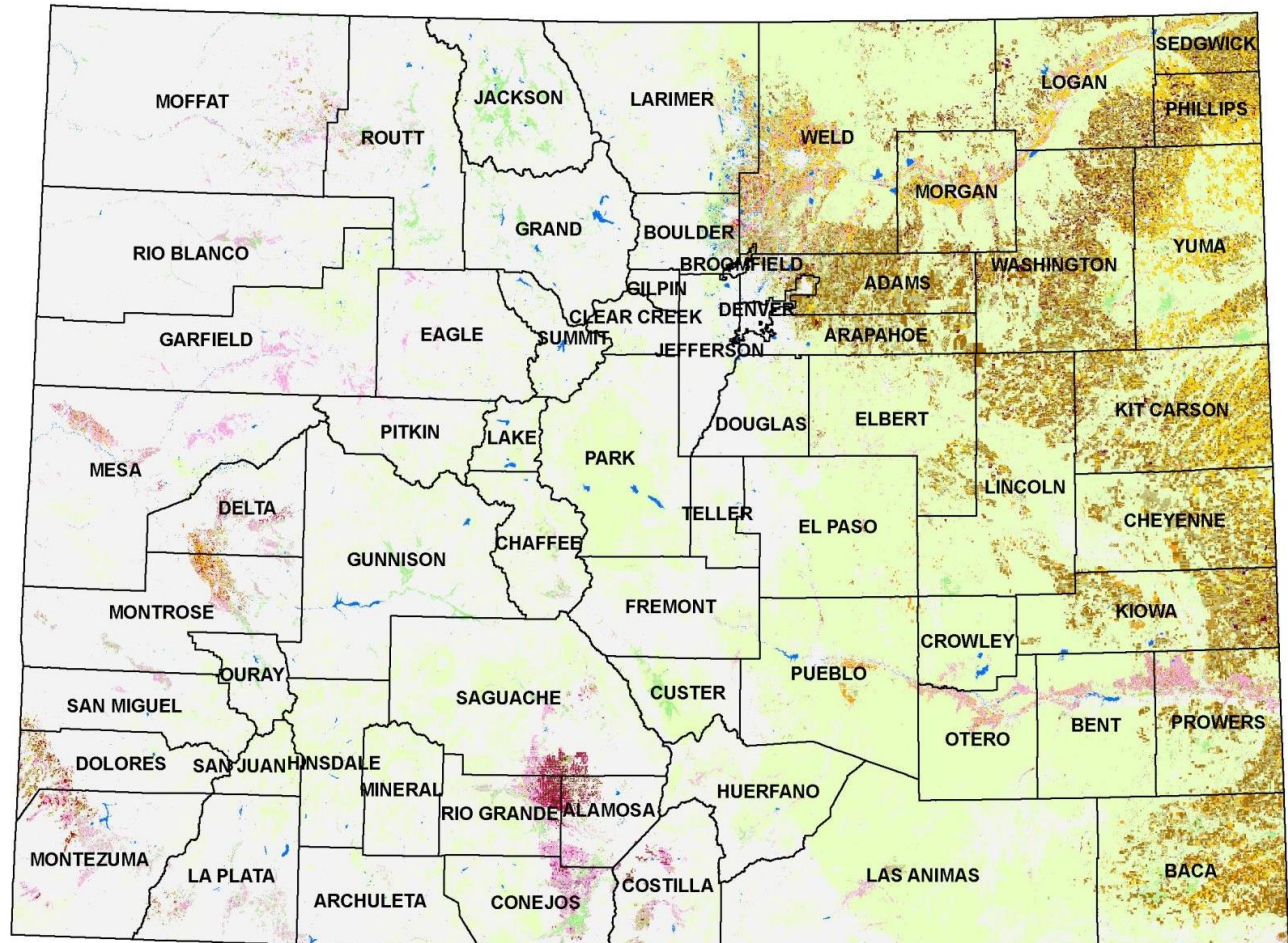
Data Source: NASS, 2012

Figure 6.6 Total Area Dedicated to Pastureland



Data Source: NASS, 2012

Figure 6.7 Crop Types Across Colorado

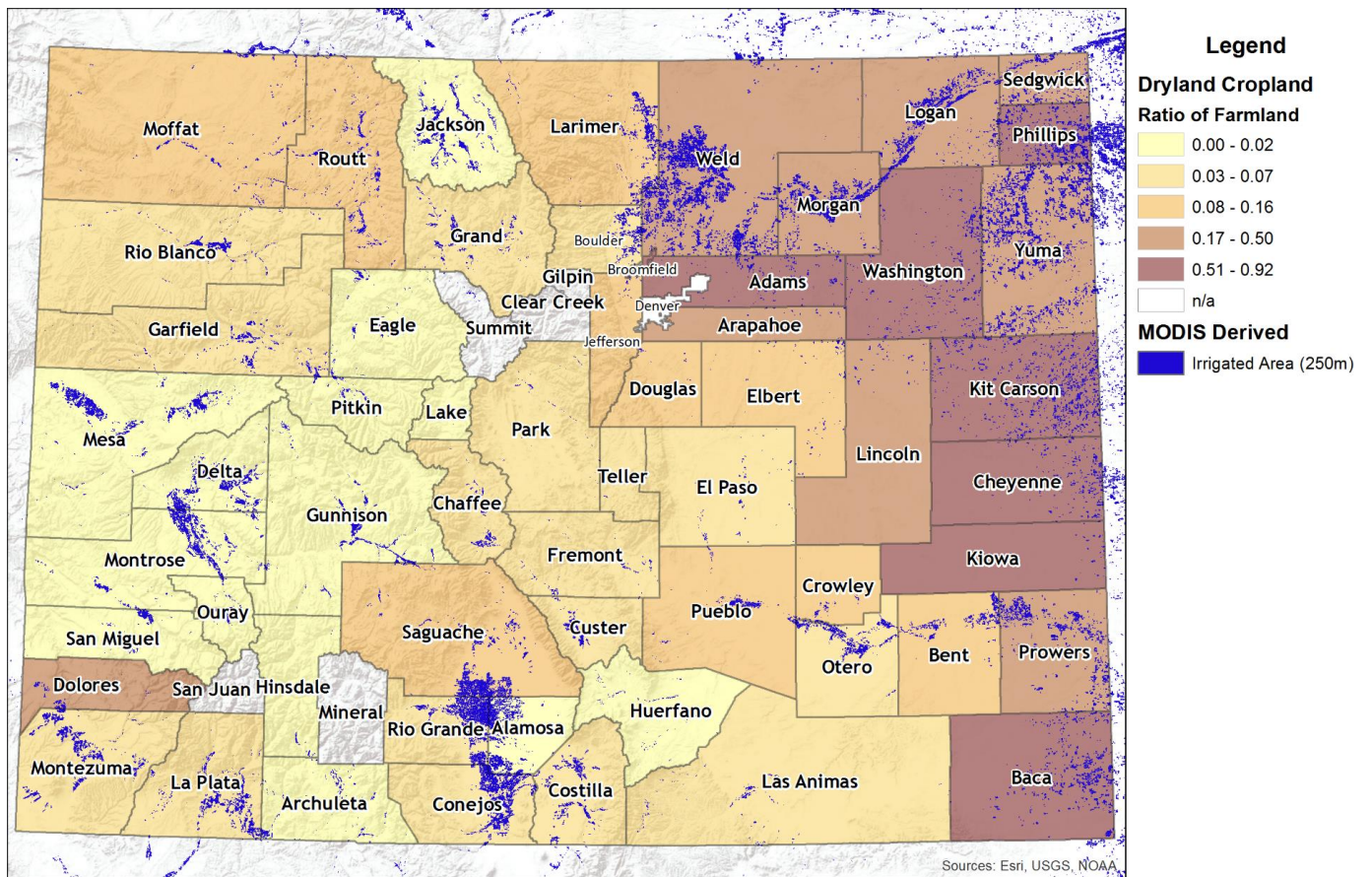


**2012 Colorado
Land Cover Categories (by decreasing acreage)**



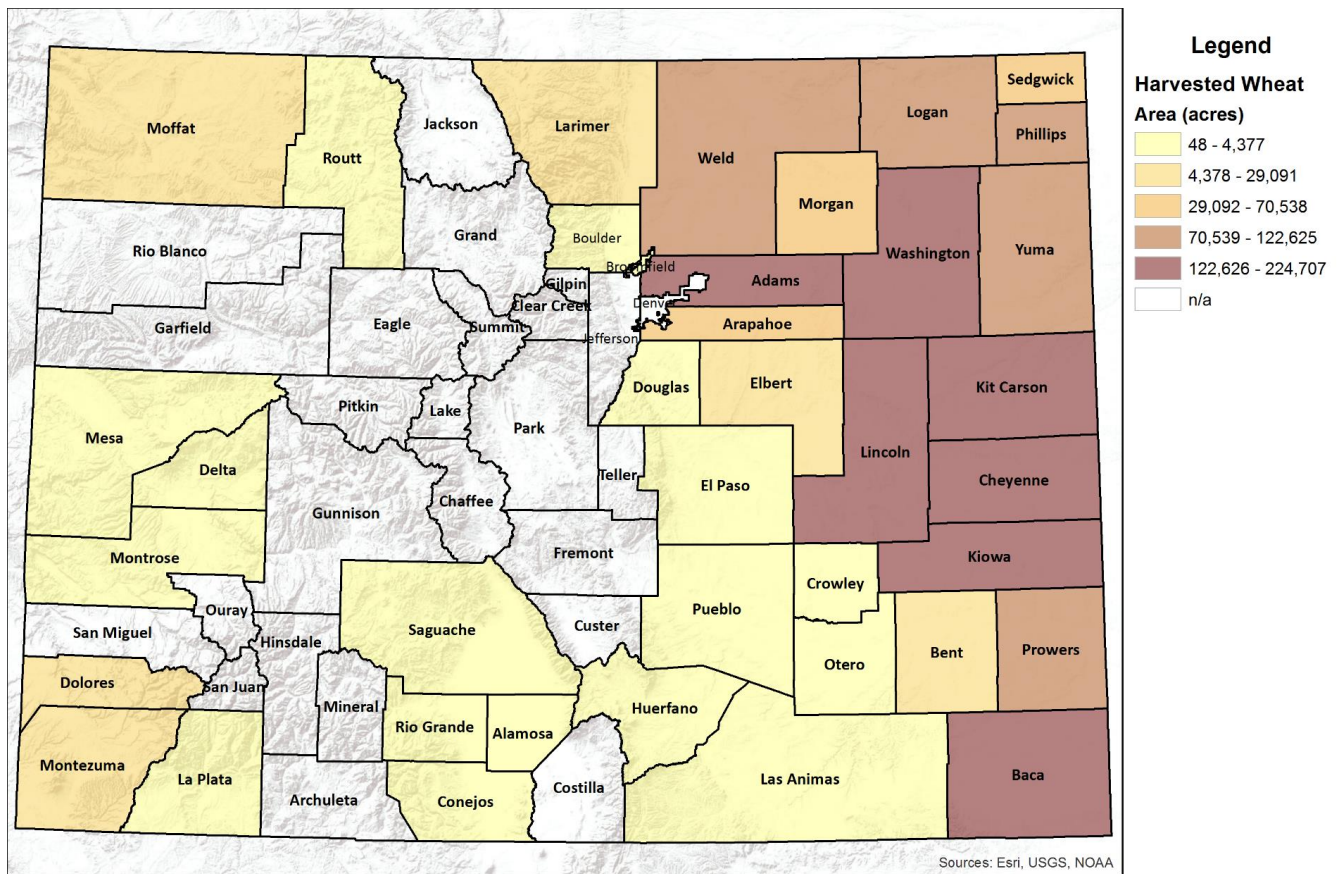
Data Source: USDA, NASS Crop Data Layer Program, 2012

Figure 6.8 Ratio of Farmland Area Consisting of Dryland Crops



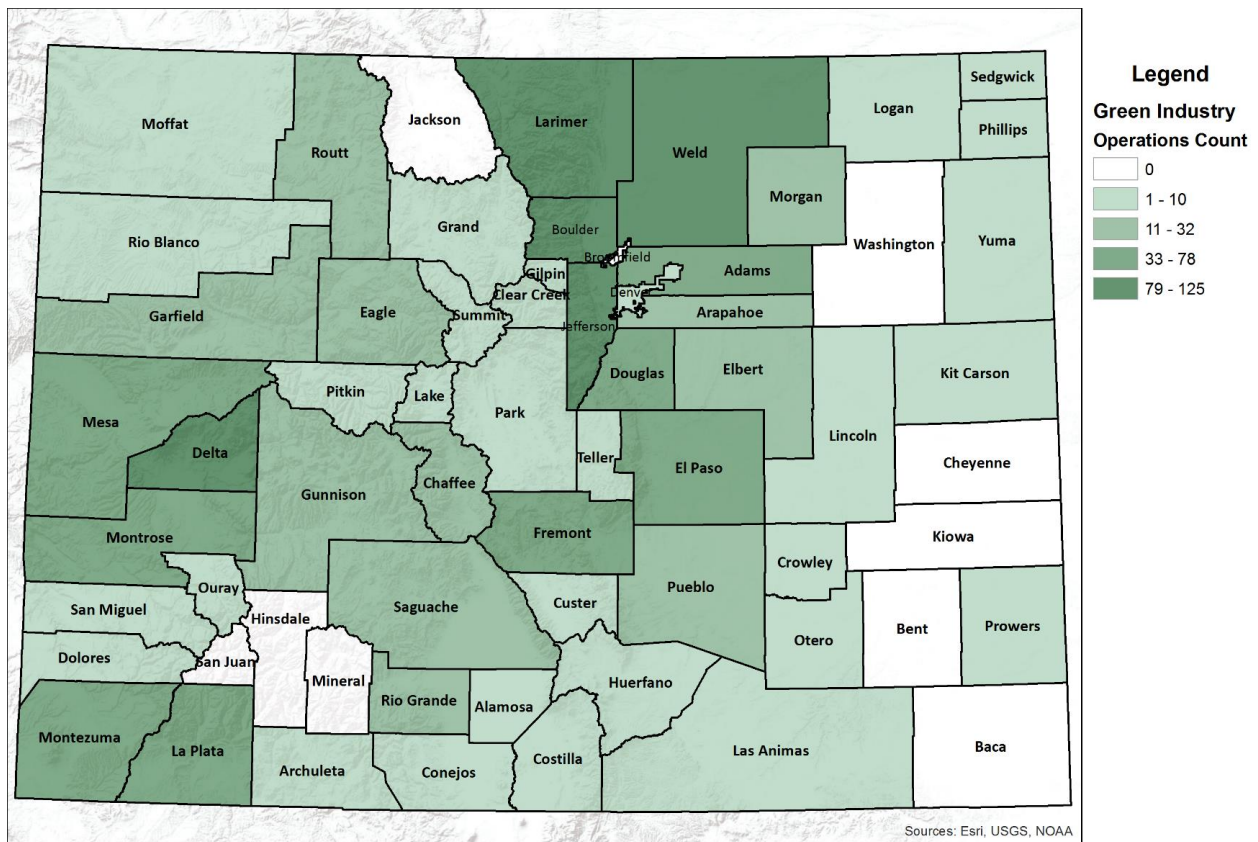
Data Source: NASS, 2012

Figure 6.9 Harvested Wheat Area



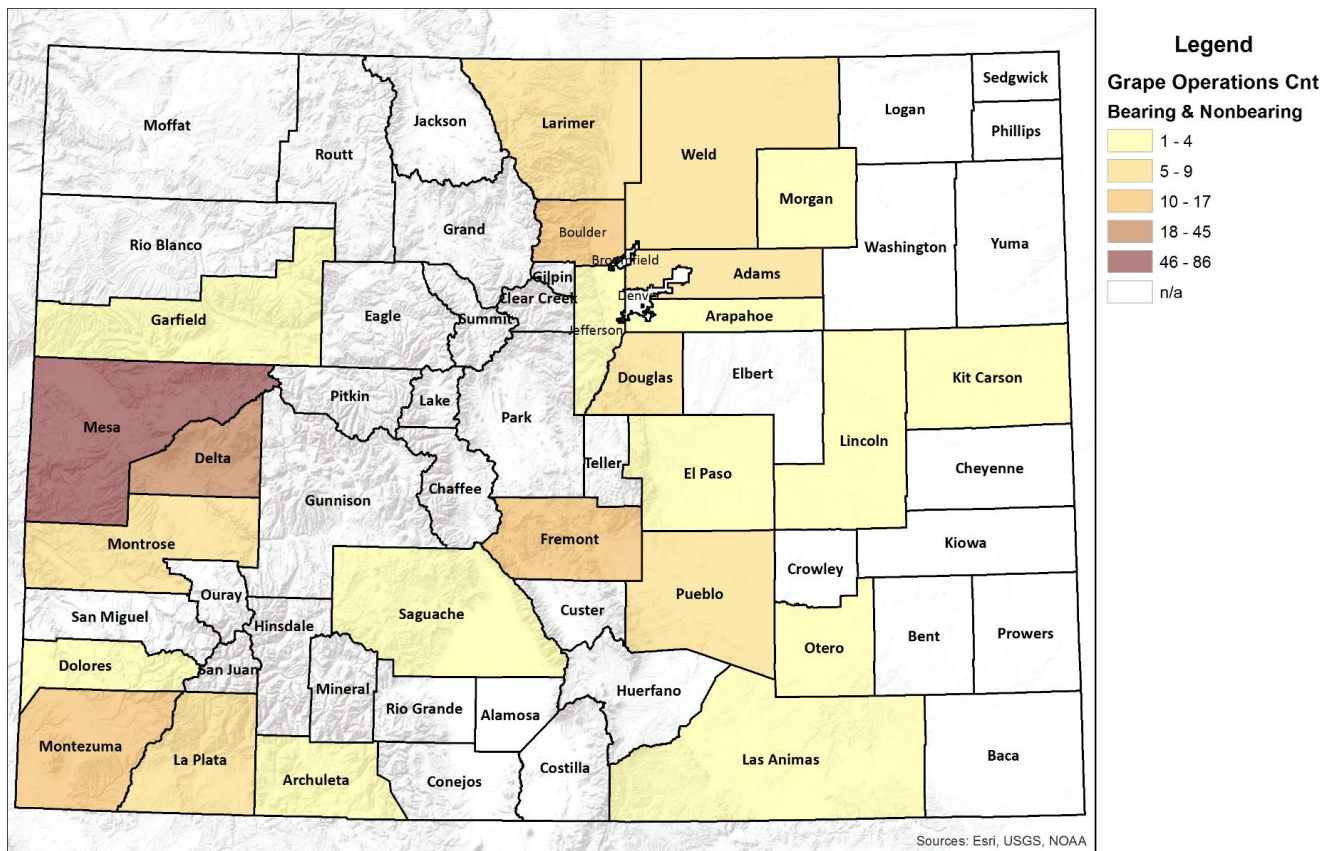
Data Source: NASS, 2012

Figure 6.10 Location of Green Industry Producers



Data Source: NASS, 2012 (includes estimates from nursery, floriculture, sod, horticulture, and cut Christmas trees)

Figure 6.11 Location of Grape Growing Operations



Data Source: NASS, 2012

6.2 Vulnerability of Agricultural Sector to Drought

6.2.1 Aspects of Vulnerability

Agriculture is vulnerable to drought when there is not enough water to sustain crops or livestock and livestock forage. This is largely dependent on precipitation, water rights, and relative magnitudes of supply versus demand that exist in the area.³ Agricultural users have four sources of water: direct precipitation, streamflow diversions, reservoir storage and releases, and groundwater withdrawals (McKee et al., 2000).

Agriculture is the dominant water use in Colorado. Estimates from the latest published Statewide Water Supply Initiative (SWSI) show that approximately 86 % of the water diverted and consumed in Colorado goes to irrigate crops (SWSI, 2010). Projected agricultural water use will continue to be primary consumer of Colorado's water supply; however, the percentage of agriculture water consumption is expected to decrease to 82 % by 2050 (SWSI, 2010). As urban development continues and the state's population grows, entities seeking new water supplies will increasingly look to agriculture to meet their growing demands for urban water (SWSI, 2010). This statement from the previous SWSI highlights the supply versus demand issue – in fast-growing areas, demand will outpace supply and municipal demands to purchase agricultural water rights could put pressure on farmers to sell. There is also long-term increased competition for water from other sectors, such as recreation and the environment. An upcoming update to the SWSI study began in 2017 and is expected to be published in the second half of 2018; with this update will be included more detailed scientific information to guide water basin roundtables, the next round of the Colorado Water Plan, and many other key pieces that relate to water use in the many sectors of Colorado's economy, including agriculture. The SWSI 2017/8 Update fact sheet can be found at CWCBC's website (SWSI 2018).

In addition to reduced water quantity due to drought conditions, the quality of irrigation water is a concern, as crops are sensitive to salts and other impurities in the water. Lower flows can concentrate soluble salts and result in lower crop yield (Bauder et al., 2007).

Table 6.2 and Table 6.3 are examples of how reduced water quality can injure crops and reduce crop yield. Degraded water quality is one effect of drought. Table 6.2 shows potential yield reduction from saline waters, and Table 6.3 shows plant susceptibility to injury from contact with saline water.

³ For example, agriculture faces growing competition with urban areas as population increases and municipalities seek to acquire new water rights.

Table 6.2 Potential Yield Reduction from Saline Water for Selected Irrigated Crops

Crop	Percent yield reduction at measured EC _w *			
	0%	10%	25%	50%
Barley	5.3	6.7	8.7	12
Wheat	4.0	4.9	6.4	8.7
Sugarbeet	4.7	5.8	7.5	10
Alfalfa	1.3	2.2	3.6	5.9
Potato	1.1	1.7	2.5	3.9
Corn (grain)	1.1	1.7	2.5	3.9
Corn (silage)	1.2	2.1	3.5	5.7
Onion	0.8	1.2	1.8	2.9
Beans	0.7	1.0	1.5	2.4

*EC_w is electrical conductivity of the irrigation water in dS/m at 25 degrees Celsius and is a common measure of salinity. Source: Bauder et al., 2007

Table 6.3 Susceptibility Ranges for Crops to Foliar Injury from Saline Sprinkler Water

	Na or Cl concentration (mg/L) causing foliar injury*			
Na concentration	<46	46-230	231-460	>460
Cl concentration	<175	175-350	351-700	>700
	Apricot	Pepper	Alfalfa	Sugarbeet
	Plum	Potato	Barley	Sunflower
	Tomato	Corn	Sorghum	

*Foliar injury, which is damage to the surface or leaves of the plant, is also influenced by cultural and environmental conditions. Source: Bauder et al., 2007

Vulnerability to the livestock sub-sector is primarily a function of forage and pastureland availability. When the lands are stressed by drought and the quality of hays and grasses for cattle to graze upon is decreased, ranchers can see sickness and deaths in herds. Decreased water quality is also a concern, as grazing cattle can become sickened if watering holes are contaminated, filled with sediment, or completely dry. In drought conditions rangelands may become unviable for grazing at the same time as feed costs soar. At some point the situation may become unviable and ranchers may be compelled to sell breeding cows to out-of-state interests. A significant impact of such an action is that it can take several years to rebuild the loss of genetic diversity from such sales. Grasslands may recover from drought (and the over-grazing that can result) very slowly, giving invasive weeds and other undesirable species the advantage over native grassland plants. Associated with a decrease in production is an increase in toxicity during drought. When the usual forage becomes scarce, cattle may reach to plants that are potentially toxic. These plants are generally grouped into nitrate accumulators, prussic acid producers, and noxious weeds.

The green industry is vulnerable to drought in much the same way the irrigated crop sub-sector is. Junior surface water rights can be called out of priority during a drought, leading to less water

available for irrigation, which could cause reduced plant yield or plant loss. There is a minority of growers who rely on municipal supplies and could be subject to municipal restrictions. Decreased water quality (i.e., increased salinity or other contaminants) can cause foliar (leaf) injury and limit the ability of the grower to sell their plants to the public and wholesale distributors. Municipal restrictions on water use can cause consumer demand for landscape plants and new turf to sharply decrease, resulting in fewer sales for growers and loss of revenue.

6.2.2 Previous Work

A review of previous works dealing with drought and agriculture in Colorado was conducted to augment findings from the 2013 Plan update. Updates focused on summarizing the newer literature and research focusing on the 2012-2013 drought period. Table 6.4 summarizes the impacts and results of the literature review.

An overview of drought conditions represented by the 2011-2014 U.S. Drought Monitor (USDM) is provided in Figure 6.12. Agricultural drought impact reports were obtained from the National Drought Mitigation Center Drought Impact Reporter database and a monthly count of new reports is overlaid on the USDM drought categorical coverage data. This illustration attempts to provide a statewide summary of drought conditions along with a general timeline of reported agricultural drought impacts. The rapidly deteriorating drought conditions during the 2012 summer are highlighted by a peak in new agricultural impact reports.

Figure 6.12 2011–2014 USDM Drought Index and Impact Reports Timeseries for Colorado

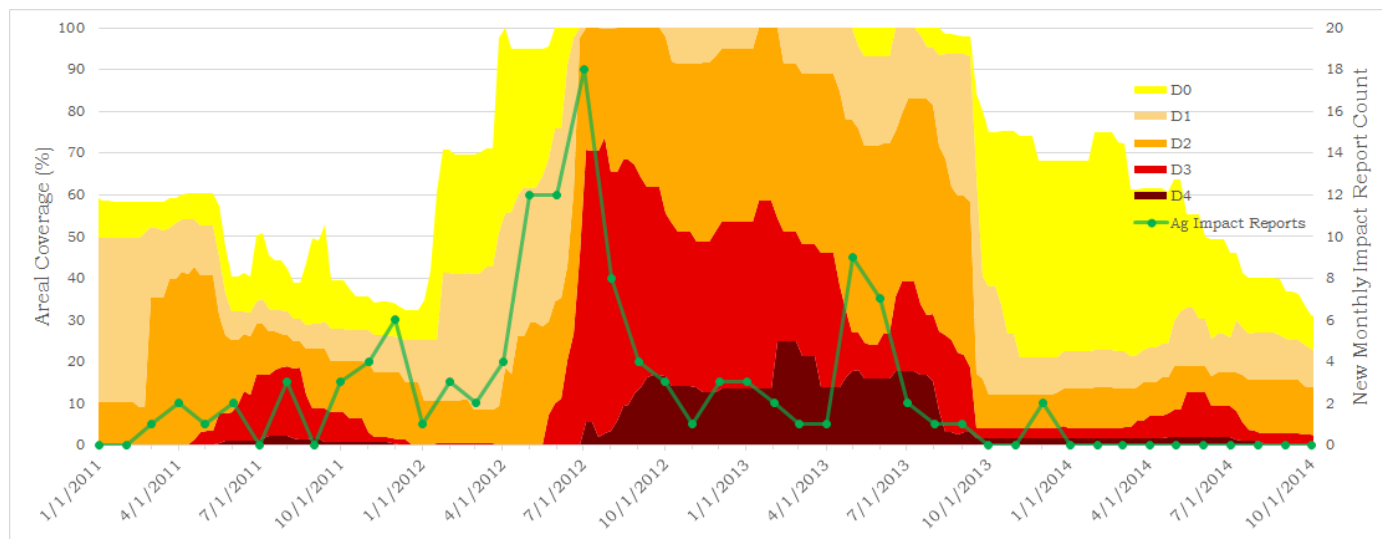


Table 6.4 Previously Reported Agricultural Impacts

Sub-sector	Previously reported impacts	Sources
Livestock	<ul style="list-style-type: none"> ● In response to the 2002 drought, ranchers ran short of pasture grass and finishing feed and were forced to sell off some of their herds. Estimates are that the herds in Colorado declined by 50%. The Colorado Farm Bureau estimated the direct loss to the livestock sector at \$154 million. ● For 2002, crop and livestock losses due to drought were estimated at \$150 million for ranchers and \$300 million for farmers... As a result of reduced forage and water for livestock, the emergency grazing provisions of the Conservation Reserve Program lands were implemented through USDA Natural Resource Conservation Service (NRCS). ● In 2002, cattle – 50% of cows were sold statewide, 80% of the cows in the southern third of Colorado were sold equating to about 450,000 head of cows, over 1 million statewide. Financial impact: \$154 million loss... Some ranchers paid high prices to move their cattle out of state to feed them in the fall and winter. ● During 2002, sheep – range in poor conditions (fall and winter), lack of crop aftermath for winter grazing (lack of wheat stubble, corn stocks, alfalfa field, etc.) ● For the 2012 drought, ranchers were once again forced to sell part of their herds, including breeding stock in some cases. ● Ranchers noted decreases in cow health, weaning rates, and breeding rates, the effects of which will carry over into subsequent years. ● Production costs increased for ranchers as a result of decreased production on ranchlands. The cost is estimated at roughly \$110 million, which is a 10-15% increase over the period 2005-2010. ● Due to the reduction of forage and feed production the cost raising a cow increased ~40% ● Survey results suggest that the number of cows statewide decreased 48% from normal during 2012. ● Due to the spatial extent of drought in 2012, ranchers were unable to transport their animals to more productive ranchlands, as the drought covered increasingly significant portions of the western US. 	<p>Luecke et al., 2003</p> <p>DWSA 2004</p> <p>Christensen 2002</p> <p>Nelson et al., 2012</p> <p>Gunter et al., 2012</p> <p>Pritchett et al., 2013</p> <p>Pritchett et al., 2013</p> <p>LMIC, 2013</p>
Crops - dryland	<ul style="list-style-type: none"> ● During the 2002 drought wheat was particularly hard hit. The loss from the drought was between 30 and 45 million bushels with an average price around \$4 during 2012. ● For 2002, the dryland corn crop was a near total loss from about 20 million bushels. ● Wheat – economic loss of '02 winter wheat was estimated at \$120 million. Crop projected at only 38 million bushels (83.4 million bushels is 10-year average – smallest harvest since 1968). 30% (700,000 acres) abandoned and not harvested. ● Dryland corn – “toast” (implying almost complete loss). ● During 2002 irrigated corn – early projections showed reduced yields by at least 10-15% or more. ● Sunflowers – down 71% in production ● For the 2012 drought, the Arkansas basin, which is ~37% dryland, saw significant decreases in crop yields (refer to ● ● 	<p>Luecke et al., 2003</p> <p>Christensen 2002</p> <p>Gunter et al., 2012</p> <p>Gunter et al., 2012</p>

Sub-sector	Previously reported impacts	Sources
	<ul style="list-style-type: none"> ● Table 6.5 below). Revenues decreased approximately \$85 million from the 1998 to 2010 average. ● Secondary impacts in the Arkansas Basin from the decrease in crop yield include a decrease in economic activity of roughly \$105 million, including loss of approximately 1300 jobs. ● August of 2012, only 3% of the total pasture and rangeland acres in Colorado were rated good condition or better while 81% were rated poor or very poor. 	Ryan & Doesken, 2015
Crops-irrigated	<ul style="list-style-type: none"> ● During the 2002 drought, yields in irrigated cornfields approached normal, although some farmers apparently cut fields early to use as silage. ● Fruit farmers on the Colorado and Arkansas Rivers were able to utilize their very senior water rights in the 2002 drought, and thus suffered only small decreases in yield. ● For the 2012 drought, irrigated crops in the Rio Grande Basin were not impacted, showing slight increases in barley, potatoes, and wheat. Revenues were \$12 million greater than the 1998-2010 average. ● An increase in yield in the Rio Grande Basin generated an approximately \$5 million increase in economic activity and 42 new jobs through secondary impacts ● In 2012, Hay production was limited to 10- 50% of average. ● Corn prices increased in 2012 by 43% in just two years 	Luecke et al., 2003 Gunter et al., 2012 Gunter et al., 2012 Ryan & Doesken, 2015
Green industry	<ul style="list-style-type: none"> ● Harm to producers due to municipal restrictions/limitation; secondary impacts to landscaping companies. ● In 2002 the green industry in Colorado lost about 15,000 jobs and \$75 million in revenue. 	Reported impact survey, municipal workshop conducted January 2010 Proctor 2003

The following commentary highlights impacts to the ranching community during the 2002 drought (Christensen, 2002):

“Many farmers and ranchers are soul-searching on whether to stay in agriculture or not. Older farmers and ranchers have or are ready to retire... The younger farmers and ranchers are struggling getting started, but have not necessarily made big investments and may choose to get out. Perhaps the most vulnerable group might be the middle-aged group of farmers and ranchers. They are in it too far to just quit, but still have a long ways to go before retirement.”

From the 2002 Colorado Drought Conference, the following drought mitigation successes were reported (Christensen, 2002):

Federal disaster assistance was requested by the governor and the USDA announced all counties in Colorado were eligible for drought disaster. Emergency grazing on Conservation Reserve Program (CRP) acres was approved by the USDA for numerous counties, extended through December 31 or until disaster no longer exists. USDA also announces \$752 million in Livestock

Compensation assistance for livestock producers, which includes beef and dairy cattle, sheep, goats, and buffalo producers.

These sentiments were also true for the 2011-2013 drought event. Farmers and ranchers struggled with decisions to stay in the business with many saying they will leave if the drought continued (Pritchett et al., 2013). Through fiscal years 2011 and 2012 the USDA-Farm Service Agency (FSA) delivered \$342.8 and \$395.6 million (respectively) in federal program payments and loans to Colorado farmers and ranchers.

In order to better understand the impacts of drought on the agriculture sector, the CWCB, Colorado Department of Agriculture (CDA), and Colorado State University (CSU) initiated a study of drought impacts for 2011. The project consists of three parts, including a history of agriculture in the Arkansas and Rio Grande River basins, a survey of producers in the impacted regions, and an economic analysis of drought impacts in the same regions.

The goal of the survey (Nelson et al., 2012) was to describe how farm and ranch managers changed their business practices in response to drought in 2011. The survey focused on 17 counties located within the Arkansas and Rio Grande River basins that FEMA designated as disaster areas in 2011 due to drought severity. 56 surveys were fully completed, with the majority of respondents from the Arkansas Valley. The following impacts were noted:

- Reduced regional spending by agricultural producers on inputs to farming operations negatively impacted associated businesses and households;
- Higher feed costs associated with a decrease in ranchland production;
- Ranchers saw significant impacts in cow health conditions, weaning rates and breeding rates;
- Ranchers were forced to sell breeding livestock to cope with the drought;
- Some ranchers were able to move livestock, substitute feed, and/or sell portions of their herd to mitigate for the drought

The survey also pointed out the relatively uneven distribution of impacts between irrigated versus dryland farming. Irrigated areas reported equal or greater profits, partially a result of being able to sell crops at relatively high prices.

The 2011 economic study by Gunter et al. (2012) built upon the survey mentioned above to examine the economic impacts of drought on agriculture in the Arkansas and Rio Grande basins in southern Colorado. Due to the severity of the drought FEMA declared 17 counties as disaster areas within these two basins. The study represents the third and final part of a study undertaken by the Colorado Water Conservation Board (CWCB), Colorado Department of Agriculture (CDA), and the Department of Agricultural and Resource Economics at Colorado State University (DARE-CSU).

For the study, drought impacts were divided into primary and secondary effects. Primary effects are those that directly impact productive capacity (e.g., yields), while secondary impacts are those industries indirectly impacted, via forward (e.g., output sold to consumers) or backward linkages

(e.g., amount paid to labor). The total economic impact of drought within the region is the sum of the primary impacts, plus the secondary impacts to households and/or industries not directly impacted by the drought.

Impacts to production costs are most felt by industries in the forward linkages, such as meat packing plants. Production costs can be impacted by a decrease in the supply of key inputs (e.g., grain products) and by an increase in demand for feed products because of reduced productivity on grazing lands. Both lead to an increase in production costs.

Most recently, Western Water Assessment (WWA) worked with the CWCB and the CDA to create an anonymous online survey for agricultural producers in Colorado. The goal was to better understand the water and drought challenges farmers and ranchers face, including their past experiences and future concerns about drought for their operations. The online survey was open from February to March of 2018. Forty-nine individuals from 33 counties completed the survey. Results from the survey suggest that farm and ranch operators look for ways to create efficiencies and minimize disruption to operations before and during drought. In the event of drought, 84% of survey respondents indicated that they would take one or more of the following actions to adapt: sell part of their herd, let some fields lay fallow, and adopt different technologies in anticipation of reduced water supply. Four of the 45 respondents indicated they would participate in municipal drought planning activities. Ninety percent of respondents had made changes since the last drought to their farmers and/or ranching practices to better prepare for the next drought. Overall, the WWA survey showed that most agricultural producers have been impacted by drought and that they are proactive in adapting their operations to be better insulated from drought impacts. Given the high level of interest in technology to adapt to reduced water supply, future outreach to the agricultural community regarding drought preparation could include a summary of the most current technology for conserving water.

Impact of Drought on Productivity

Impacts to primary industries were calculated as the difference between actual reported revenue and what they might have earned under normal (i.e. non-drought) conditions (these calculations assume that the drought was not anticipated, so planting behavior was unaltered, and that the prices of associated goods and services were similar to those observed in non-drought conditions.) Drought impacts in the study area were quite different between the two basins examined. This is largely thought to be a result of the fundamental difference in crop composition in each of the basins. The Rio Grande basin has a much smaller percentage of dryland farming (<10%) than the Arkansas (~37%), and the disparity between the two basins can be seen in yield numbers Table 6.5 In the Rio Grande, yields were actually higher for some crops (i.e., barley, potatoes, and wheat), while in the Arkansas significant reductions were reported in all crops.

Table 6.5 Actual and Adjusted Average Yields

Crop	Rio Grande			Arkansas		
	Adjusted Actual	Average	% Difference	Adjusted Actual	Average	% Difference
Barley	135.10	133.86	0.93%	-	-	-
Corn (grain)	-	-	-	136.00	147.00	-7.48%
Hay	2.72	2.90	-6.21%	2.70	2.97	-9.09%
Potatoes	393.00	372.10	5.62%	-	-	-
Sorghum (bu/ac)	-	-	-	28.00	34.70	-19.31%
Sunflowers (lbs/ac)	-	-	-	945.00	1242.69	-23.96%
Wheat (bu/ac)	102.00	100.00	2.00%	27.00	30.19	-10.57%

Source: Gunter et al., 2012

Adjusted average yield is calculated as the average of 1998 to 2010 excluding the highest and lowest reported yields from that period.

The difference in yield is also observed in revenue, where in the Arkansas basin revenues were approximately \$85 million less than revenues earned in ‘normal’ years. This is in sharp contrast to revenues for the Rio Grande basin, which were approximately \$12 million greater than actual 2011 revenue.

Secondary impacts were calculated through the use of input-output models. These models essentially generate multipliers which are then applied to the numbers calculated for the direct costs. In summary, the Rio Grande saw an increase in economic activity by roughly \$5 million, including ~42 new jobs. The Arkansas basin experienced a decrease of approximately \$105 million, including ~1300 jobs.

Modeling Forward and Backward Linkages

Forward and backward linked industries were modeled using the Colorado Equilibrium Displacement Mathematical Programming Model (CEDMP) developed at CSU. While originally developed for other purposes, the model provides an opportunity to investigate the impacts of drought to livestock.

Results suggest that the impact of the drought on production levels was negligible - a reduction of less than 1% of total revenues statewide. However, production costs increased significantly as ranchers were forced to provide supplemental feed because of the lost production on grazing lands. The increase in cost is estimated to be approximately \$110 million, or a 10-15% increase over the period 2005-2010, as cited in CAS, 2011.

Conclusions of the economic study

The analyses presented in Gunter et al., 2012 estimates the economic impact of drought to the Rio Grande and Arkansas basins for the 2011 drought. The report notes that insurance payments (totaling roughly \$50 million) were not taken into account, as their influence on secondary impacts is unclear. The analysis is, quite obviously, only appropriate for short-term conclusions. On-going drought impacts are likely compounding in ways not addressed in this report. For example, ranchers began selling off cattle herds in anticipation of an extended drought, but the analysis does not reflect those sales.

Statewide Updates to the Economic Studies

The analysis compiled by Pritchett et al., 2014 presents a comprehensive evaluation of the 2012 drought and the continued economical and societal impacts relating to the agriculture sector throughout Colorado. The study incorporated a detailed survey that was made available online and distributed to various stakeholder groups. The survey opened in December of 2012, closed in March 2013, and focused on impacts to production, managerial response, and local community impacts. 533 surveys were completed with 412 revealing their location with zip codes, covering roughly 4.4 million acres of agricultural land. Final conclusions of the study provide valuable insight into the impacts of the 2012 drought to the agriculture sector including insight for approaching future drought mitigation practices (Pritchett et al., 2013).

Impacts to Production

The first goal of the survey was to determine the extent of drought impacts on agricultural production. Nearly 50% of respondents reported lower than normal revenues. Using the zip codes to disaggregate the results on location, that number increases to over 60% reporting lower than normal revenues in the East Central agricultural district. This is contrasted against the Northwest and Mountains agricultural district where nearly 60% of respondents reported near normal revenues. Statewide less than 10% of respondents reported greater than normal revenues, with the highest percentage at just over 10% in the northeast district. The district with the lowest percentage of respondents reporting greater than normal revenues is the northwest and mountains (Pritchett et al., 2013).

The 2012 drought also impacted hay and forage production. Alfalfa, grass, and pasture production decreased by 37%, 40%, and 45% respectively. This decrease in production has direct impacts to Animal Unit Months (AUMs)⁴, which decreased on grazing lands (40% owned pasture, 9% private lease, 31% federal lease, and 34% state lease), yet increased 51% for purchased hay.

⁴ AUMs are calculated by multiplying the number of animal units by the number of months spent grazing. It is one way to track the amount of forage consumed. An animal unit is a consumption estimation tool based on a 1000- pound cow consuming 26 pounds of forage dry matter per day.

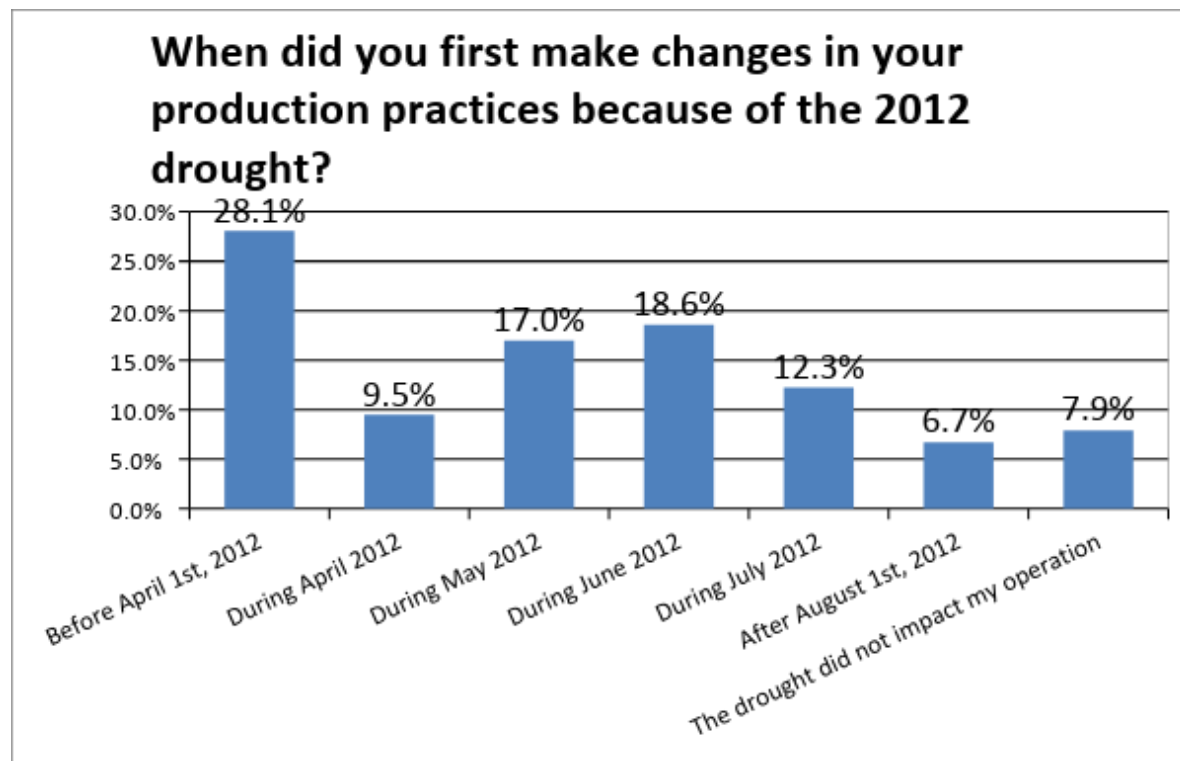
This impact to forage and feed production was felt in cow and calf production rates. The overall number of cows decreased 48% from normal with a culling rate of 21% (meaning roughly 1 out of every 5 cows was removed from the herd for one reason or another). Overall cow health was also affected by the lack of forage production. Cow condition and average weaning weight decreased by 18% and 16% respectively. Ultimately, the average cost of each cow increased 40% (Pritchett et al., 2013).

Managerial Response

A second goal of the survey was to examine whether or not ranch managers altered their operations in anticipation of, or in response to, the drought. Survey respondents answered questions about when they took action and what those actions were. While proactive actions generally improve flexibility, they may limit the opportunities to take advantage of indirect impacts (Pritchett et al., 2013).

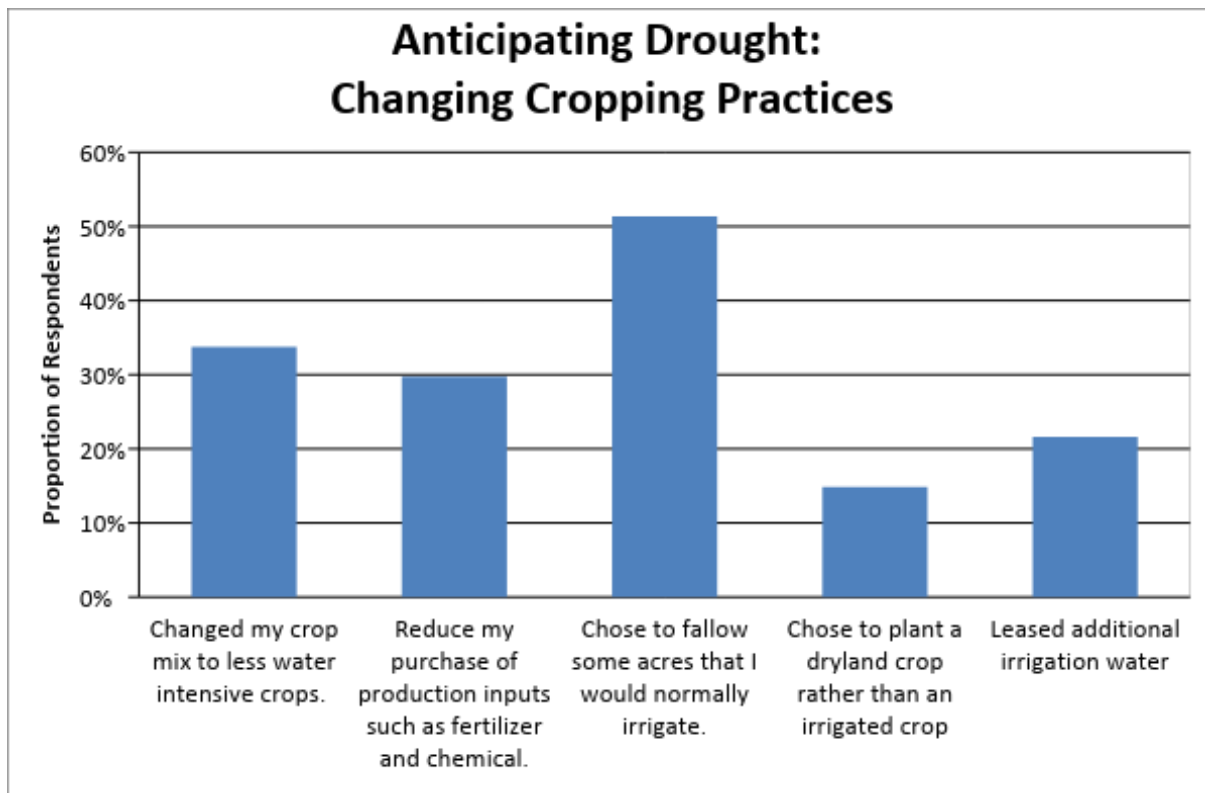
Figure 6.13 below shows when respondents chose to alter their operations in response to drought. Over 90% of respondents took action at some point during the 2012 season, with nearly 30% acting before April 1st. Figure 6.14 shows what those actions included for crop operations. The most common response was to reduce water use by setting acres aside that would normally be irrigated (Pritchett et al., 2013).

Figure 6.13 Respondent Drought Response Times



Source: Pritchett et al., 2013

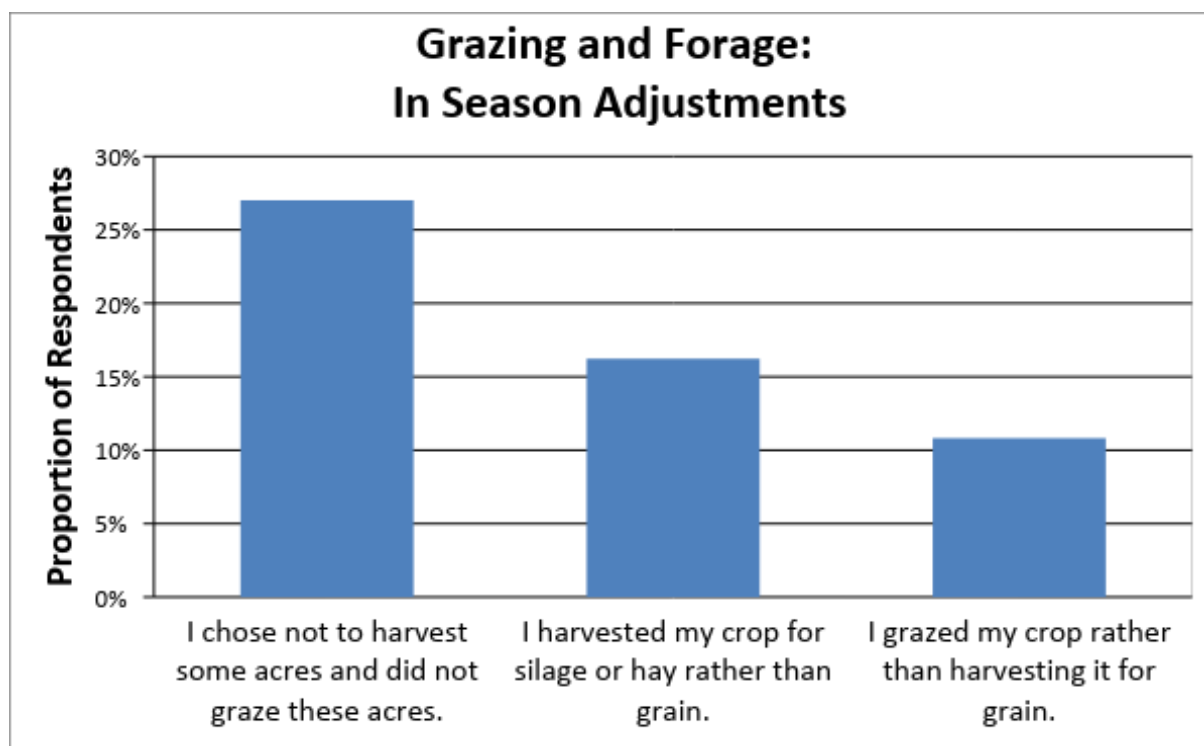
Figure 6.14 Crop Respondent Actions Taken During the 2012 drought



Source: Pritchett et al., 2013

Managers of irrigated farmland took a number of actions to reduce their water use. Roughly half of the respondents reduced their water use by focusing resources on a particular portion of their operation while reducing in other areas (Pritchett et al., 2013). Other common mitigation actions included reducing the amount of water used per watering (~30%) and reducing the number of irrigated fields overall (~40%) (Pritchett et al., 2013). For those operations focused on grazing and forage, Figure 6.15 indicates that the most popular action was to selectively harvest and graze certain acreage.

Figure 6.15 Adjustments Made by Those Operations Focused on Grazing and Forage



Source: Pritchett et al., 2013

Farmers and ranchers were also asked how the drought has impacted the way they manage their assets and cash. Questions were posed by asking what respondents had done and what they thought they might do if the drought persisted. The most common approach used to reduce impacts to cashflow was to reduce family expenses (59%), while 40% indicated family expense reduction would be the main way to save money if the drought persisted (40%). One quarter of respondents sought to supplement income with off-farm employment. Assets were managed more conservatively with the most popular response being to sell breeding livestock (41%). Selling equipment (13%) and land (2%) were not commonly sought options, with few indicating either would be an option (Pritchett et al., 2013).

Finally, respondents were asked questions about their likelihood to remain in the industry (whether or not the drought persisted). The majority of respondents (~80%) indicated they are not likely to leave the industry if the drought ends. However, if the drought persists that number decreases to approximately 45%.

Drought Water Supply Assessment

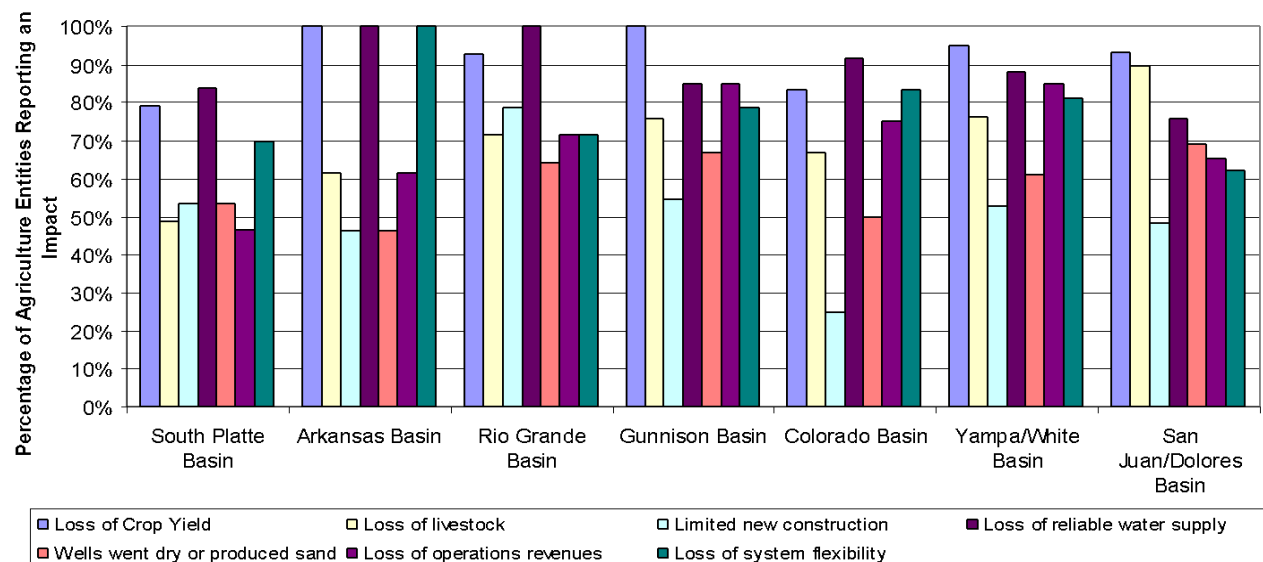
To determine the State's preparedness for drought conditions, the Colorado Water Conservation Board (CWCB) conducted a Drought Water Supply Assessment (DWSA) back in 2004. As discussed in the introduction, this study identified limitations and related measures to better prepare for future droughts (DWSA, 2004). It entailed a survey, or opinion instrument, where 537

responses were received statewide on specific impacts experienced during the dry period of 1999-2003 (i.e. the time encompassing the 2002 drought). Various entity types were surveyed including power, industry, agriculture, municipal, state, federal, water conservancy and conservation districts, and “other” (e.g., tribes and counties).

The results of the DWSA survey were helpful in understanding the opinions of Colorado’s water users statewide and on a basin-wide scale at the time, compared to those of today. However, the DWSA survey results did not provide impacts related to drought on a county level and therefore cannot be used in the spatial context of this assessment. Nevertheless, and although much has changed since then in terms of beliefs about drought and actual drought and water management practices, the DWSA results continue to be informative given the historical context, hence proving useful as a starting point in addressing issues of current and future water conditions.

Figure 6.16 provides the percentage of surveyed agricultural entities that experienced the impacts listed at the bottom of the figure. Examples of the agricultural entities surveyed include irrigation districts, ditch companies, ranches, and land and cattle companies.

Figure 6.16 2002 Drought Impacts to the Agricultural Sector (DWSA, 2004)



Note: Despite a comprehensive review and internal testing process of the survey tool, these DWSA 2004 surveyed impact results are subjective. The impacts in the figure above are a reflection of the surveyees’ interpretation of the listed impacts.

It is important to note that only categories applicable to the Agriculture Sector are shown in Figure 6.16.⁵ Of the 203 agriculture entities surveyed across each of the state’s seven basins, at least 25%

⁵ The DWSA survey included other sectors, such as municipalities, water conservation districts, power providers, etc. These entities reported impacts that would not necessarily apply to agricultural producers. These impacts have been omitted from this analysis.

of them reported impacts to the following categories during the 1999-2003 dry period (i.e. 2002 drought):

- Loss of crop yield
- Loss of livestock
- Limited new construction
- Loss of reliable water supply
- Wells went dry or produced sand
- Loss of operations revenue
- Loss of system flexibility

Loss of crop yield was the most frequently experienced impact throughout the state by the Agriculture Sector, followed by loss of reliable water supply and loss of system flexibility. While difficulties were felt in each basin by construction being limited and wells going dry or producing sand, fewer entities reported these categories as causing an impact. Overall, the 2002 drought caused widespread hardship to the Agriculture Sector. No singular basin fared worse than any other as evidenced by the fairly consistent survey results seen across basins and impact categories. This information is another way of confirming that the Agriculture Sector is very sensitive to times of low water supply. Without sufficient supplies of water to irrigate crops, impacts are felt in every area of the Sector, all resulting in lost revenue.

Statewide Water Supply Initiative (SWSI)

On May 15, 2013 an Executive Order from Governor John Hickenlooper was issued directing the Colorado Water Conservation Board to commence work on a statewide Water Plan. The Water Plan was released in December 2015. The plan addresses a number of water related issues, including drought, agricultural transfers, and interstate compact rights. The plan also addresses the water supply and demand gaps forecasted as part of the SWSI.

Although it did not specifically focus on drought as the DWSA did, the SWSI process was another important initiative taken and directed by the CWCB to understand existing and future water supply needs and how those needs might be met through various water projects and water management techniques. As described in Chapter 1, SWSI also uses a statewide and basin-level view of the water supply conditions in Colorado. The original SWSI analysis was completed in 2004 and updated in 2010. An additional SWSI update is scheduled to be completed during 2018-2019 (beginning in 2017), and it is recommended that subsequent updates to the Plan incorporate content from the updated SWSI document.

A large portion of SWSI addresses agriculture because of its importance to Colorado's economy and due to its majority share of overall statewide water use. One of SWSI's water management objectives is to "sustainably meet agricultural demands" in large part because competition for water is intensifying throughout the state as a result of increased population growth. Increases in Municipal & Industrial (M&I) demands in the future may cause a reduction in irrigated lands as

providers seek additional supplies from senior water right holders, many of which are associated with agriculture. This decrease in irrigated acreage may be larger if the existing identified projects and processes are not successfully implemented to the degree planned for. As a result, SWSI sought to develop families of options to provide solutions or mitigation to the remaining water supply gaps that would also help to preserve agriculture. The options related to agricultural transfers include:

- Permanent Agricultural Transfers
- Interruptible Agricultural Transfers
- Rotating Agricultural Transfers (Fallowing) with FIRMING for Agricultural Use
- Water Banks

It is important to note that other options exist including: M&I and agricultural conservation; additional storage development; conjunctive use of surface water and groundwater; M&I reuse; and control of non-native phreatophytes. SWSI noted that some combination of these options should be explored so that increased M&I demands are met through various approaches and management objectives. However, a brief overview of only the agricultural transfer options is presented in Table 6.6 to illustrate how future water management throughout the state may affect the Agriculture Sector in times of both ample water supply and drought conditions.

Table 6.6 Potential Benefits and Issues Surrounding Options for Resolving Supply and Demand Gaps

Agricultural Transfer Option	Description
Permanent Agricultural Transfer	<ul style="list-style-type: none"> ● The acquisition of agricultural water rights and the cessation of irrigation on these historically irrigated lands. Water rights are transferred to other uses.
Interruptible Agricultural Transfer	<ul style="list-style-type: none"> ● An agreement with agricultural users that allow for the temporary cessation of irrigation so that the water can be used to meet other needs.
Rotating Agricultural Transfer (Fallowing) with FIRMING for Agricultural Use	<ul style="list-style-type: none"> ● An agreement with a number of agricultural users that provides for the scheduled fallowing of irrigated lands on a rotating basis so that the water not irrigating fallowed lands can be used for other uses. Includes a set aside and storage of some of the yield to provide a pool for use by the agricultural users during below average water supply years.
Water Banks	<ul style="list-style-type: none"> ● A mechanism where water users can announce they have unused supplies that can be leased by other users.

Source: SWSI 2004

Some of these options, particularly Interruptible Agricultural Transfer and Rotating Agricultural Transfer (Fallowing) with FIRMING for Agricultural Use, can benefit the Agriculture Sector in times of drought in the following ways:

- Provides a more stable income during droughts

-
- Preserves the land for future agricultural use rather than causing a permanent dry-up
 - Less water development and additional storage is needed in order to provide reliable water supply
 - A firming of agricultural supplies may be necessary. This would require additional storage, infrastructure and advanced water treatment.

However, the permanent agricultural transfer option has negative implications for not only the Agriculture Sector, but also the local economy and socioeconomic associations. This is because less income to farming communities can result in reduced property taxes to schools and local governments and less revenue to local businesses. As a result, as part of SWSI Phase 2 in 2007, a technical roundtable (TRT) was created to address alternatives to the option of permanent agricultural transfer. Recognizing that all basins in the state have agricultural water shortages no matter what hydrologic conditions exist, the TRT worked on refining which areas of the State have more severe shortages. It is evident that the South Platte, Arkansas, and Rio Grande Basins are losing agricultural production to permanent transfer of water rights and voluntary groundwater reductions. As a result, two structural water supply concepts, one in the Arkansas Basin (Arkansas River Agricultural Pumpback) and one in the South Platte Basin (South Platte River Agricultural Pumpback), were developed by the TRT to illustrate alternative agricultural transfer methods. More information may be found in the second phase of SWSI regarding this topic.

SWSI also discussed how conservation may benefit the Agricultural Sector in times of drought. Examples of efficiency measures include ditch lining, conversion of flood irrigation to gated pipe, and sprinkler or drip system installation. These measures may assist agricultural water users by, extending existing supplies in terms of the increased ability to deliver water and decreasing the likelihood that new diversions would be required. However, it is also important to note that some efficiency measures, like drip irrigation and sprinklers, can increase a crop's consumptive use of water.

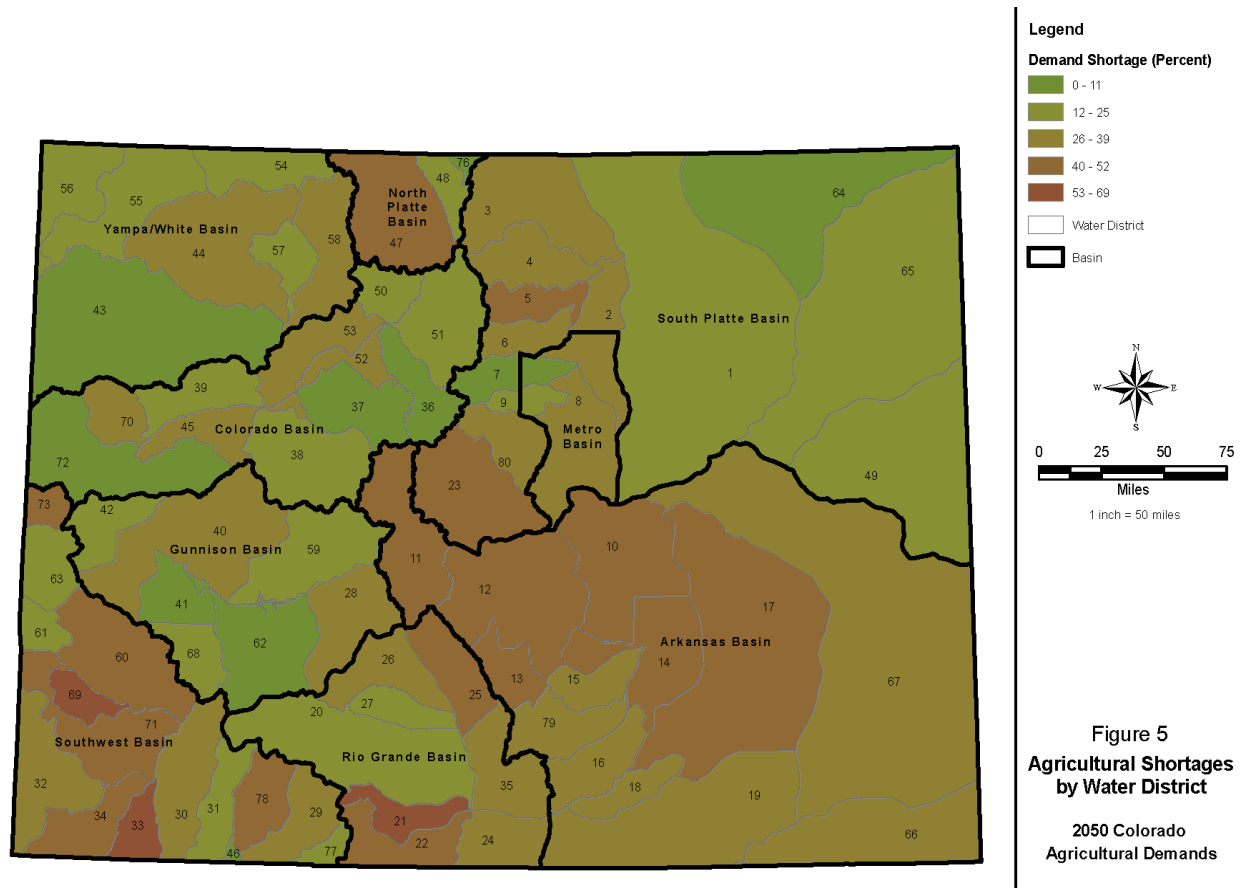
A technical memorandum from CWCB (CWCB, 2010) was produced to estimate current (2010) and 2050 agricultural demands across Colorado. This work shows historical trends in farmland and irrigated acres, estimated current agricultural demand by basin, and a map of projected 2050 demand shortages by water district, which is shown in

Figure 6.17. The areas with the highest 2050 demand shortages are located in the Arkansas, North Platte, and Southwest Basins, with lesser demand projected in the Yampa/White, Colorado, and Gunnison Basins. The Rio Grande and South Platte Basins show water districts with both high and low demand shortages. Overall, the memorandum concluded that statewide irrigated acres are projected to decrease between 15 % and 20 % between now and 2050. The basins with the largest expected decreases in irrigated acres from current usage to 2050 are the Yampa/White, South Platte, and Colorado Basins.

The dialogue on how agriculture can be sustained throughout the state while still providing for increased M&I demands, particularly during drought conditions, will only continue on a more

detailed level. The SWSI process brings together interested parties to work towards options that will mitigate negative impacts to affected sectors, and continuing work by CWCW in the form of current and 2050 agricultural demands projections further the exchange of ideas.

Figure 6.17 Projected 2050 Agricultural Demand Shortages



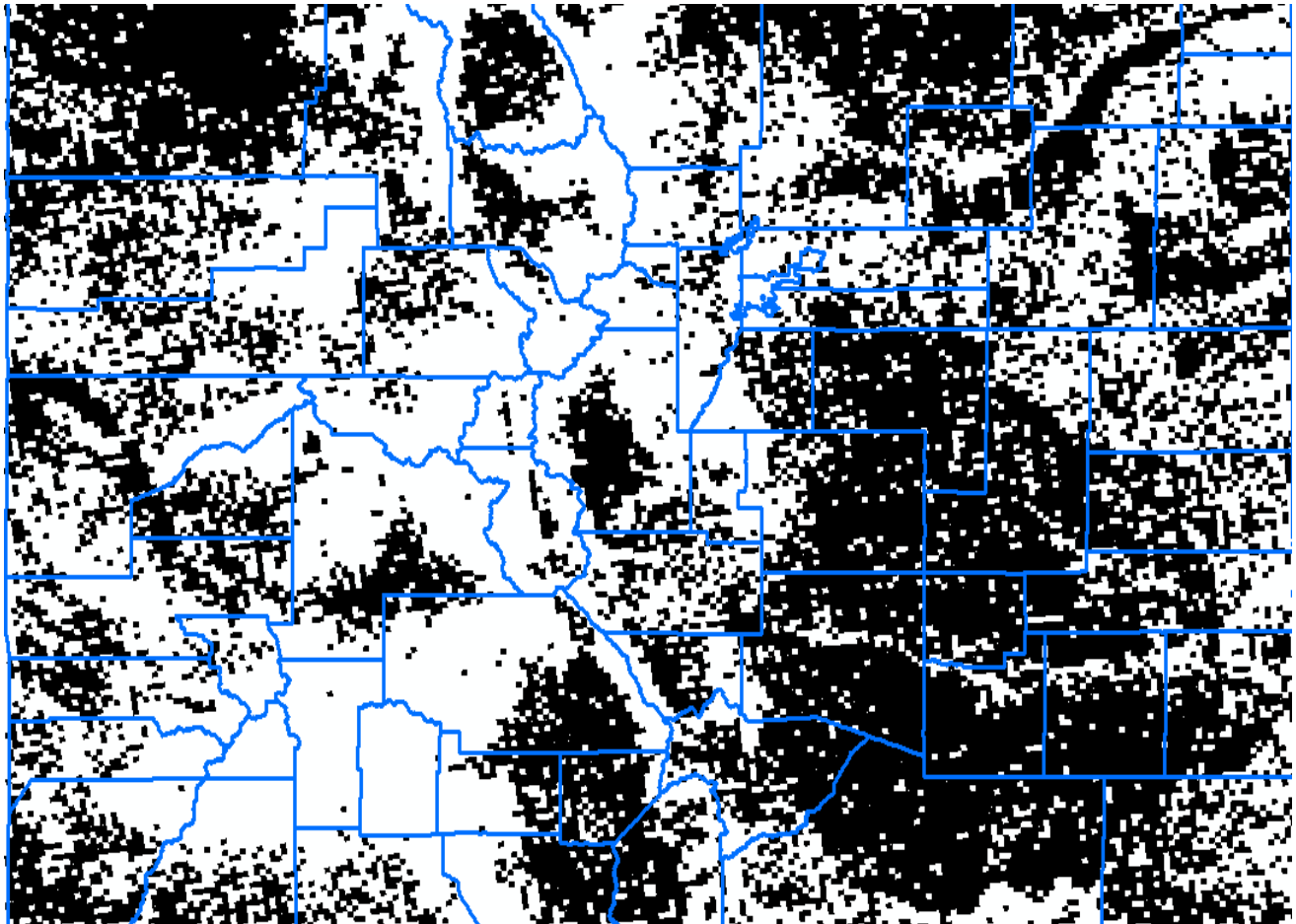
Source: CWCW-SWSI 2010

NASA CASA Model

As reported in several of the studies above (e.g., Pritchett et al., 2013), the impact of drought on rangeland production is an issue for ranchers, and also for wildlife. Researchers at the NASA Ames Research Center's Ecosystem Modeling Group have been using remotely sensed data to develop a monitoring system that can be used to measure and track the health of rangelands across the state. The Carnegie-Ames-Stanford Approach (CASA) model combines satellite image analysis with plant production modeling to examine the spatial variability in monthly plant production and soil moisture. Synoptic "greenness" data from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor are collected at 16-day intervals at a 5 km ground sampling distance (Li et al., 2012). (Greenness refers to the Enhanced Vegetation Index data product which has been shown to be useful in assessing processes that depend on absorbed light, such as gross

primary production (Li et al., 2012). By comparing subsequent datasets and model outputs with a defined baseline condition, managers can track the severity of the drought through the health of vegetation on the ground. The CASA model was applied to rangelands in Colorado for 2012, using 2010 as a non-drought baseline year, in order to calculate losses in forage production. Rangelands across Colorado were identified using National Land Cover Database (NLCD) categories for grassland, pasture/hay, and shrub/scrub. The black pixels in Figure 6.18 below show the extent of rangeland, as defined above, in Colorado.

Figure 6.18 Colorado rangeland as defined using the NLCD database



Source: Fry et al., 2011

Using NLCD rangeland extent to identify the areas of Colorado to be modeled, the CASA model was run for 2012. Figure 6.19 below shows the model results. Red-yellow pixels indicate a loss of rangeland production in 2012, while blue shades indicate gains in production. Many of the gains are associated with irrigated agriculture. For example, there are significant blue patches in the San Luis Valley. Significant losses can be seen in the Arkansas Valley in the southeast and along the South Platte in the northeast (personal communication, Christopher Potter on March 11, 2013).

The relatively high spatial resolution of the MODIS sensor allows the model results to be aggregated up to county (or any other spatial boundary) levels. For example, if the results shown in Figure 6.19 are summed for each county, it is possible to rank counties based on the total loss of biomass measured for rangelands. Referring to Figure 6.20, nearly all counties experienced a net decrease in rangeland production for 2012. San Juan does not have any pixels classified as rangeland in the NLCD database. Conejos County experienced a slight net gain in rangeland production, as a result of irrigation in the San Luis Valley. Figure 6.19 can also be somewhat misleading as relatively few pixels can create the illusion of dire conditions. For example, many of the mountain counties (e.g., Mineral, Hinsdale) only have a few pixels, yet the entire county is shaded as an overall decrease in production.

Figure 6.19 CASA Model Results for 2012

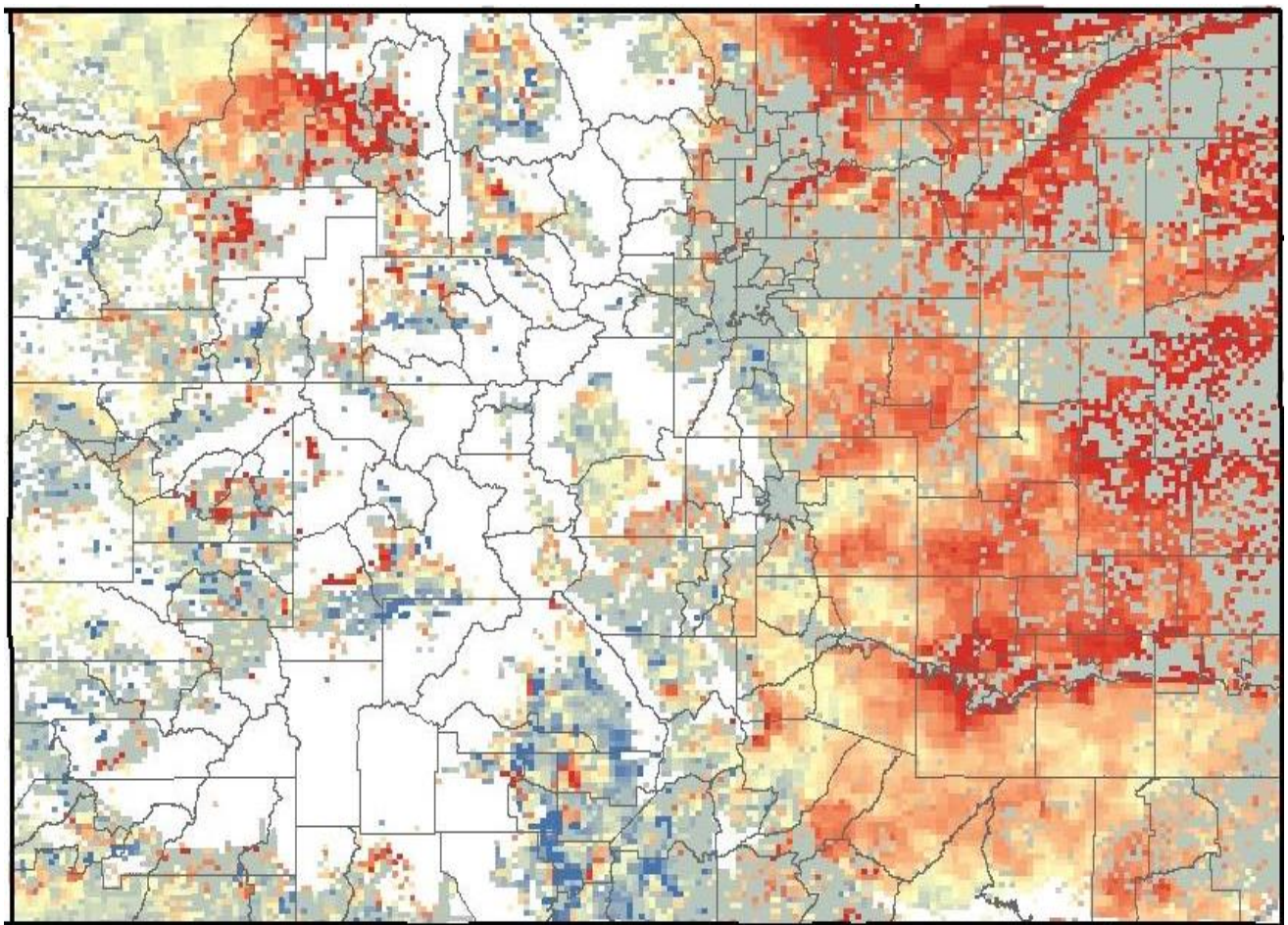


Figure 6.20 CASA Results Aggregated to the County Scale, Showing Net Total Change in Biomass

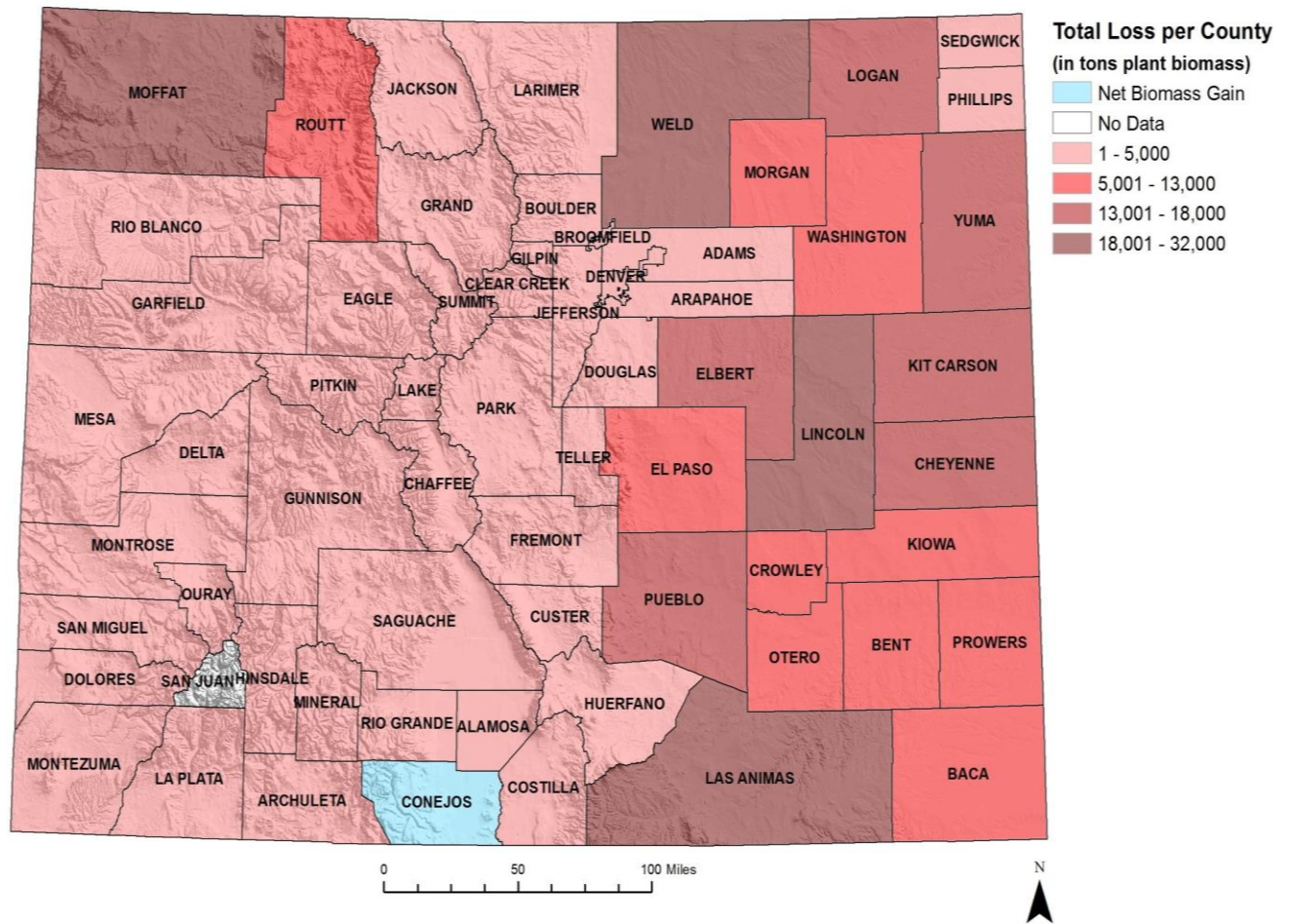
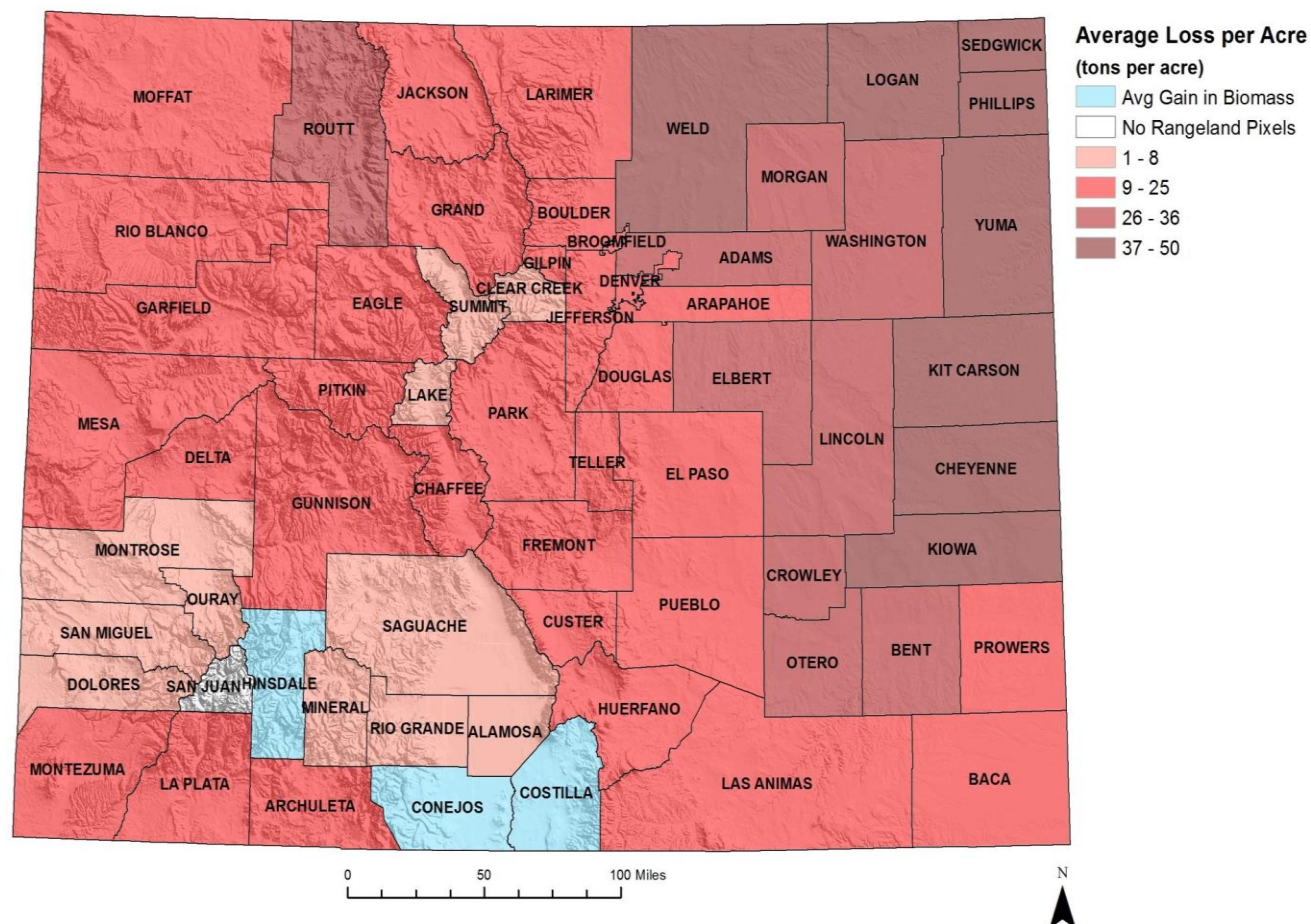


Figure 6.21 CASA Results Aggregated to the County Level, Showing Mean Biomass Change per Acre



Alternatively, results can be classified by the average biomass loss (or gain) for all the pixels that fall within the county. For example, Figure 6.21 shows the mean loss per acre. Hinsdale and Costilla counties now also show a gain in biomass, but it is a per acre gain, relative to the county-wide loss seen in Figure 6.20. Again, similar perception issues as those discussed above for Figure 6.20 are generated here, suggesting that county aggregations may not be the best way to present environmental data. The CASA model has been run for portions of west Texas and New Mexico for some time (personal communication, Christopher Potter on March 25, 2013). Model output, along with several other datasets (e.g., evapotranspiration; soil moisture change), is being served online through NASA's Drought Assessment and Response Tools (DART) website. Several other western states, including Colorado, have recently been added, and users can query and download any relevant datasets.

CASA model output has clear application to future drought studies and management plans. It allows managers to measure specific impacts to particular land cover types in a synoptic, cost effective and efficient manner. Future applications of the model involve taking advantage of the model's spatial resolution and applying the results to other land cover types and drought sectors. The CASA model operates on a 5 km spatial resolution which provides opportunities to

disaggregate (or aggregate) model output in various ways. For example, instead of examining rangeland production on a county scale, output could be summarized based on watershed boundaries, land ownership, and/or management units. This could help focus resources on the area(s) most affected by the hazard. Other potential applications include monitoring forest health, although managers should take caution in attributing a decrease in forest production solely to drought as Colorado's forests are subject to multiple stresses (e.g., beetle infestation, disease) (personal communication, Christopher Potter on March 11, 2013).

6.3 Assessment of Impacts and Adaptive Capacities

The Agricultural Sector is split into three specific impact groups: livestock, crops, and the green industry. This section contains a discussion of the potential impacts and actions for adaptive capacity these sub-sectors have during drought.

6.3.1 Potential Impacts

As noted in Section 6.2, previous reports on agriculture impacts from drought identify large losses of revenue in each sub-sector. Table 6.7 below, outlines some potential/general drought impacts.

Table 6.7 Drought Impacts to Agriculture

Sub-sector	General Impacts
Livestock	<ul style="list-style-type: none"> ● Short-term or severe summer drought can significantly reduce grazing forage available to herds. Ranchers could be forced to supplement with purchased feed, causing increased costs to the farm. If purchased feed is not available due to drought conditions or short supply, ranchers could be forced to sell portions of their herd or ship the herd to greener pastures. Cost of freight is problematic. Greener pastures may not be available within feasible shipping distances. ● Poor grazing conditions may lead to more livestock poisoning as they feed on poisonous plants normally eliminated. Nitrate, sulfate and prussic acid toxicity may occur, as may anthrax. ● Colorado has a large confined animal feeding industry which may become unprofitable as cattle price drops and feed prices increase. ● The condition of the animal deteriorates as food becomes scarce. This drives the value of the cattle down, while the cost of raising that animal increases. ● Secondary impacts to beef processors and related industry if the ranchers are shipping their cattle out-of-state. ● Long-term impacts to ranchers if they sell portions of their herd at a loss (price of cattle will fall when the market is flooded with ranchers trying to offload some of their herd) and years later have to rebuild the herd at additional expense. Also increases competition with out-of-state ranchers who were able to build up their herds by purchasing Colorado cattle at a lower price.
Crops - dryland	<ul style="list-style-type: none"> ● Lack of fall precipitation could inhibit seed germination. Inadequate spring and summer precipitation could keep the grain from sprouting, causing crop loss for the farmer. ● Long-term drought can deplete soil moisture and make dryland crops unviable, forcing changes in livelihood and farming practices. ● Weeds may outcompete crops ● Soil erosion can occur due to decreased cover and increased blowing.

Sub-sector	General Impacts
Crops - irrigated	<ul style="list-style-type: none"> ● Junior water rights holders could see a reduced irrigation allocation or be cut off entirely, causing reduced or lost crop yield. ● Decreased water quality can impair plant growth (Table 6.2 and Table 6.3).
Green industry	<ul style="list-style-type: none"> ● Nurseries and sod growers on junior water rights could see their irrigation allocation reduced or cut off entirely, causing lost products and revenue. ● Landscape nurseries see reduced product demand if municipal water restrictions are implemented on the public. In addition, utilities can ban lawn watering and laying new sod, impacting the sod growers. ● Short-term revenue loss, but also potential for revenue gain after the drought ends when people buy new plants to replace landscape that died during watering restrictions. The inverse of this is public demand for drought-resistant plants may manifest faster than the industry can produce the plants. ● Secondary impacts to landscape service industry if workload is reduced, laying-off some of their employees might be necessary.

The agricultural sub-sectors are interrelated; a drought that impacts crop growers will also have an effect on livestock owners. Livestock owners may also be hay and feed producers. Dryland farmers provide much of the supplemental feed (e.g., hay, alfalfa, etc.) for the cattle ranchers, and if the crops fail, ranchers will be faced with higher prices for feed or be forced to look outside of the state. In all cases, secondary impacts will occur to the rural communities where farming is the primary economic driver. This “trickle down” effect of lost farm revenue can significantly impact local economies, making small communities where farming is prevalent more vulnerable to drought than communities where the economy is more diversified. Wheat returns more than 25% of crop sales in eight Colorado counties: Kiowa (98%), Washington (53%), Cheyenne (49%), Baca (>25%), Kit Carson (>25%), Sedgwick (>25%), Logan (>25%), and Prowers (>25%) (Situation Statement - CSU, 2010), making potential impacts in those counties large.

Figure 6.22 depicts the total harvested acreage per county separated by dryland and irrigated crops and averaged for 10 years (1999-2008). Harvested acreage is actual yield. The other data type in the NASS database are “planted” acreage, which measures the total acreage the farmer planted but might not have been able to harvest for any number of reasons, including drought, hail, fire, pests, etc. “Harvested” acres were used for this vulnerability ranking assessment.

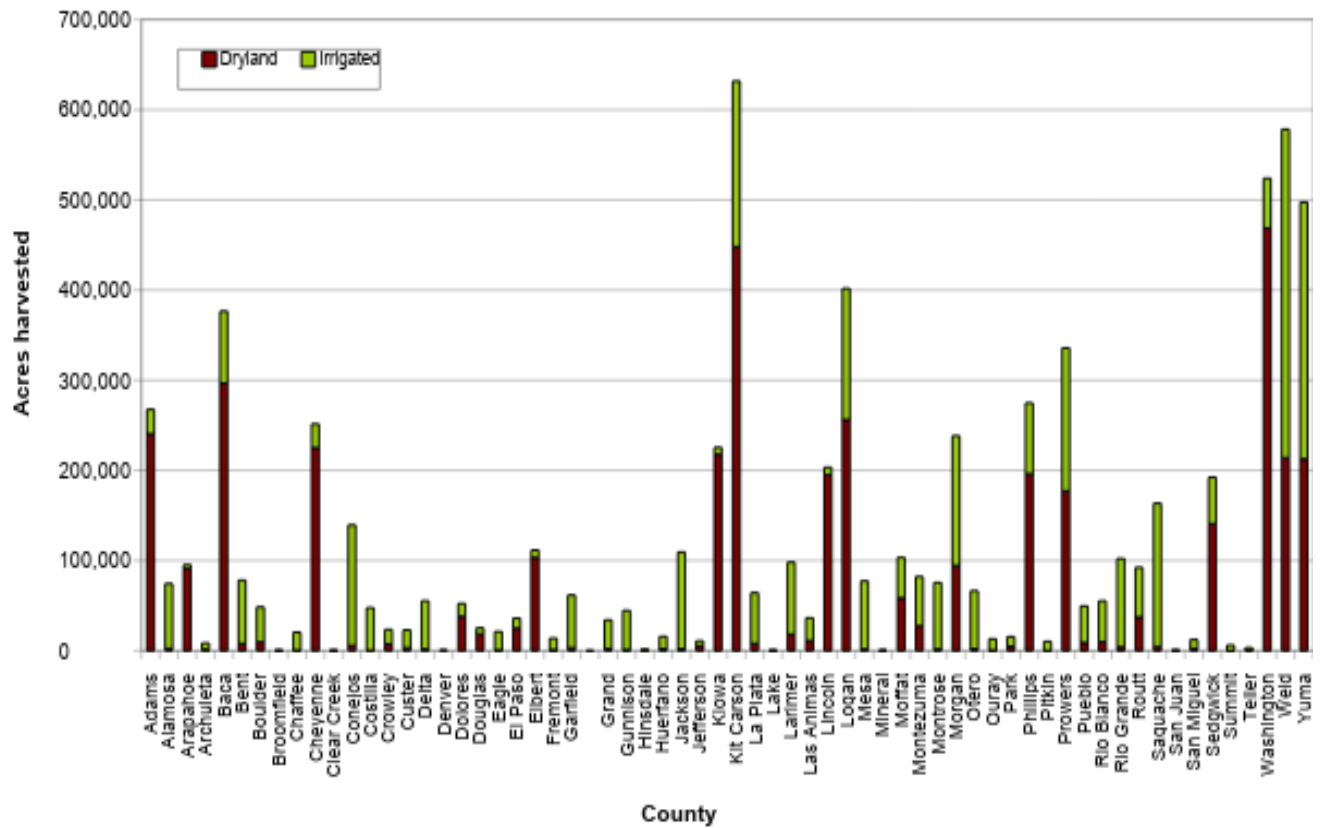
As noted in the discussion of the Colorado State University economic impact studies above, there have been anecdotal reports of ranchers selling off portions of herds as a result of the drought. One auction house located on the western slope has seen the numbers of animals sold nearly double since 2010. However, they do not know how many animals were cows, but do notice more cows selling, as well as people selling ‘more deeply into their herds’ (personal communication, May 21, 2013).

During 2012, the drought was nationwide, impacting resources in Colorado as well as feed supply areas in the Midwest. As a result, feed production decreased across the region, driving the price up. For example, in 2010 the price of alfalfa hay ranged from \$110 to \$120 per ton, but increased

to \$215 to \$221 per ton through April of 2013 (NASS online database, 2013). This made it significantly more expensive for ranchers in Colorado to send their livestock to feedlots, or purchase feed themselves. One potential adaptive capacity is for ranchers to transport cattle to more productive rangelands. For example, ranchers in Texas and Oklahoma moved livestock to other western states, including Colorado, during the 2010 (and ongoing) drought event. Since the drought covered a significant portion of the west during 2012, there were fewer productive rangelands to which to move the herds (LMIC, 2013), though some may have moved herds to Montana (e.g., Woodka, 2011).

Data showing drought-related decreases in cattle is sparse, but the NASS database provides estimated annual numbers. By querying the database for beef cows, the percentage decrease from 2012 to 2013 for many counties in Colorado can be seen (Figure 6.23). As this data is the result of a survey effort, numbers for all counties were not available for all counties. For those counties containing estimates, all showed either no change or a decrease in cattle numbers ranging from 2% in La Plata County to 17% in Summit County. The vulnerability assessment in the previous Plan used a reduction in herd size calculation that compared the 2001 survey data against the average of the 2002-2005 survey data. To supplement the previous analysis a new comparison was generated from the difference between 2011-2012 average values and the 2014-2015 average values (pre-drought vs. post-drought). As the spatial coverage and intensity of the 2012-2013 drought was more severe over southeastern and eastern Colorado, a combination of the 2002 drought reduction and the 2012-2013 reduction was generated to help avoid spatial artifacts associated with a single drought event. The maximum herd reduction between the two calculation periods was used in the development of the updated vulnerability assessment (Figure 6.24). When the 2017 Census of Agriculture is made public, data will be available for each county and it is recommended that these new numbers be evaluated to update subsequent plans.

Figure 6.22 Total Crop Acreage by County, 1999-2008 Annual Average



Source: NASS, 2010

Figure 6.23 Percentage decrease in the number of beef cows per county between 2012 and 2013

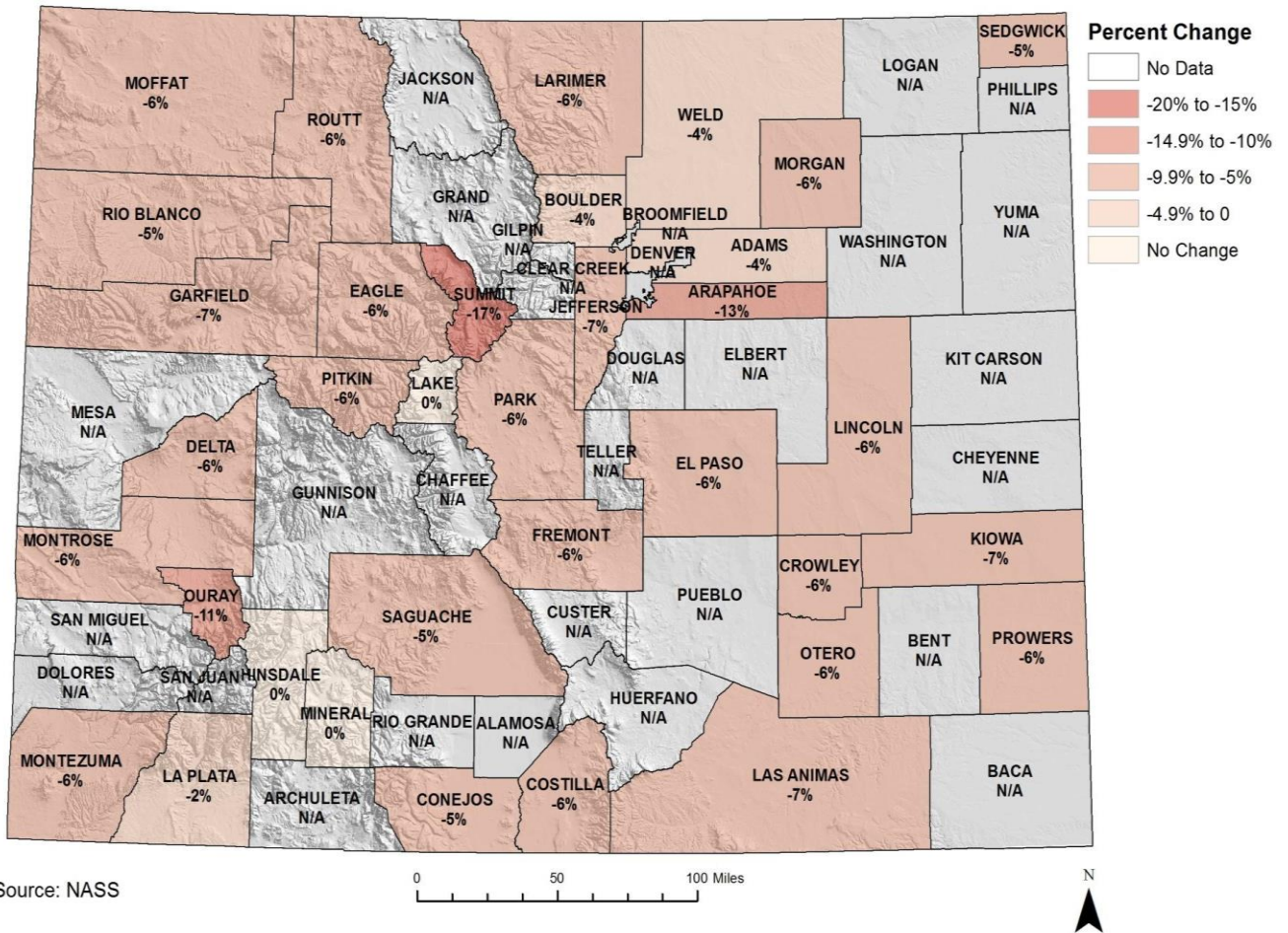
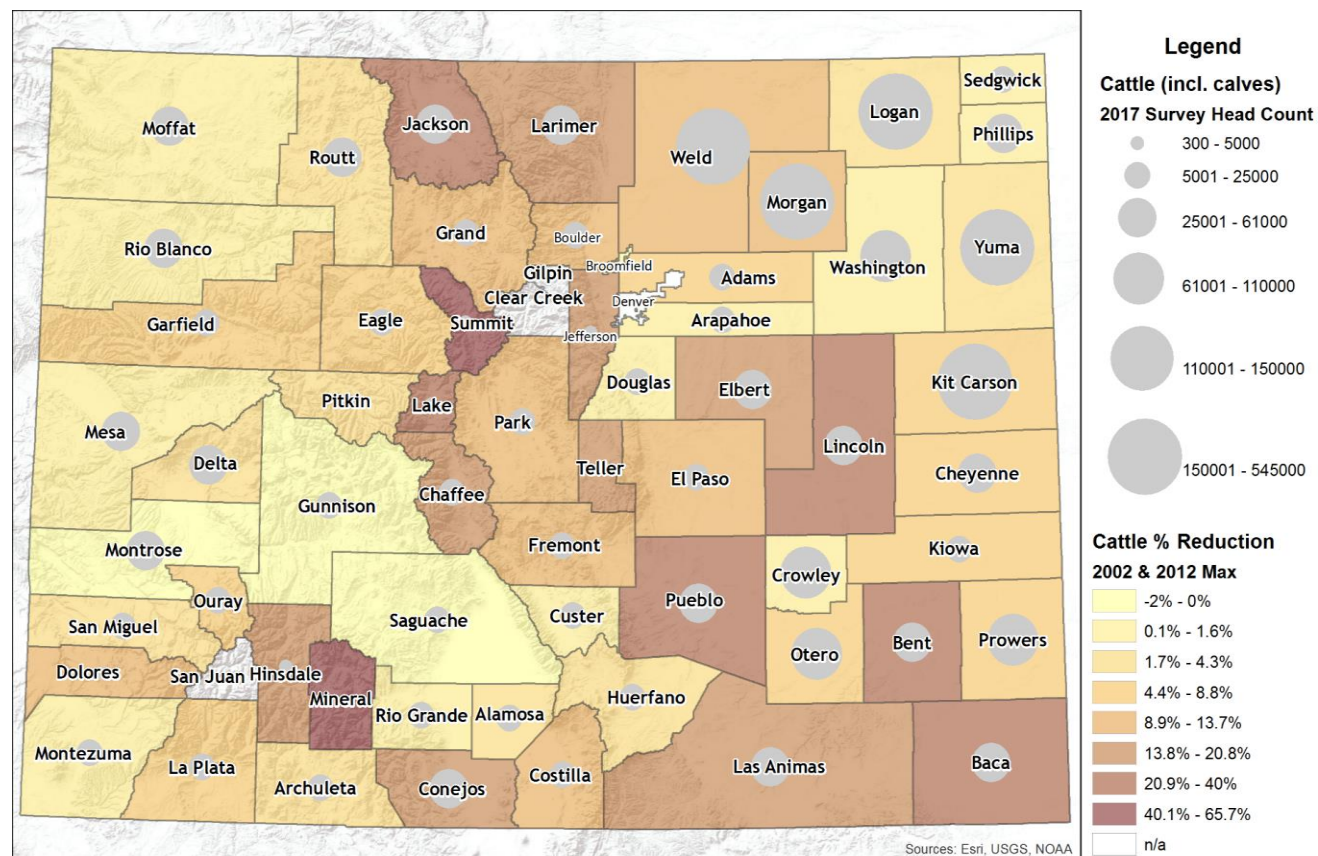


Figure 6.24 Percentage decrease in the number of cattle per county (max reduction between pre- and post-drought for 2002 and 2012 periods)



Potential impacts to the green industry include restrictions on water use imposed by utilities and municipalities. Growers rely both on water rights and municipal supply. A limited amount of water for irrigation can cause plant loss or degraded plant quality, which will affect the ability of the grower to sell the product, resulting in lost revenue. Secondary impacts within the green industry include job and revenue losses to landscape designers and landscape maintenance companies, who rely on both the availability of plants and public demand for their installation. Landscaping companies can also be impacted by municipal water restrictions that target landscaping water restrictions in the earliest stages of drought.

6.3.2 Adaptive Capacity Actions

Adaptive capacities work to offset the impacts of drought, which reduces the overall vulnerability. There are a number of adaptive capacities for ranchers and farmers. When producers are faced with reduced surface water supplies, they have three options that will allow them to continue production: 1) reduce irrigated acreage; 2) reduce irrigation amounts to the entire field (i.e., limited irrigation agriculture); and 3) include different crops that require less irrigation (Schneekloth and Andales, 2009). Cattle ranchers also may have several options in a drought: 1) use stored feed

and/or purchase supplemental feed; 2) change operation, move herd to pastures that are not impacted by drought or reduce herd; and 3) cull the herd (communication with CDA, 2010). However, as seen in the 2011-2013 drought, larger events may limit the ability of ranchers to both purchase feed and move their animals to more productive rangeland. Table 6.8 lists adaptive capacities for agriculture and provides a comment of the pros and cons to each option.

Table 6.8 Agriculture Adaptive Capacities

Sub-sector	Adaptive Capacities, Pros and Cons
Livestock (cattle)	<p>1. Use stored feed. <u>Pros</u></p> <ul style="list-style-type: none"> • Enables the herd to stay intact. <p><u>Cons</u></p> <ul style="list-style-type: none"> • Using feed in the summer may deplete stores for the winter. • Use of stored feed requires proper management of low- and high-quality feed to maintain cattle health. • Creates dependence on the ability to grow feed crops. <p>2. Change operation, move herd or lease grazing fields in another area. <u>Pros</u></p> <ul style="list-style-type: none"> • If operational change is possible, enables herd to stay intact. <p><u>Cons</u></p> <ul style="list-style-type: none"> • Cost of freight for cattle can exceed the cost of a year's worth of supplemental feed. • As seen in 2012, healthy rangelands may be in short supply. <p>3. Sell portion or all of herd. <u>Pros</u></p> <ul style="list-style-type: none"> • Short-term monetary gain for rancher. <p><u>Cons</u></p> <ul style="list-style-type: none"> • An influx of cattle to the market changes the market structure by reducing prices. • Selling quality cattle at artificially low prices (due to large supply) can put ranchers at long-term disadvantage as out-of-state ranchers are able to build competitive herds at low prices. • Rebuilding the herd may take several years. <p>4. Avoid growing the herd above a certain limit, leave some flexibility for the next drought. <u>Pros</u></p> <ul style="list-style-type: none"> • A management practice that does not require any investment of funds, just advance planning. <p><u>Cons</u></p> <ul style="list-style-type: none"> • Rancher could miss out on possible monetary gains in years with ample water and forage supply.
Crops - dryland	<ul style="list-style-type: none"> • Relatively few adaptive capacities identified: winter wheat, a major dryland crop in Colorado, is planted on a two-year rotating cycle, making it less flexible to planting changes. • Suggestions include forgoing summer dryland crops, reducing tillage, selecting drought tolerant wheat varieties, and shifting dryland corn to less water intensive crops (e.g., millet, sorghum, sunflower). <p>1. Apply for crop insurance. <u>Pros</u></p> <ul style="list-style-type: none"> • Ensures a payment if the crop fails due to drought.

Sub-sector	Adaptive Capacities, Pros and Cons
	<p><u>Cons</u></p> <ul style="list-style-type: none"> ● Insurance may not be available for all crops in all areas.
Crops - irrigated	<p>1. Dry-year leasing, a mechanism that allows for temporary water transfer (usually from agriculture to municipalities) during dry years when farming is less feasible or profitable (DWSA 2004).</p> <p><u>Pros</u></p> <ul style="list-style-type: none"> ● Provides an income to the farmer even when growing crops is not practical or possible. <p><u>Cons</u></p> <ul style="list-style-type: none"> ● Requires agreements between multiple parties <p>2. In principal, growers could significantly reduce water use by switching between crops (Frisvold 2009).</p> <p><u>Pros</u></p> <ul style="list-style-type: none"> ● When applicable, a viable way to maintain income by planting less water-intensive crops and choosing drought tolerant alternatives. ● Shift some crops to fall or spring crops. <p><u>Cons</u></p> <ul style="list-style-type: none"> ● May not be practical in some instances. ● It assumes the farmer is sufficiently diversified for new crop to be successful. <p>3. Practice deficit irrigation.</p> <p><u>Pros</u></p> <ul style="list-style-type: none"> ● A way to produce a crop with less irrigation. <p><u>Cons</u></p> <ul style="list-style-type: none"> ● May not yet be recognized by insurance agencies as a valid adaptive method, and could prevent the farmer from receiving insurance money if the crop fails anyway. <p>4. Apply for crop insurance.</p> <p><u>Pros</u></p> <ul style="list-style-type: none"> ● Ensures a payment if the crop fails due to drought. <p><u>Cons</u></p> <ul style="list-style-type: none"> ● Insurance may not be available for all crops in all areas. <p>5. Reallocate irrigation water to higher-value crops.</p> <p><u>Pros</u></p> <ul style="list-style-type: none"> ● If possible, allows the farmer to prioritize crop irrigation and still receive an income. <p><u>Cons</u></p> <ul style="list-style-type: none"> ● May not be feasible in all situations, may require transfer agreements with multiple parties. ● Machinery and operations may make it difficult to switch crops without large capital investment on the part of the farmer.
Green industry	<p>1. Focus on edibles (e.g., vegetables, fruit trees, and berries), native, and drought-tolerant plants (Haight 2010).</p> <p><u>Pros</u></p> <ul style="list-style-type: none"> ● Demand for these products is generally strong. <p><u>Cons</u></p> <ul style="list-style-type: none"> ● Increased cost of switching plant focus, and a lag in production time (i.e., public demand happens sooner than plants are ready to go on the market).

Sub-sector	Adaptive Capacities, Pros and Cons
	<p>2. Focus on xeriscape materials, look for regional markets outside of Colorado, add ability to help people redesign their landscapes (i.e., diversify services), cooperative agreements with landscape designers (conversation with green industry representative, 2010).</p> <p>Pros</p> <ul style="list-style-type: none"> ● Diversifying services can help insulate against major drought impacts to one specific market. <p>Cons</p> <ul style="list-style-type: none"> ● Requires advance planning, so not an immediate fix to drought impacts.

Adaptive capacities for the green industry are similar to those in the Recreation Sector; meaning public perception is a key concern, and growers who are more diversified are better adapted for drought conditions. Sod growers have experienced difficulties because the public perception is shifting away from grassy lawns and towards less water-intensive plantings (Proctor, 2003). Xeriscaping has continued to grow in popularity (e.g., Boldery, 2012), possibly in response to the restrictions imposed during, and the impacts of drought in 2002. Again, in similar fashion to the rafting industry, the green industry is re-working their operations to maximize the use of the limited water they do have by carefully focusing their water applications (Kluth, 2012). During the 2002 drought some utilities actually banned installation of new turf in order to further conserve water, which had an adverse impact on the sod growers specifically. One landscaping company, in response to municipal lawn-watering restrictions in 2002, began offering lawn-painting services for customers who wanted green lawns but were not able to water them (Proctor, 2010). Nurseries that offer drought-resistant and other low-water plants, whether in anticipation of future drought or in direct response to consumer demand, are consequently less vulnerable to drought than nurseries that do not have these offerings. Public interest in sustainability and environmentally-friendly products means that xeriscaping and edibles are gaining popularity. Educating producers is a valuable adaptive capacity in the green industry. For example, in 2008 GreenCO, the umbrella organization for the green industry in Colorado, developed best management practices to educate producers on efficient ways to use water prior to and during drought. Additionally, they have worked to market drought resistant alternatives to homeowner's associations and communities, and they have supported research with Colorado State University (Kluth, 2012). As a result of these efforts, the industry expects to be more prepared during the next drought in Colorado.

6.4 Measurement of Vulnerability

The vulnerability metrics are quantifiable factors that can be analyzed to assess the vulnerability of this sub-sector. These can be offset or mitigated by existing or future adaptive capacities. Priority of water rights, which is not included in this analysis, will have a significant impact on a farmer's vulnerability. The following section presents the vulnerability metrics used for each agriculture sub-sector. Refer to Section 3.1 of Chapter 3 (Annex B) for a general description of the numerical methodology.

The 2013 Plan update noted that “while the 2012 agriculture census effort is likely to fill in many of these data gaps, the reality is that it may or may not paint an accurate picture of the impacts felt

during the 2011-2013 drought”. For this reason, the 2017 update largely focused on evaluating and comparing the previously developed input data (2010 & 2013 update) with the newer data products where available (e.g. 2012 NASS Census and 2016-2017 NASS Survey). This evaluation yielded subtle differences to the underlying metrics when comparing the most recent data to the previous data products. For the sake of efficiency, the following vulnerability sections summarize the vulnerability metrics with regards to both the previous and newer data inputs.

6.5 Vulnerability Metrics

6.5.1 Livestock

Spatial Density Metrics

Head of cattle per county

This data was obtained from the NASS database, querying for *cattle, including calves* as of January 2017. The total cattle head count gives an idea of which counties have the biggest herds and how the cattle industry is distributed throughout the state.

Impact Metrics

Livestock indemnity allotments

The 2014 Farm Bill authorized the Livestock Forage Disaster Program (LFP) to provide compensation to eligible livestock producers who have suffered grazing losses for covered livestock on land that is native or improved pastureland with permanent vegetative cover or is planted specifically for grazing. The grazing losses must be due to a qualifying drought condition during the normal grazing period for the county. Also, LFP provides compensation to eligible livestock producers who have suffered grazing losses on rangeland managed by a federal agency if the eligible livestock producer is prohibited by the federal agency from grazing the normal permitted livestock on the managed rangeland due to a qualifying fire.

These indemnity data are dollar amount allotments for 2010-2017 were obtained from the USDA (personal communication, 3/2/2018). The program is called the “Livestock Forage Program.” The data are money allotted annually by the USDA to each county to pay claimants specifically for drought-related damages. It does not indicate the amount that has already been paid; rather, this is the amount set aside for each county. For the 2017 Drought Plan, it was assumed that the higher the amount allotted to a specific county, the more vulnerable it is expected to be.

There are different requirements and limitations that must be considered when a county applies for LFP assistance. The FSA posts these stipulations online; variables include:

- Drought conditions

- Livestock eligibility
- Producer characteristics
- Payment limitations
- Enrollment suitability

The table below outlines the counties in Colorado eligible for LFP resources in 2014-2017, as well as the type of applicable support. The FSA will provide payments for eligible livestock producers for grazing losses at 60 percent of the lesser of either the monthly feed cost for all covered livestock, or the normal carrying capacity of the eligible land. Payments are determined based on the type of grazing crop.

Table 6.9 Eligible counties in the LFP Program 2014-2017

Year	LFP Program	Number of Eligible Counties
2014	Forage Sorghum	14
	Improved Pasture	15
	Native Pasture	15
	Long Season Small Grains	15
2015	Long Season Small Grains	9
2016	-	-
2017	Long Season Small Grains	4

Source: USDA Farm Service Agency

As noted in the table above, 2014 was a significant year for the LFP program, with up to 15 counties receiving compensation for grazing losses in four different crop categories (Forage Sorghum, Improved Pasture, Native Pasture, Long Season Small Grains). In 2015 and 2017, Long Season Small Grain areas was the only eligible category, and there was no LFP funding allocated to any Colorado counties in 2016. Most eligible counties are located in the eastern portion of the state.

Reduction in herd size

The reduction in herd size indicates which counties had more ranchers selling portions of their herds during the 2011-2013 drought. A major impact reported by ranchers during both the 2002

and 2011-2013 drought events was there was not enough forage for their cattle, and because of this they were forced to sell portions of their herds to ensure survival of the animals.⁶

The 2013 plan compared the head of cattle per county on January 1, 2010 to the average head of cattle on January 1st in the years 2012-2013. A higher percent reduction, which implies more ranchers in that county were forced to sell cattle during drought years, equates to a higher vulnerability ranking. After the 2013 plan update, it was recommended that using an overall reduction in herd size as a drought impact metric should be replaced with reductions to the number of beef cows per county. Annual data for historical herd sizes per county were obtained from the USDA NASS survey.

To supplement the previous analysis a new comparison was generated from the difference between 2011-2012 average values and the 2014-2015 average values (pre-drought vs. post-drought). As the spatial coverage and intensity of the 2012-2013 drought was more severe over southeastern and eastern Colorado, a combination of the 2002 drought reduction and the 2012-2013 reduction was generated to help avoid spatial artifacts associated with a single drought event. The maximum herd reduction between the two calculation periods was used in the development of the updated vulnerability assessment.

Number of dairy cattle

This metric serves as an adaptive capacity, since dairy cattle are typically raised in confinement and the dairy owners have sufficient flexibility that feed can be obtained out-of-state if need be (this can cost more, but is anticipated by the dairies and generally does not disrupt operations). Querying the 2017 NASS database, six counties had dairy cattle data, with a significant amount (~9% of the state total) of animals attributed to “other counties”. When examining the 2007-2017 NASS annual survey data 13 counties were found to have at least one annual value. The 2007-2017 average was calculated for each of the 13 counties and then updated in the vulnerability assessment. To apply the adaptive capacity, if the county had 1 to 10,000 dairy cows, the livestock vulnerability was divided by 1.1, and if the county had greater than 10,000 dairy cows the vulnerability ranking was divided by 1.2. While it is acknowledged that other cattle operations, like feed lots, may have a similar adaptive capacity, data for these groups are not available across the state in a consistent manner. It is recommended that future work investigate the feeding practices of other livestock operations to update this adaptive capacity metric.

⁶ Some ranchers, instead of selling their cattle, shipped them to pastures located out-of-state during 2002. For 2011-2013 the spatial extent of the drought complicated the application of this mitigation action.

6.5.2 Crops

Spatial Density Metrics

Acres of total farmland per county, 2009

This metric provides a rough impression of how many acres of farmland are in production per county. The data are obtained from the USDA NASS, 2007 & 2012. This information is not updated as part of the NASS Survey Program. This metric should be reevaluated when the 2017 NASS Census data becomes available.

Impact Metrics

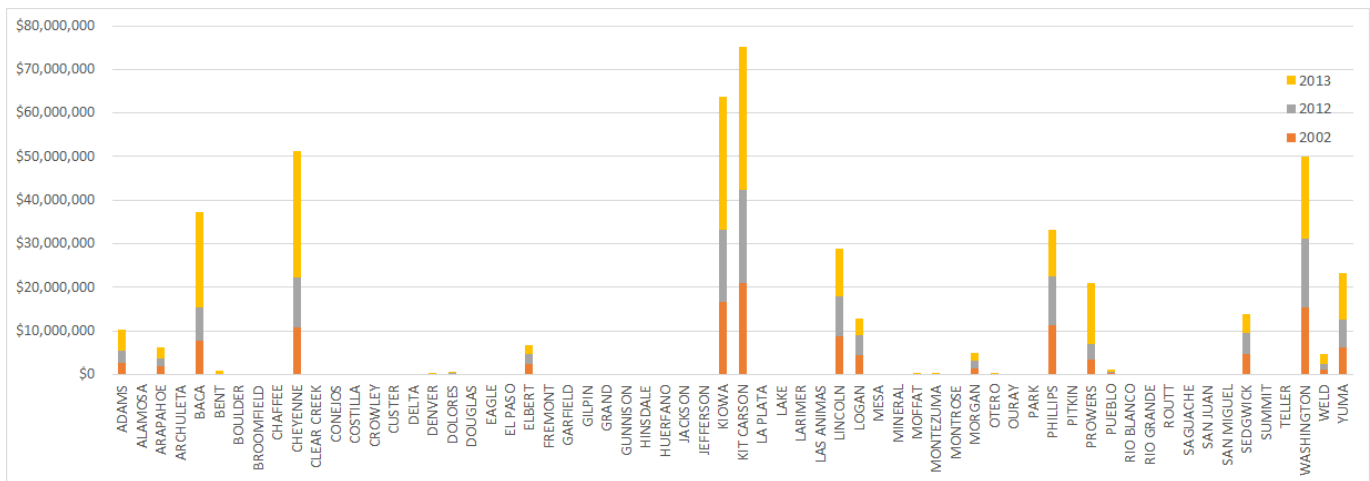
Percent dryland acreage out of total acreage, 2012

Dryland crops are more vulnerable to drought because they are entirely reliant on precipitation. The percentage of dryland acreage out of total acreage was estimated from data obtained from the USDA NASS, 2012 Census. Total dryland cropland area was calculated by subtracting the ag land irrigated area from the total farm area. The dryland ratio of total farmland was calculated for all counties with relevant data (6 counties missing data), and the applied vulnerability thresholds are based on standard percentile thresholds: 40%, 60%, and 80%. This metric is weighted 50% because of the clear vulnerability and lack of adaptive capacity of these crops. The data associated with this metric is only available as part of the NASS Census Program and should be reexamined in future updates with the latest data.

Crop indemnities due to drought, 2007-2016

Crop indemnities data were obtained from the USDA Risk Management Agency. Crop indemnities indicate the dollar value of insurance payments each county received for insured crop losses, specifically for drought-related damages incurred. The payouts for each crop type were summed to obtain a total indemnity payment per county; the higher the payment, the higher the vulnerability weighing. Annual data for 2002 data were applied to the drought vulnerability development in the 2013 update. Data for the 2012-2013 period were analyzed as a simple comparison to the 2002 data (Figure 6.25). County data for the three years yield consistencies among the county distribution and magnitude of indemnities.

Figure 6.25 Crop Indemnities Due to Drought by Colorado County



Source: USDA RMA

Non-insured assurance program outlay, 2012

The non-insured assurance program (NAP) is run by the USDA and provides coverage for non-insurable crops.⁷ The metric is the outlay requested per county (i.e., money set aside to be distributed if necessary), and the assumption is the higher the outlay, the more vulnerable the county. Data were obtained from the USDA. Forty-nine counties have allotment data for 2012, so the percentile bins were adjusted to be evenly distributed across the non-zero data set. The adjusted thresholds are as follows: 43%, 61%, and 81%. This metric is weighted 25%, the same as the previous metric, to reflect the fact that neither has a clear advantage over the other.

6.5.3 Green Industry

The vulnerability of the green industry is not represented in this assessment due to lack of data. There are not enough green industry producers for the USDA to publicly release data and still be able to maintain the anonymity of the producers. Vulnerability of the green industry is somewhat reflected in the “crops” sub-sector in Section 6.5.2, since greenhouses and nurseries are essentially irrigated crops. Qualitative impacts to the green industry are discussed in other sections.

A map of the spatial distribution of green industry producers, as listed in Section 6.1, is shown in Figure 6.10.

⁷ There are many factors that go into a crop being non-insurable, and these can vary across counties. No generalities are made regarding the types of crop or irrigation style that are covered by this program.

6.5.4 Results

Many of the impacts discussed above indicate that the conclusions from the previous vulnerability assessment continue to be applicable to the current state of drought vulnerabilities across the state. The vulnerability analysis shows higher vulnerability to drought exists on the eastern plains, where the dryland crop production is highest and farming activity is a key economic driver, a conclusion echoed in the economic study by Gunter et al., 2012 for the Arkansas Basin. Results by county are presented in Table 6.10. It should be noted that the results of the vulnerability analysis are limited because of the lack of statewide data. Many of the datasets should be reexamined when the 2017 census becomes available.

Table 6.10 Results of Vulnerability Assessment

Counties	Overall Vulnerability Score
Gilpin	0
Clear Creek, Denver, Gunnison, Mineral, Montrose, San Juan	1-1.9
Alamosa, Archuleta, Boulder, Broomfield, Chaffee, Costilla, Crowley, Custer, Delta, Douglas, Eagle, El Paso, Fremont, Garfield, Grand, Hinsdale, Huerfano, Jefferson, La Plata, Lake, Mesa, Moffat, Montezuma, Ouray, Park, Pitkin, Rio Blanco, Rio Grande, Saguache, San Miguel, Summit	2-2.9
Arapahoe, Bent, Cheyenne, Conejos, Dolores, Elbert, Jackson, Larimer, Las Animas, Logan, Morgan, Otero, Phillips, Prowers, Pueblo, Routt, Sedgwick, Teller, Washington, Weld	3-3.9
Adams, Baca, Kiowa, Kit Carson, Lincoln, Yuma	4

These rankings indicate different levels of agricultural activity within each county and different levels of adaptive capacity within those activities. Below is a discussion of each ranking. Gilpin County has no agricultural activity reflected in the livestock and crops data obtained from the USDA NASS, so it was ranked “zero” to reflect this absence.

Counties ranked 1 for overall vulnerability (lowest vulnerability):

A 1 ranking means that agricultural activity is largely absent from the county or there is a small proportion compared to the size of the county. Most of the counties in this category are located in the mountainous regions of the State, which have more dominant recreation and tourism sectors than agriculture.

Counties ranked 2 for overall vulnerability:

A 2 ranking indicates that agriculture is present but may not be the dominant activity in the county. Most of the counties in the state fall within this ranking category. Without significant tracts of crops and herds of cattle, these counties are not expected to experience devastating agricultural

losses during a drought. Much of the western half of Colorado is largely made up of counties with a ranking of 2.

Counties ranked 3 for overall vulnerability:

A 3 ranking implies there is significant agricultural activity in the county, but it may not be entirely dominated by dryland crops or there may not be much in the way of allocated insurance funds. Most of the counties in this category are located in the eastern portion of the state and have a fair amount of dryland crops. The differences between counties ranked 3 and 4 are relatively small and counties in this category should be given equal attention with respect to mitigating for future drought. Dolores County is in this category because it saw fairly significant reductions in cattle herd size between 2001 and 2002-2005. Pueblo and Jackson county are noted for increasing from a ranking of 1-2 in the previous assessment to a 3 in this 2018 assessment, and this change is largely driven by the large head reduction ratio during the 2011-2014 period. However, the fact that Dolores, Pueblo, and Jackson county herd sizes are still as small in 2017 as they were in the 2013 plan warrants further exploration regarding whether this might be a lingering drought impact (given herd size affects the overall vulnerability scoring). Inclusion in this category also could indicate significant agricultural activity in one sub-sector but not another.

Counties ranked 4 for overall vulnerability (highest vulnerability):

A 4 ranking reflects significant agricultural activity, a high percentage of dryland crops, and/or large cattle herds that saw a noticeable decline following either the 2002 or 2012-2013 drought. Kiowa, Kit Carson, Lincoln, and Yuma Counties were added to this category (Adams and Baca were included in previous assessment). These counties showed high vulnerability rankings (3-4) in both livestock and crops sub-sectors.

Figure 6.26 and Figure 6.27, on the following pages, demonstrate graphically the inventory and impact results for the livestock and crops sub-sectors.

Figure 6.26 Livestock Inventory and Vulnerability Ranking

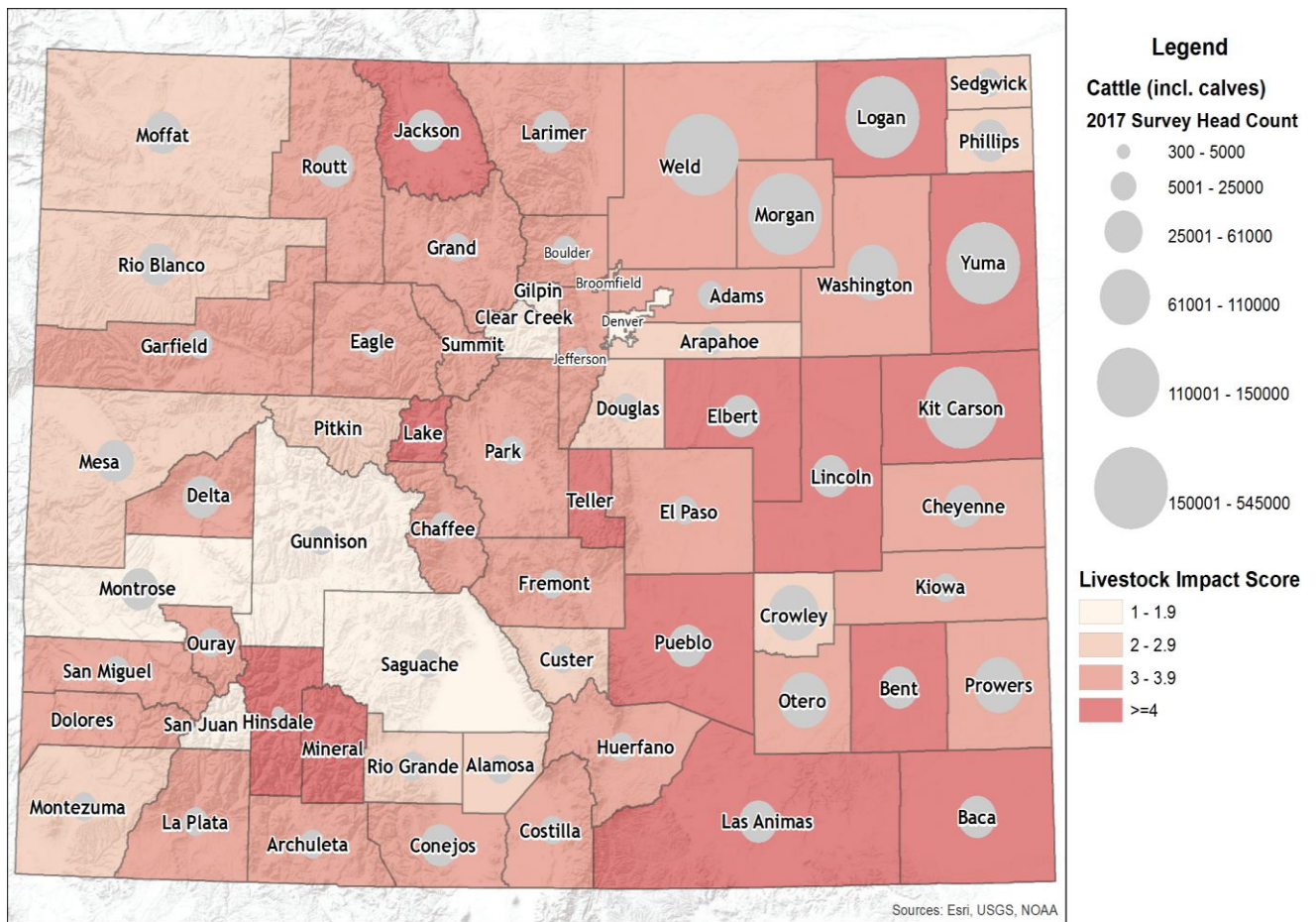


Figure updated 2017.

Figure 6.27 Crop Inventory and Vulnerability Ranking

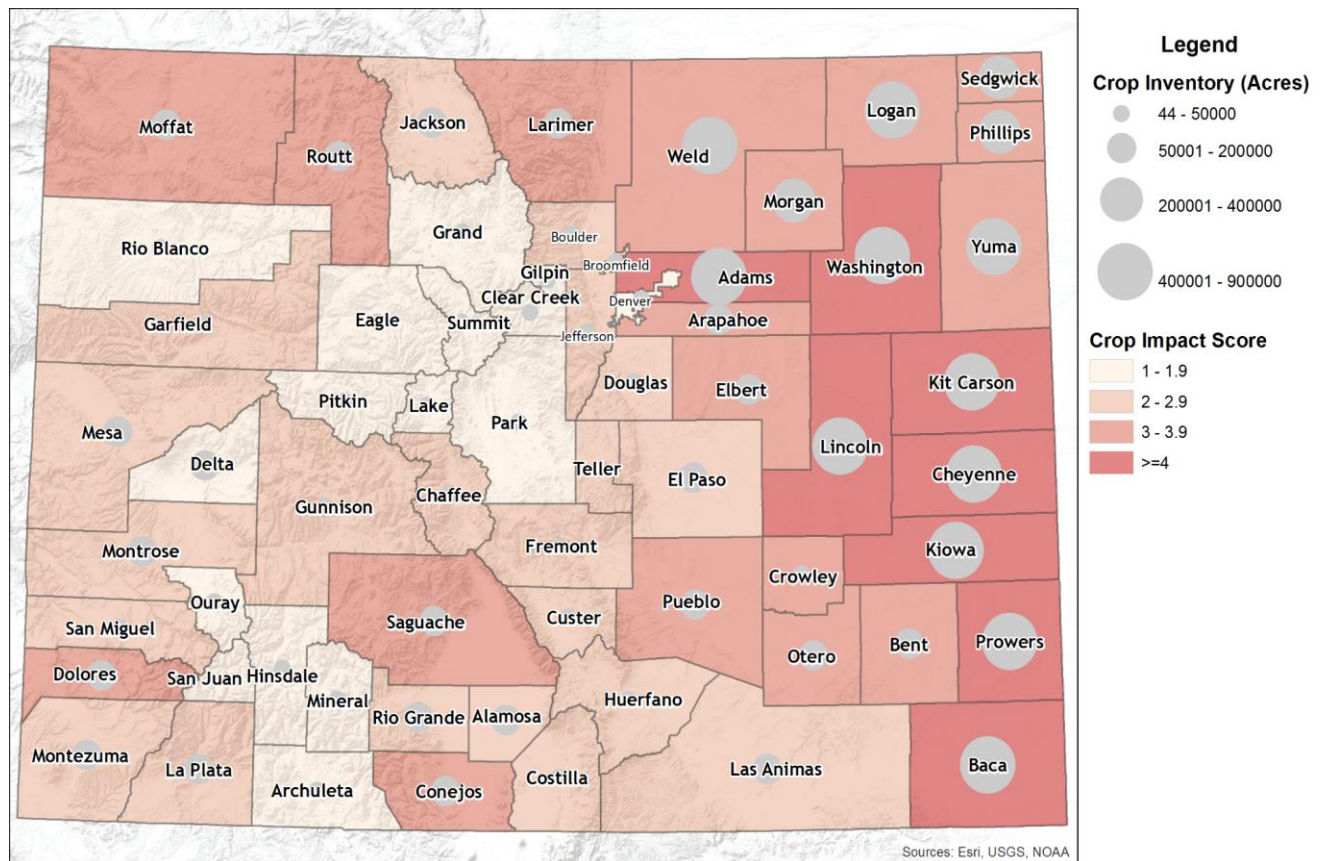


Figure updated 2017.

6.5.5 Spatial Analysis

Spatially, the Agriculture Sector as a whole is fairly well distributed around the state. There are distinct concentrations of crop and livestock activity, primarily on the eastern plains (e.g., dryland crops, cattle), the northeast corner of the state (cattle), and in the San Luis Valley (crop inventory).

The livestock inventory shows a low number of cattle in the Denver Metro area, the central Rockies, and near the south-central and southwest parts of Colorado. The highest numbers of cattle are found in the northeast corner of the state, especially in Weld County. High numbers of cattle are also located in Morgan, Logan, Yuma, and Kit Carson Counties.

Crop acreage is distributed similarly to livestock. Highest crop acreage is found in the east and northeast, and the least amount of planting is in the central portion of the state and in the mountainous regions.

The livestock vulnerability metric is insurance allotments (Livestock Forage Program), comparison of herd size between 2001-2015 (pre- vs. post drought periods), and number of dairy cattle as an adaptive capacity. The Livestock Forage Program payments data was also updated for the 2012-2013 period. Most of the counties in the state have a livestock vulnerability impact

ranking between 2 and 3 (average for all counties = 2.6). This indicates that cattle ownership is well-distributed across the state. Weld and Morgan Counties are good examples of how the dairy cow adaptive capacity metric works. Weld County has a large number of cows, but over 10% of those are dairy cows, and Weld did not have a sharp decline in cattle following the summer of 2010. In the previous vulnerability assessment, Morgan County, which also has a large number of cattle (roughly 10% of its cows are dairy cows), had no livestock forage allotments in 2010, and saw a very slight decrease in herd size following the 2002 drought. These factors combined gave it a relatively low impact score for livestock, and highlights the point that even though the county has many cattle, it is not necessarily highly vulnerable to drought. With the updated assessment, including the 2012-2013 drought period, Morgan County reported livestock forage allotments (approximately \$3 million) with a relatively small reduction in herd size. This finding may be the result of variable drought conditions and highlights the need for continuous and routine updates to the drought-related input data used in the livestock risk assessment. Counties that are ranked 3.1-3.9 are counties with livestock forage program allotments and no dairy industry. The insurance allotments indicate their historic struggle with livestock.

The crop vulnerability metric is percent dryland crops, crop indemnities due to drought in 2012, and non-insured assurance program outlays in 2012. Rankings here actually go above a “4” in some counties because of qualitative adjustments to counties with over 70% dryland crops. (Counties with this qualitative adjustment include Adams, Broomfield, Morgan, Weld, Yuma, Logan, and Kit Carson). Figure 6.8 (ratio of dryland cropland to total farmland) largely depicts the underlying driver of the crop vulnerability scores. While these scores were not updated in the previous Plan update (2013), the updated 2017 output closely resembles the vulnerability scores produced for the 2010 drought plan. In general, the map gives a sense of where dryland crops are located and, to a lesser degree, the counties that received crop indemnities. The limitation of using dryland crops as a metric is reflected in the relatively low vulnerability rankings assigned to counties in the San Luis Valley. This area is a crop-producing region, and the literature review and interviews conducted indicated the area experienced significant impacts from the 2002 drought. However, Gunter et al., 2012 were able to show a net economic gain to the region for the 2011-2013 drought, suggesting a possible discrepancy between perception and reality. Future work should further seek to identify drought specific datasets and metrics that can be used to accurately track the impacts of drought. NASA’s CASA model and the joint Colorado State University-CWCB economic studies provide examples of how to move forward.

The publication of the 2017 agriculture census will allow these metrics to be updated with data that has minimal drought-related impacts. Data from the most recent NASS Census (2012) and NASS Survey (2017) were used to update the vulnerability scores, and the updated data produced similar overall vulnerability results to the previous vulnerability metrics data. Results from the 2017 drought plan are presented in Figure 6.28 and score changes are illustrated in Figure 6.29. Overall agriculture vulnerability scores were calculated by combining subsector impact and inventory information. A notable feature is the abundance of counties with a 1 or 2 ranking in the central-western portion of the state, reflecting the fact that agricultural activity takes place in these counties but perhaps not to the degree that would make them highly vulnerable to drought. In

Figure 6.28 Overall Agriculture Impact Vulnerability Ranking

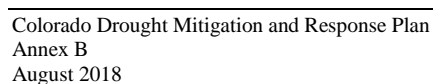


Figure 6.29 Overall Impact Vulnerability Ranking Change (2017 Scores – 2010 Scores)

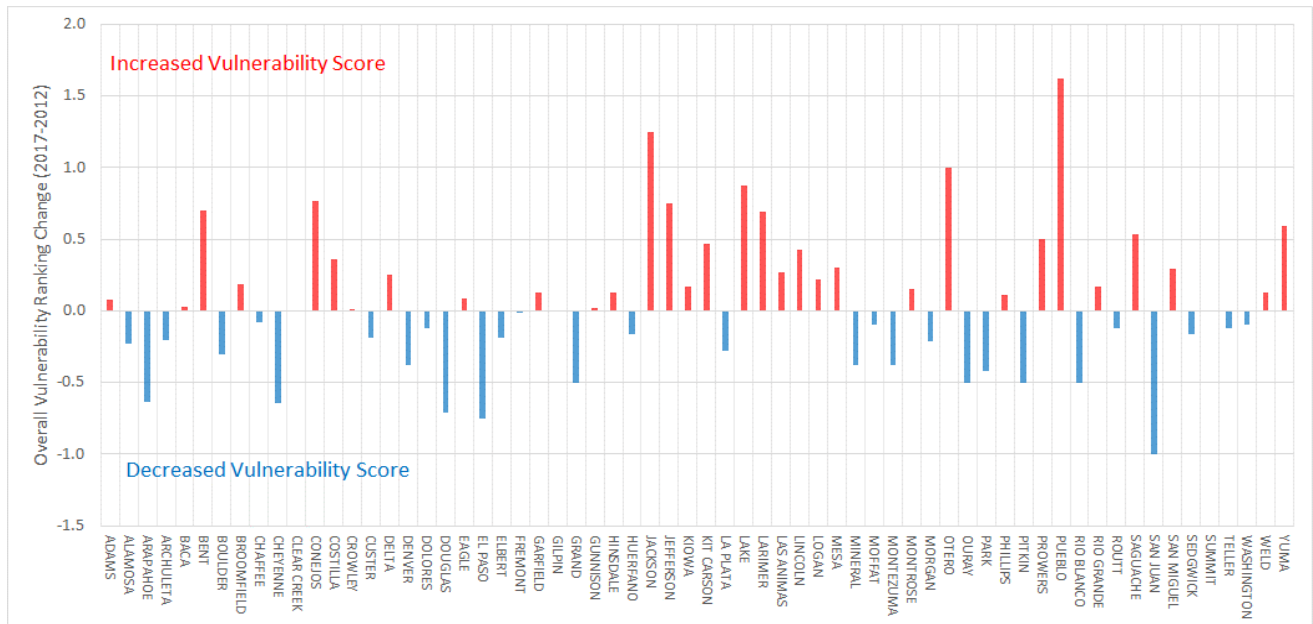
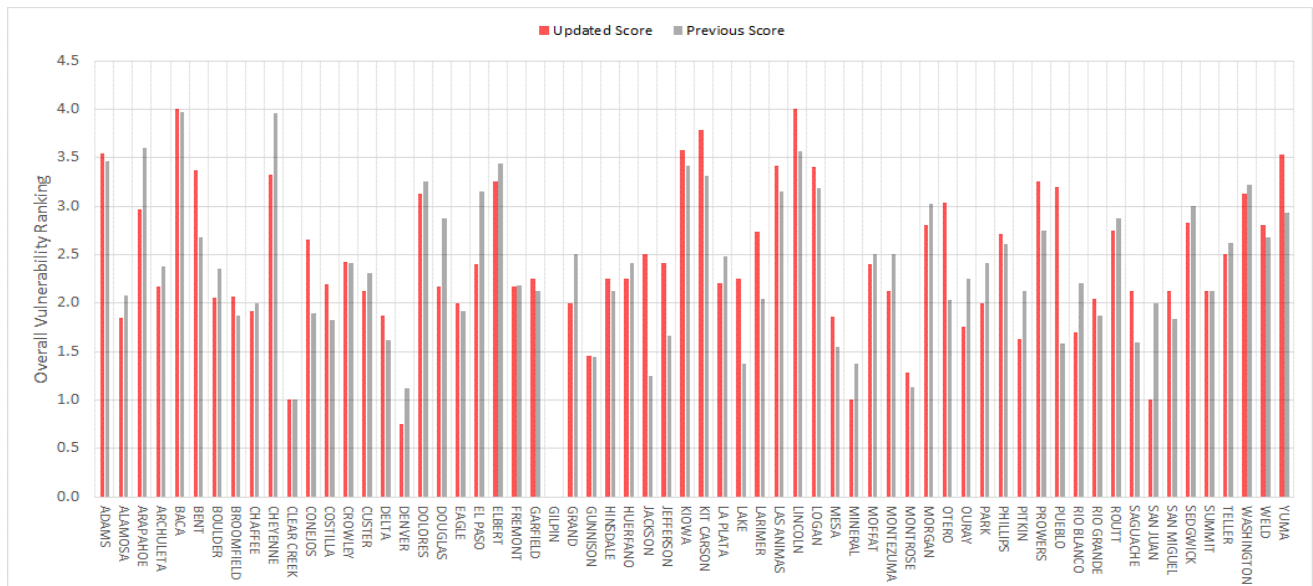


Figure 6.30 Drought Impact Vulnerability Comparison (Previous vs. Updated Scores)



6.5.6 Compound Impacts

Compound impacts are secondary, or indirect, impacts brought about by changes in sectors that are directly impacted. For example, direct drought impacts to the Agricultural Sector may entail loss of revenue to farmers, ranchers, and greenhouse/nursery/sod growers. This loss of revenue can in turn contribute to an overall slowing of the local economy as farmers spend less money on equipment, supplies, and other consumer items, thus compounding the initial impact. If spending decreases for a prolonged amount of time, effects such as loss of agribusiness jobs (e.g., seed

retailers, farm equipment suppliers, crop insurance sales, and raw food processors) and population decline in rural communities could be seen. These impacts have been seen in the Arkansas Basin for the 2011-2013 drought (Gunter et al., 2012).

Another compound impact of drought occurs to the environment – in past emergency situations, the government has authorized grazing on lands otherwise closed to cattle (i.e., the USDA approved emergency grazing on Conservation Reserve Program acres for numerous counties during the summer of 2002 [Christensen 2002]). Increased cattle grazing can negatively impact plant life and have a detrimental effect on the local wildlife. Decreased plant life can lead to increased soil erosion, which can impact water quality due to increased sediment. Degraded water quality can have a negative effect on aquatic life and downstream communities.

If surface water supplies are inadequate for irrigation demands, farmers may turn to groundwater to supplement. A general decline in aquifer storage is seen in times of drought. On the very eastern side of Colorado, there is no surface water supply and all irrigation water is obtained from the Ogallala Aquifer (Simpson 2002). Lack of precipitation can result in increased pumping and decreased recharge, which causes aquifer drawdown. This has two impacts: 1) to the environment as the aquifer generally does not recharge as quickly as it is depleted (it can take multiple years of management to return water levels to pre-drought conditions); and 2) on the energy side, more energy to run the pumps means greater power demand and higher cost to the pump operators. The Ogallala is an example of an aquifer with a vital role to the agricultural production of the state, but which is currently experiencing critical conditions due to low storage and slow recharge rates. Although a recent study was published discussing the measures that Colorado is expected to take in coordination with other states, producers, and stakeholders to manage the aquifer in the future (McGuire, 2017), the aquifer's situation is destined to directly and indirectly impact other facets of the economy in ways such as described above. Finally, drought tends to lead to more sun and heat, causing increased evapotranspiration which means crops need more water in a time of already prevalent water scarcity.

As discussed in the review of previous works (Section 6.2.2), farmers can lease or transfer their water rights to municipalities to offset lost revenue during a drought. Permanent agricultural transfer has negative implications for not only the Agriculture Sector, but also the local economy and community as it can lead to unemployment and population decline.

6.6 Recommendations

6.6.1 Adaptation to Drought

As with other sectors, diversification and early warning within the Agricultural Sector are key adaptive capacities. Planning and developing strategies to cope with drought is a mitigation strategy that can benefit all farmers and ranchers. For example, ranchers can develop business relationships with multiple feed providers in case one or two providers are unable to meet the demand. Early warning to the anticipated drought allows ranchers and growers to be more flexible

with their operations. Crop growers would benefit from having drought-resistant crops in their rotation along with the flexibility to lease water to municipalities in years when it is impractical to plant their fields. Alternative transfer options (as detailed in SWSI Phase 2) could also be explored as ways for farmers to adapt to drought.

The best management practices developed by the green industry might have applications for irrigated crops as well. A formalized set of best management practices could also be developed for dryland farmers. The CSU Extension maintains a helpful website with educational articles on numerous farming topics including techniques for managing crops during a drought.⁸

6.6.2 Improving Vulnerability Assessment

The Agriculture Sector is large and diverse, and would benefit from a more specific analysis. For crops, instead of just irrigated or dryland, the crop type could be included in the discussion of vulnerability (e.g., separating vegetables from feed). Since crops vary depending on how much and what quality of water is needed, those two factors could be part of an expanded analysis. Additionally, irrigated and dryland crops could just become separate impact groups. For livestock, an analysis of where the cattle are sent to graze should be conducted (i.e., who owns the land and what is the land owners' historical reaction to drought as it influences cattle grazing). The number of cattle living in confinement could be refined from just dairy cattle to include stockyard cattle, a statistic not available from NASS but that could be calculated on a county level by obtaining each county's stockyard capacity.

The 2017 update was challenged by a number of data limitations, including a lack of some statewide county-level data. This assessment is also limited by a reliance on data that is only published every 5 years. Advancements in remote sensing, such as those provided by NASA's CASA model, provide examples of how to measure and monitor drought events as they occur.

The green industry is too small to obtain statistics through the USDA, but a survey effort might be effective to find vulnerabilities specific to a region or a type of grower.

The bullets below are some suggested vulnerability metrics that could enhance this assessment in the future.

- Livestock:
 - Limit analysis to beef cows.
 - Refine cattle data to reflect grazing vs. confined cattle.
 - Expand focus to include other animals (e.g., sheep, goats, pigs, chickens, etc.)
- Crops:

⁸ <http://www.ext.colostate.edu>

-
- Include details such as crop type and crop sensitivity to reduced and/or degraded water quality.
 - Perform a detailed soil analysis by county and make available to the public. Specifically focus on soil texture and available water holding capacity (which is a function of soil texture and organic matter [Ball 2001]) to identify areas where soil moisture may be depleted more rapidly than others during a drought. Available water holding capacity generally ranges from 0.25 inches of water per foot of depth (for coarse sand) to 2.5 inches of water per foot of depth (for silty loam) (Ball, 2001). This range of root-zone available water is fairly limiting, however, as the time difference between the worst-case (coarse sand) and best-case (silty loam) soils is only a week or two, given the evapotranspiration rate of the crop (average plant evapotranspiration is on the order of 0.33 inches per day) and the water infiltration rate (the rate the water percolates down through the soil) (conversation with CSU Extension, 2010). Soil data are available from the USDA NRCS soil survey data mart.
- Green industry:
 - In the absence of comprehensive publicly available data, conduct a survey designed to identify areas and growers that are more vulnerable to drought than others.
 - Develop metrics that all business owners can track, and that will help state water managers monitor drought impacts.
 - Attempt to quantify the medical and recreational marijuana industry water use impact and demand as the industry continues to grow

7 ENERGY SECTOR

Key Findings

- Thermoelectric power plants can be impacted by inadequate water supplies and increased cost of water during drought.
- Although the percentage of electricity that is provided by hydropower in Colorado is only about 2%, there are currently over 60 operating hydropower facilities throughout the state with a combined capacity of 1,150 MW, and generation capacity can decrease as reservoir levels drop and releases decrease. Colorado also has a number of “run-of-river” hydropower plants which could also be affected by reduced streamflows.
- Colorado is home to a prosperous and diverse mining industry. Mining activities are spread out across the State but are generally concentrated in the western half. Water use for mining varies greatly depending on the mineral extracted and technology used. As such, mining operations can be impacted by increased costs of water for operations and may have to slow down if sufficient water is not available.
- The energy sector is generally drought tolerant. Power providers and mining operations tend to have very senior water rights portfolios and some power providers already have conditional drought agreements in place.

Key Recommendations

Most of the following key recommendations were originally developed in 2010 and continue to be relevant in 2018. These recommendations should be considered in light of regional differences. For example, planning decisions regarding infrastructure in urban or high-density areas are different than those that are applicable to rural communities.

- To protect critical infrastructure during drought conditions and possible secondary influences, power providers should continually assess their systems to identify areas prone to failure or impact. For example, Xcel Energy began efforts in 2013 to reduce vulnerability of their infrastructure due to pine beetle impacted forests and the wildfires that may result in these areas attributed to dry conditions. Light detection and ranging technology (LiDAR) is being used to identify dead and dying trees that could fall on power lines. Debris management then occurs in critical areas to reduce costly impacts (Denver Post, 2013).
- Although power production was not curtailed during the 2011-2013 or 2002 droughts, power providers are still vulnerable to curtailment in severe droughts. As population expands, power demand increases and competing demand on water resources intensifies. Power providers should be aware of this possibility. Purchasing additional water rights and developing conditional drought lease agreements may be helpful. Demand-side management, integration of low water-use renewable generation methods, and use of legally-reusable effluent for cooling can also reduce drought impacts. Companies involved in fracking should also continue to research innovative ways to reuse produced water.

-
- Power providers can decrease vulnerability by transitioning to less water intensive generation methods while considering available fuel choices. Renewable generation methods like wind and solar use negligible amounts of water and are part of the legislated mandate of 30% renewable energy sources by 2020. Increasing renewables reduces the water required for system-wide generation on an annual basis, but water supplies are required to operate conventional plants and those plants need to be prepared at all times, in case renewable generation is not adequate on any given day or time.
 - As additional renewable power generation facilities come online, transmission line capacity should be increased to facilitate flexibility during drought.
 - Mining companies should increase their drought awareness and consider technologies that are less water intensive.
 - Several counties located towards the western edges of Colorado (e.g., Moffat, Routt) and others in the central (e.g., Fremont) and eastern parts (e.g., Cheyenne) continue to have vulnerabilities to drought for the Energy Sector. This conclusion is based on the finding that their mining and power generation operations are reliant on surface water sources, which are considered more at risk of decrease during drought events than are groundwater sources. Further vulnerability comes from a lack of renewable energy resources to supplement power generation (lack of adaptive capacity) and from an economic base proving fairly dependent on those mining and power operations, making the counties susceptible to economic impacts during drought. A few counties suffer from high water withdrawal rates, lack of water diversification options, and high reliance on mining and power generation economies. To better prepare and minimize impacts, local governments should be cognizant of these matters, and consider actions such as economy diversification and drought mitigation plan implementation.

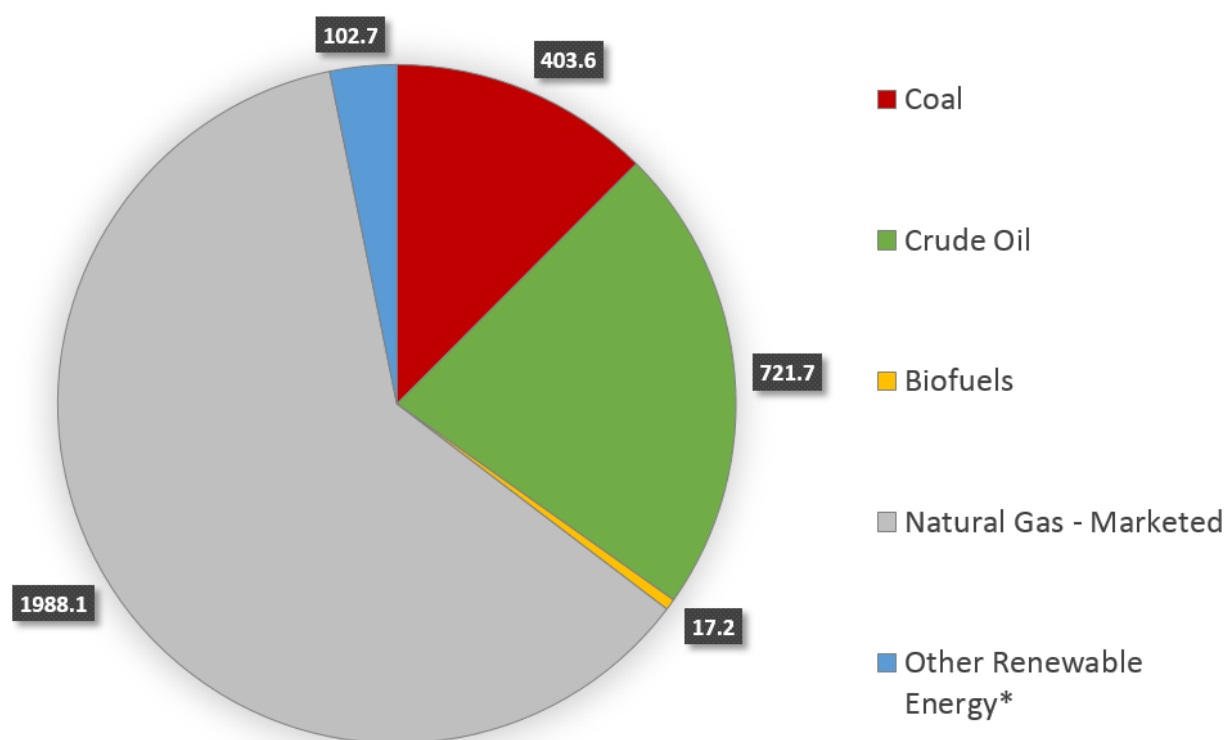
7.1 Introduction to Sector

The Energy Sector encompasses mining and power production. While these two activities are often interrelated, their use and dependence on water resources is quite different. As such, for the purpose of this analysis, the Energy Sector has been divided into two sub-sectors: power and mining. For a general description of the vulnerability assessment approach refer to Chapter 2 (Annex B).

Colorado is rich in mineral reserves, and mining is an important part of the economy. The total value of mineral and energy fuels production in 2015 was estimated to be \$13.43 billion. The future of mining in Colorado remains promising. The oil and gas market provides 70% of Colorado's yearly mineral resource revenue, on average. In addition, Colorado is the number one molybdenum producing state and was the number three gold producing state in the nation, as of 2015. The State was, as of 2016, fifth in the nation for marketed natural gas production, with over 1.7 million cubic feet (U.S. Energy Information Administration, 2017). In 2008, the Rockies Express Pipeline began service, greatly enhancing Colorado's ability to export natural gas to Wyoming and east towards Midwest markets near the Appalachian regions.

Additionally, there are enormous deposits of oil shale in the western part of the State estimated to hold one trillion barrels of oil. If mined, this is equivalent to the entire world's proven oil reserves, but to date extraction of this resource has been limited by high costs. Colorado is also a top state for proven coalbed methane reserves (accounting for more than one-fourth of all coalbed methane produced in the U.S.) (U.S. Energy Information Administration, 2013). Figure 7.1 shows the relative magnitude of production of the various energy activities in the State in 2015, in trillion British thermal units (Btu). Total production amounted to over 3,233 trillion Btu.

Figure 7.1 Colorado Energy Production Estimates, 2015 (Trillion Btu)



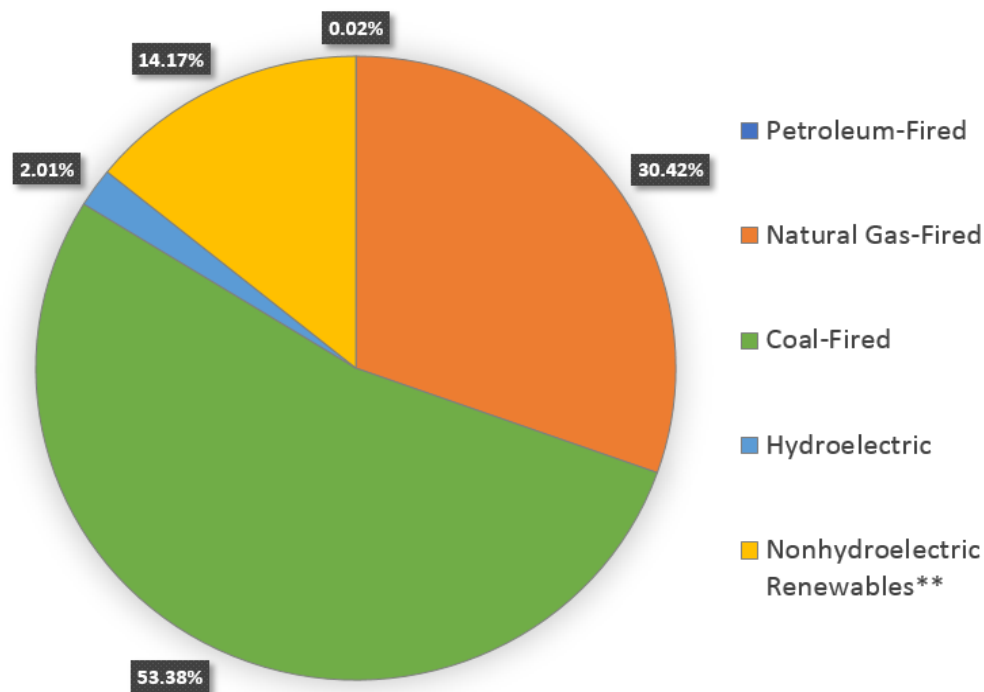
*Other Renewable Energy sources include: wood, black liquor, other wood waste, biogenic municipal solid waste, landfill gas, sludge waste, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind.
Source: U.S. Energy Information Administration, Figure revised in 2018 with 2015 data.

In 2016, retail power providers generated almost 54.5 million megawatt-hours (MMWh) of energy (EIA, 2018). The economic impact of power generation goes far beyond sales revenue or the jobs directly created. It is nearly impossible to fully quantify the impact of power production on the State. Without reliable power generation nearly all other sectors would be crippled. Figure 7.2 shows the 2017 distribution of net electricity generation by fuel type in Colorado. The majority of Colorado's generation (~53.4%) is coal-fired. The remainder comes from natural gas-fired

(30.4%), non-hydroelectric renewables (14.2%), hydroelectric sources (2%), and a minute amount from petroleum-fired sources (0.02%). It is important to note that Colorado’s electricity profile is changing. A mandate was passed by the Colorado General Assembly in 2007 to require large utilities to obtain 20% of their energy from renewable resources by 2020, but in 2010 House Bill (HB) 1001 increased this requirement to 30% for investor owned utilities. It is expected that a large portion of this will be provided by wind, hydroelectric, and solar technology. In addition, Colorado Governor Executive Order D2017-015 went out in 2017, calling for emission reductions economy-wide but with a focus on the utility sector, in an effort to encourage clean air programs and projects to create “a healthy and productive citizenry” while bolstering recreation capabilities and diversifying the economy. Alongside these clean energy goals, Xcel Energy’s recent Colorado Energy Plan also offers portfolio options that “build wind and solar capacity, invest in Colorado’s economy, reduce emissions, and ensure reliable, affordable electricity into the future” (Xcel Energy, 2018).

In 2016, Colorado ranked 10th in the U.S. for installed solar capacity, with over 925 MW of solar energy installed, and 11th nationally for actual solar electricity generation (EIA, 2018). The State’s average installed photovoltaic (PV) system prices fell by 64% in the last five years. Similar to HB 1001 but for rural utilities, the 2013 Senate Bill (SB) 252 requires rural electric co-ops to obtain 20% of their energy from renewable sources by 2020. It also encourages the use of methane capture technologies.

Figure 7.2 Net Electricity Generation by Source in Colorado, 2017



**Non-hydroelectric Renewables include: generation from wind, solar, geothermal, and other renewable sources such as wood and wood wastes, municipal solid wastes, landfill gas, etc.

Source: U.S. Energy Information Administration. Figure revised in 2018 with 2017 data.

The Energy Sector is closely connected to water resources both through mining processes and power generation. Power producers consume water through evaporative cooling and passive evaporation from reservoirs for hydroelectric plants. The Colorado Water Board's (CWCB's) Statewide Water Supply Initiative (SWSI) has analyzed water usage by various economic sectors. Self-supplied industry, which includes the energy sector, consumes approximately 4% of water in the State annually (SWSI Update, 2017). Self-supplied industry includes a variety of activities, including thermoelectric generation, snowmaking, and other activities. It is estimated that thermoelectric generation comprises approximately 2% of water consumption in the State, approximately half of the sector's water consumption.

Water consumption by the municipal and industrial (M&I) and agricultural sectors accounts for approximately 10% and 86% of water use in Colorado, respectively. By 2050, SWSI 2010 predicted that water consumption by M&I and agriculture will be 15% and 82%, respectively. Because of the relatively small water footprint of electric generation within Colorado, caution should be used when extrapolating the drought benefits resulting from implementation of generation technology which uses less water, particularly when those technologies take significant time to implement, are very expensive, and may or may not be available in sufficient quantity during drought-related weather conditions of high temperatures (e.g., dry cooling).

The National Renewable Energy Laboratory estimates that, in Colorado, thermoelectric generation requires 0.51 gallons of water per kilowatt hour (gal/KWh), and hydroelectric requires 17.91 gal/KWh (Torcellinin, Long, and Judkoff, 2003). It is important to note that, while hydroelectric generation requires more water, it is non-consumptive (i.e., it is typically available for other uses following its usage for energy generation), while thermoelectric generation is consumptive. Water use for mining varies greatly depending on the resource extracted and the methods used. Water is often used for drilling and transport. Conversely, large quantities of water (often of impaired quality) can be extracted during mining production. Table 7.1 outlines the primary connections between water and energy as detailed in Cameron et al. 2006. This information will be discussed in more detail in later sections.

Table 7.1 Connections between the Energy Sector and Water Availability and Quality

Energy Element	Connection Water Quantity	Connection to Water Quality
Energy Extraction and Production		
Oil and Gas Exploration	Water for drilling, completion, and fracturing	Impact on shallow groundwater quality
Oil and Gas Production	Large volume of produced, impaired water	Produced water can impact surface and groundwater
Coal and Uranium Mining	Mining operations can generate large quantities of water	Tailings and drainage can impact surface water and groundwater
Electric Power Generation		
Thermoelectric (fossil, biomass, nuclear)	Surface water and groundwater for cooling and scrubbing	Thermal and air emissions impact surface waters and ecology

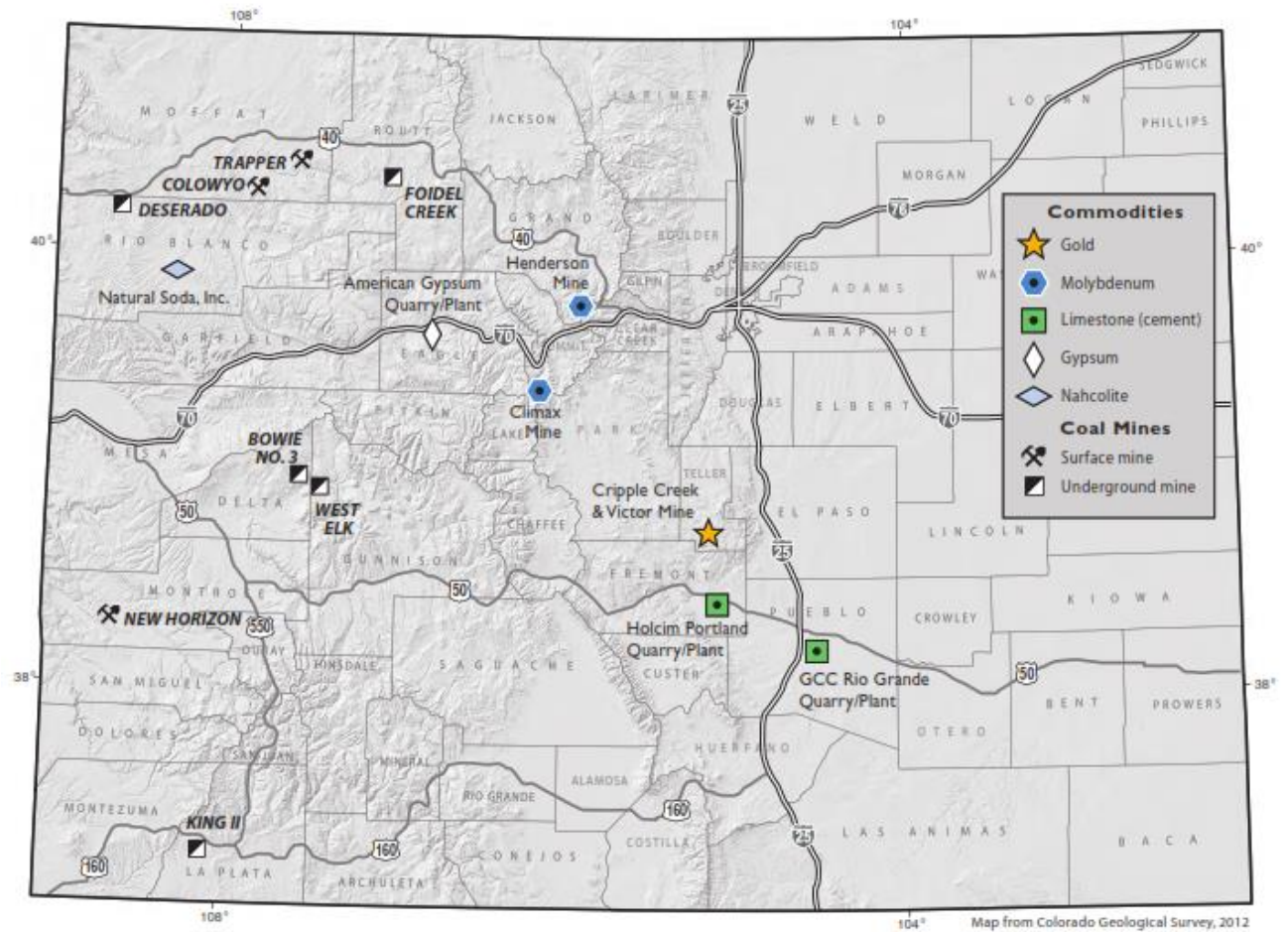
Energy Element	Connection Water Quantity	Connection to Water Quality
Hydroelectric	Reservoirs lose large quantities to evaporation	Can impact water temperatures, quality, ecology
Solar PV and Wind	None during operation; minimal water use for panel and blade washing	None during operation; minimal water use for panel and blade washing
Refining and Processing		
Traditional Oil and Gas	Water needed to refine oil and gas	End use can impact water quality
Biofuels and Ethanol	Water for growing and refining	Refinery wastewater treatment
Synfuels and Hydrogen	Refining water for synthesis or steam reforming	Wastewater treatment
Energy Transportation and Storage		
Energy Pipelines	Water for hydrostatic testing	Wastewater requires treatment
Coal Slurry Pipelines	Water for slurry transport; water not returned	Final water is poor quality; requires treatment
Barge Transport of Energy	River flows and stages impact fuel delivery	Spills or accidents can impact water quality
Oil and Gas Storage Caverns	Slurry mining of caverns requires large quantities of water	Slurry disposal impacts water quality and ecology

Source: Cameron et al. 2006

The implications of hydraulic fracturing, or “fracking”, used in oil and gas development has become an important topic throughout Colorado, especially the Front Range, as large-scale drilling intensifies. The water demands associated with fracking, including the water required to drill the wells, has been estimated to be 22,100 to 39,500 acre-feet annually in Colorado. This is equivalent to serving the water needs of 66,400 to 118,400 homes in the State for an entire year (Western Resource Advocates, 2012). Due to its water requirements, and because most new oil and gas activities on the Front Range use municipal water supplies, the fracking process is vulnerable to the impacts of drought and scarce water supplies. However, it is unclear how water supplies will be allocated to fracking endeavors during drought. Water providers may continue to sell higher priced water to the oil and gas industry while asking their customers to conserve water during drought, or, the industry may find itself dealing with the same water use restrictions as the rest of the general population. Due to this uncertainty, and to the water requirements of the process, the fracking industry should continue to fund research to develop innovative ways to reduce overall water use as well as reuse the water that is produced, rather than treating it as a waste product and re-injecting it into the ground.

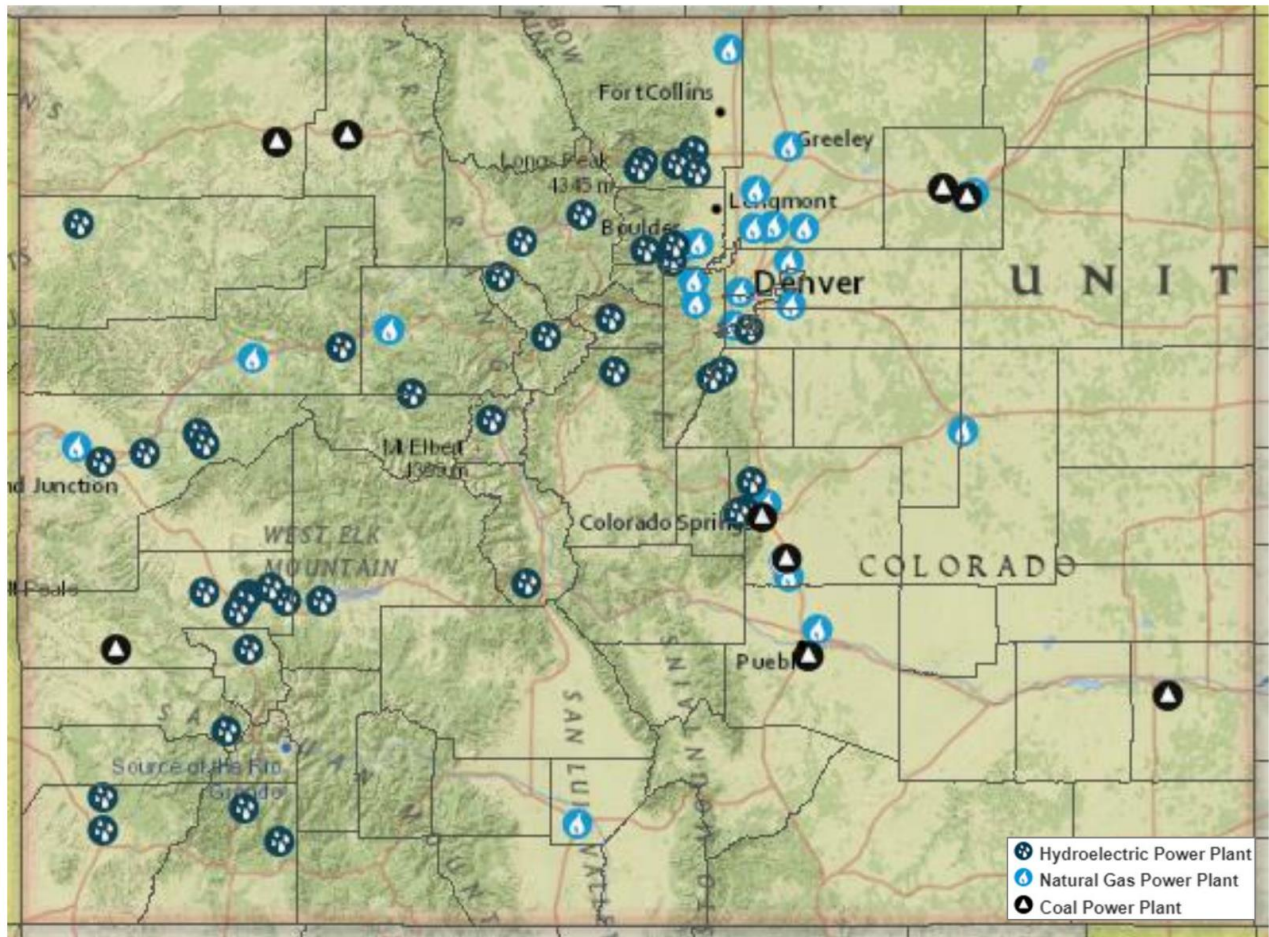
The Energy Sector is distributed across the State but more concentrated in the western half. The following figures illustrate the spatial distribution of mining activities and water intensive power production across the State. Figure 7.3 shows the distribution of major industrial mineral mines across the State, excluding clay and aggregate mines. Clay and aggregate mines tend to be spread out across the State but often in close proximity to population centers and transportation corridors. Distribution of individual resources is discussed in more detail in Section 7.3. Figure 7.4 shows the distribution of hydroelectric plants in Colorado and thermoelectric plants that use cooling water.

Figure 7.3 Significant Industrial Mineral and Coal Mines in Colorado



Source: Colorado Geologic Survey, 2012

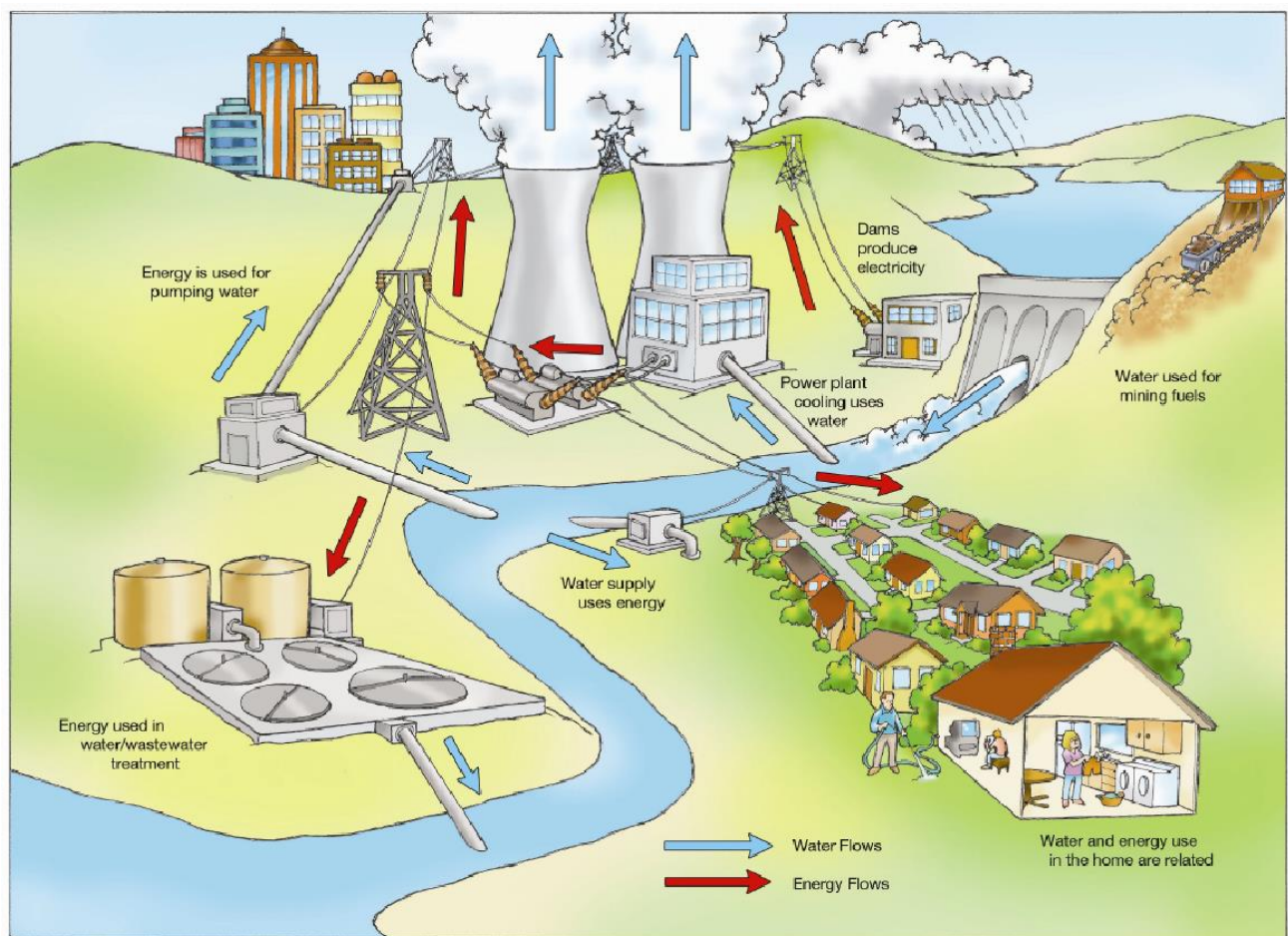
Figure 7.4 Location of Water Cooled and Hydroelectric Power Generating Facilities in 2018



Source: U.S. Energy Information Administration, 2018.

There are few activities in the State that are not reliant on the stability of the Energy Sector. Most industries and individuals in Colorado rely on power providers, and power providers, in turn, depend on reliable fuel sources that are often provided by Colorado mines. Throughout the United States, 3% of all power generation is used for water supply and treatment. Electricity represents approximately 75% of the cost of municipal water processing and distribution (Cameron et al., 2006). Without power, many municipal providers who rely on pumps and power for treatment processes would be unable to supply water. The same is true for agriculture, especially groundwater irrigation which also relies on pumps. Figure 7.5 details some of the basic interrelationships between water and energy.

Figure 7.5 Examples of the Interrelationships between Water and Energy



Source: Cameron et al. 2006

7.2 Vulnerability of Energy Sector to Drought

7.2.1 Aspects of Vulnerability

Table 7.2 outlines the key impacts and adaptive capacities of the Energy Sector with respect to drought. The primary vulnerability to power providers during a drought is loss of cooling water

supply for thermoelectric power. To compensate for this, electric providers may perform load-sharing, e.g., reducing load where dry conditions are prevalent and moving energy in from other areas that are not as affected. Transferring load and balancing power for the Western Grid, which Colorado is a part of, is coordinated by the Western Electricity Coordinating Council (WECC) to ensure electric system reliability throughout the Western U.S. This type of allocation process can be an effective management strategy during drought because power can be bought and sold on a nearly instantaneous manner (Personal communication with Xcel Energy, 2013). However, widespread drought, such as that in Texas in 2011, can pose problems to entire electric grids, especially where ‘once-through’ cooling based on river flow is the dominant technology. Several thousand MW of power generation were at risk of not being available due to the severe drought there, which prompted considerations to close some facilities (The Texas Tribune, 2011). This is due in part because the grid supplying electricity to Texas is located solely in the State. In contrast, the Western Grid includes approximately half of the country, so Colorado is not as at risk for this type of problem (Personal communication with Colorado Energy Office, 2013). Additionally, cooling towers, which do not require high water volumes to operate (as opposed to ‘once-through’ cooling), is the dominant technology in Colorado. This technology is less vulnerable to drought and therefore used more commonly in the Western United States.

Although demand may be met by other providers if production in one location declines for any reason, shifts in production method may result in increased impacts to the environment or costs to the consumer. In a worst-case scenario, the generation capacity could be so impaired that rolling blackouts or outages would result. Neither of these scenarios is that likely in Colorado, as power providers tend to have very senior water rights and historical drought curtailment has been non-existent. However, with population growth and the resulting increase in demand for power and strain on water resources, the situation could be more tenuous in future droughts.

Infrastructure related to electric power distribution is also vulnerable during drought conditions, and secondary drought impacts can be most significant. For example, falling timber due to wildfires and beetle kill can fall on transmission lines, causing power outages and necessitating prompt repair. During the Four Mile fire west of Boulder in September 2010, many of Xcel Energy’s transmission lines were damaged (Personal communication with Xcel Energy, 2013). Steep terrain and challenging access where many wildfires occur requires power providers to sometimes have equipment and firefighters dropped in via helicopter to protect critical infrastructure, a costly and dangerous process. To assist with mitigating these impacts, Xcel Energy is currently using LiDAR to identify mountain pine beetle impacted trees near its 13,000 miles of power lines. Typically, each line is checked once every five years, but in pine-beetle prone areas this frequency has increased to every two years. As of 2013, more than 250,000 trees had been removed at a cost of approximately \$17 million (Denver Post, 2013).

Hydroelectric generation capacity can also be impacted by drought events given decreased reservoir elevations, although the magnitude of this impact is minimal due to the small amount of power generation in Colorado supplied by hydroelectric (~2%). Often, providers can compensate for this by purchasing additional water during a drought; however, if this is not possible, power

production at some plants may be decreased or shut down completely. Across the WECC region, hydroelectric generation can drop by up to 30% in a severe drought year (Colorado Energy Office, 2012). Additionally, several major utilities in Colorado purchase hydroelectric power from the Western Area Power Administration. If drought is prevalent in other western states, these utilities may need to purchase more expensive generation sources (Personal communication with Colorado Energy Office, 2013).

Table 7.2 Summary of Impacts and Adaptive Capacities

Impacts	Adaptive Capacities
Decreased power generation due to inadequate water supply for evaporative cooling	Power providers can diversify water sources
Increased costs for power providers to purchase additional water during drought	Power providers can purchase conditional water leases
Decreased hydropower generation due to lower reservoir levels	Transition to less water intensive generation methods using traditional fuels or renewable energy resources
Decreased power generation due to inability to discharge waste water	Increase transmission line capacity to allow for greater versatility
Change in power supply mix and operation costs can result in increased price for electricity	New mining technology that is less water intensive
Severe power cutbacks could result in rolling blackouts	
Environmental impacts from shifts in power production	
Increased intake water temperatures can decrease plant efficiency	
Plant shutdowns due to water levels dropping below intake elevations	
Increased costs for mining operations to obtain water rights	
Decreased mining activity due to inability to obtain water rights	

Power providers can decrease their vulnerability to drought by diversifying water sources and increasing water right portfolios. Additionally, continuing to research and develop ways to reduce, recycle, and reuse produced water from fracking is another means to decrease vulnerability associated with low water supplies during drought. Since the 2002 drought, some providers have purchased conditional lease water from agriculture as a backup during times of drought, and there are proven thermoelectric technologies like combined cycle plants and dry cooling systems which require significantly less water. Reducing the use of conventional coal-fired power plants and increasing reliance on certain types of renewable energy, combined cycle natural gas plants, and advanced cooling systems (like dry cooling) could reduce the amount of water used for electricity generation in the State. Many renewable energy options like wind and solar photovoltaics require virtually no water. Increasing use of these alternatives may lessen the impacts when a drought occurs.

Although these technologies are expensive and take time to implement, they are beginning to be adopted more widely in Colorado. However, it is important to recognize the technical challenges with some of these technologies. For example, dry-cooling relies on temperature differentials, i.e., an increased duration of elevated temperatures, which may not be present during all kinds of droughts. Further, retrofitting existing, larger power plants to dry-cooling may not be an option. Although the effectiveness of these technologies may be limited under various climatic conditions, other options exist that may provide more protection during drought. For example, Xcel's Comanche Unit 3 in Pueblo is a hybrid-cooled facility which takes advantage of dry-cooling when ambient air temperature differentials are sufficient, but uses water cooling when they are not, i.e., water savings are greatest in cooler months of the year. Energy providers can also pursue temporary water supplies, e.g., through interruptible supply agreements or other mechanisms, to sustain operations during drought. This approach is a more cost-effective means of providing drought protection and also benefits other sectors. For example, the entity supplying the water (typically agriculture), will receive much-needed revenue during periods of drought when water supplies are not sufficient for growing crops.

As a State, Colorado can increase transmission line capacity to enhance flexibility among power sources; currently transmission limitations inhibit utilization of low water energy sources in some regions of the State. Investment in transmission lines is required parallel to investment in new renewable energy production areas. In addition, engaging in collaborative efforts, contracts, and coalitions with other utility service providers and networks, such as the Southwest Power Pool stretching across 14 states in the U.S., could help bolster energy capabilities, lower utility costs, and possibly bring in more than \$1 million to regional utilities (Svaldi, 2017).

Although the mining industry does require some water, vulnerability to drought is generally considered to be minimal and has not been analyzed in detail. Presumably, mining activity could be halted if companies are unable to obtain the necessary water rights to maintain production; however, these purchases generally take place years in advance and are not typically impacted by short-term droughts. More likely, a drought or water shortage would prevent new mining activity from occurring rather than impeding existing mines.

As previously mentioned, Colorado has vast oil shale reserves in the northwestern part of the State that are not currently in production. It is estimated that 3 to 4 barrels of water would be required for each barrel of shale oil extracted. At a production rate of 1.55 million barrels per day this would result in an annual water demand of more than 378,000-acre feet (Western Resource Advocates, 2009). Given this substantial water requirement, drought vulnerability for oil shale should be specifically investigated as part of any feasibility analysis.

7.2.2 Previous Work

While there is a considerable body of work on the water-energy nexus, there is relatively little information specific to drought vulnerability.

However, this appears to be a topic which is gaining more attention. For example, in 2009 the National Energy Technology Laboratory (NETL) conducted a modeling project to analyze the effect of drought on electric power generation in the western U.S. (NETL, 2009). They used data from the U.S. EIA and previous evaluations of cooling water intake location and depths. Power generation was modeled on an hourly basis using a probabilistic dispatch model.

In their analysis, hydropower generation was curtailed based on historical drought operations. Thermal power plants were cut back in areas designated as undergoing a moderate or more severe drought. Based on this analysis, 3,284 MW of power were identified for possible drought curtailment. Under drought conditions, generation from coal plants dropped 8% from baseline and hydroelectric power dropped nearly 30%. Natural gas plants were identified as likely candidates to fill power gaps left by hydropower reduction because they generally operate below capacity. However, because the cost of generation is much higher for natural gas, this shift resulted in a \$4.5 billion increase in production costs and rate hikes of more than 30% in summer months. Furthermore, increased reliance on fossil fuels resulted in a 5% increase in carbon dioxide emissions.

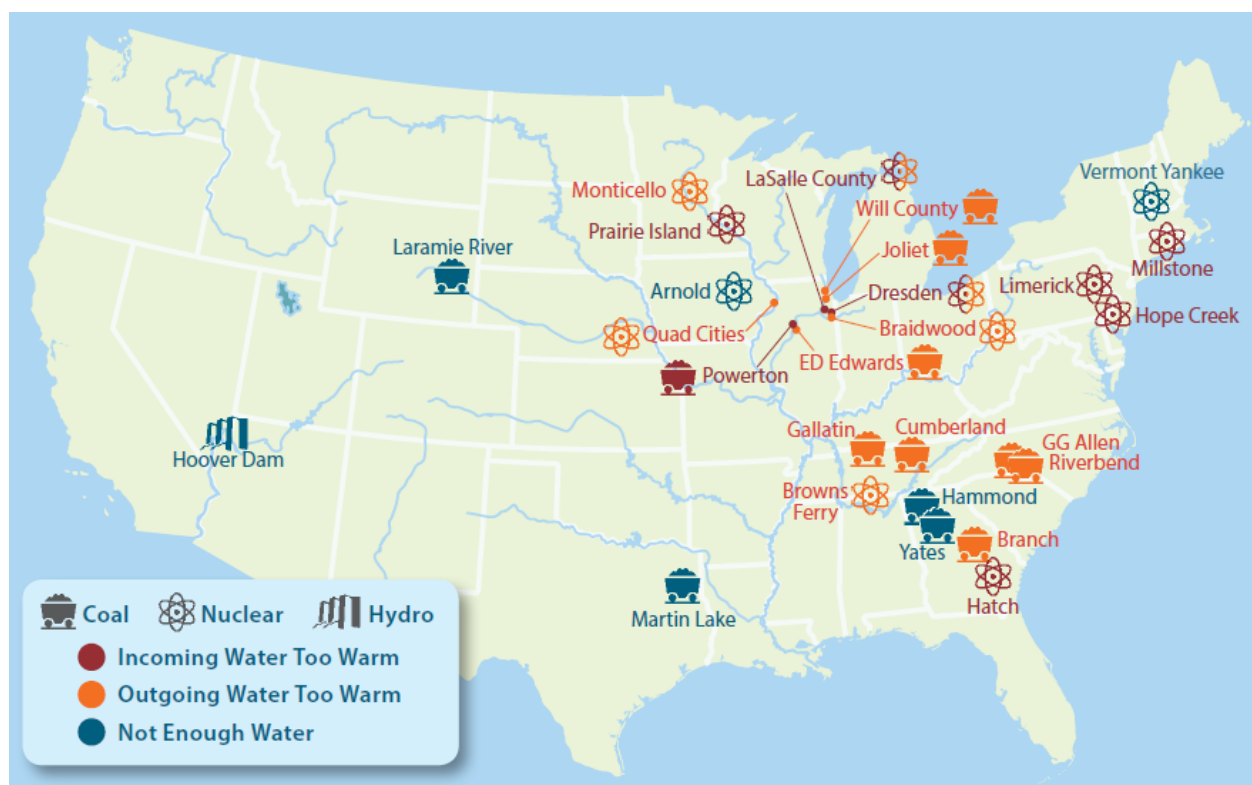
The NETL study covers the entire western U.S. and is not specific to Colorado. Vulnerability to the State may be overestimated in this report for several reasons. First, Colorado's reliance on hydropower for energy generation is very small (~2%). Also, based on interviews with power providers and industry experts in this study, there is no previous occurrence of significant power curtailment in Colorado, because power providers in the State tend to have very senior water rights and are not likely to shut down unless drought is more severe than has been previously experienced. Still, the results from the NETL study are informative with respect to the far-reaching impacts power curtailment could have on the State.

One online publication from the Union of Concerned Scientists in 2013 provides a useful synthesis of policy-relevant research on the water demands of energy production within the context of climate variability and change. This document highlights the severe impacts that recent drought has had on the U.S. electricity sector, including, for example, Texas power plant operators having to truck in water from miles away to keep power plants running in 2011, and power plants from the Gallatin coal plant in Tennessee to the Vermont Yankee nuclear plant on the Connecticut River being forced to reduce their output or shut down during 2012.

The report's examination of the electricity-water landscape reveals some prominent challenges, including the reliance of many power plants on lakes, rivers, and groundwater for cooling water that can exert heavy pressure on those sources while also leaving the plants vulnerable to energy-water collisions during drought. The report argues that such energy-water collisions are likely to worsen in a warming climate, as the power sector itself helps drive climate change, which in turn can negatively impact the availability and quality of water. Plants have recently run into three kinds of challenges: incoming cooling water that is too warm for efficient and safe operation, cooling water that is too hot for safe release into nearby rivers or lakes, and overall inadequate water supplies. In response, operators must reduce plant output or discharge hot water anyway, at

times when demand for electricity is high and rivers and lakes are already warm. However, from the standpoint of Colorado, it is noteworthy that the energy-water collisions noted in this Union of Concerned Scientists report are primarily in the eastern United States (see Figure 7.6). The lack of drought-related impacts in the western US is likely due to the fact that energy providers in the west have evolved, to varying degrees, to be resilient to drought. The Western US is arid and energy generation facilities with inadequate water supplies have always been subjected to drought-related curtailment at some point during previous drought events, thus developing mitigation and adaptation strategies over time. Further, Western states have evolved institutions which are more adapted to drought and arid/semi-arid conditions versus the Midwest and coastal regions of the US.

Figure 7.6 Energy-Water Collisions at Power Plants Nationwide



Source: https://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_energy/Water-Smart-Power-Full-Report.pdf

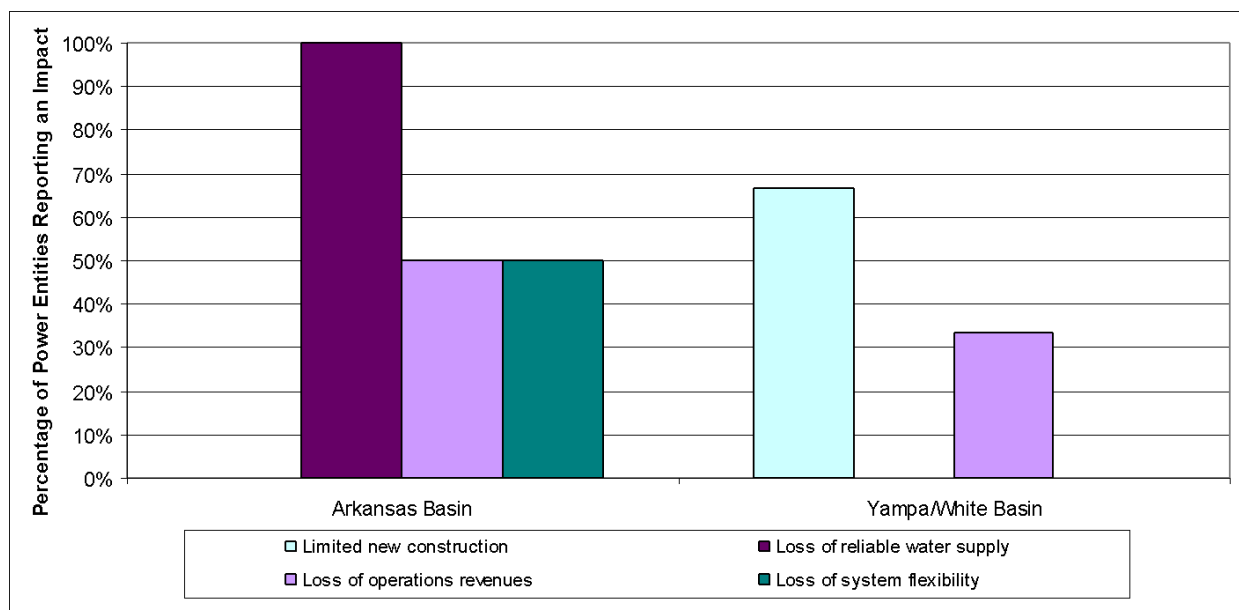
Energy specific drought vulnerability analyses have not been conducted specifically for Colorado. However, there are several studies that address drought and water supply planning in the State that are relevant. The CWCBC conducted a Drought and Water Supply Assessment (DWSA) in 2004 to determine the State's preparedness for drought and identify existing limitations that inhibit preparation for future droughts. The details of this work are discussed in Chapter 1 (Annex B). The DWSA entailed a survey where 537 responses were received statewide on specific impacts experienced during the drought of 2002. Various interests were surveyed including power, industry, agriculture, municipal, state, federal, water conservancy and conservation districts, and "other," (e.g., tribes and counties).

The results of the DWSA survey are helpful in understanding the opinions of Colorado’s water users in terms of current and future water conditions. However, responses were not received from everyone in the State and coverage is not sufficient to resolve results to a county level. These spatial limitations along with uncertainty in the interpretation of specific survey questions by the respondents make it difficult to incorporate DWSA results into the vulnerability methodology developed for this study. However, there is pertinent information that should be analyzed in a qualitative way to inform and verify vulnerability findings.

Figure 7.7 provides the percentage of DWSA surveyed power entities that experienced the impacts listed. These power entities included various energy stations, many of them owned by Xcel Energy. It is important to note that only those categories that are applicable to the power sector are shown in the figure. Additionally, only power entities within the Arkansas and Yampa/White Basins (e.g., Xcel Energy stations) responded to the survey, and therefore only their results are shown. Of the five power entities surveyed, two or more of them reported impacts to the following categories during the drought of 2002:

- Limited new construction
- Loss of reliable water supply
- Loss of operations revenue
- Loss of system flexibility

Figure 7.7 1999 – 2003 Drought Impacts to the Power Sector

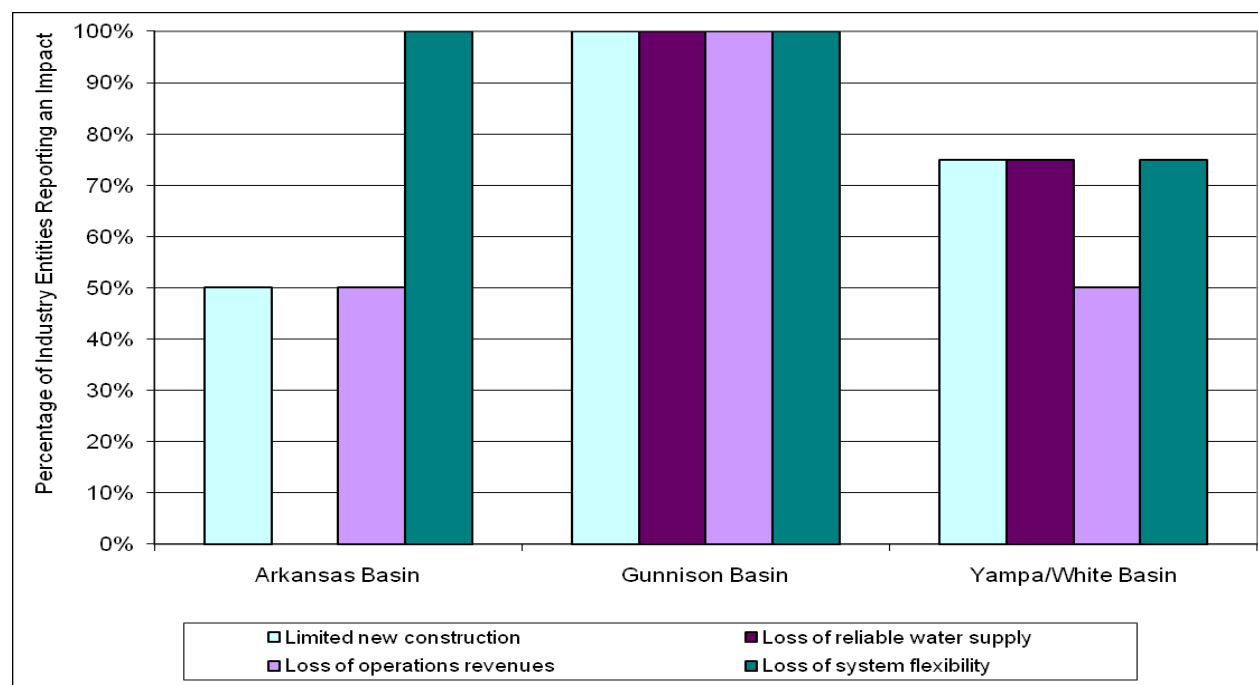


In the Arkansas Basin, both of the power entities surveyed experienced loss of reliable water supply, whereas none of the three entities in the Yampa/White Basin did. Construction was limited in the Yampa/White Basin, and the Arkansas entities felt a loss of system flexibility during this time period. Loss of operations revenue was an impact in both basins. Given the sparse survey results it is difficult to draw spatial conclusions from these summaries. However, it is clear that power providers are aware that drought does impact them. This is a significant finding because many of the power experts interviewed for this study noted that they were well prepared for drought and do not expect severe impacts in future droughts.

The DWSA survey also included industrial entities such as various mining and mineral companies. A total of eight mineral and mining entities were surveyed. Two of those were located in the Arkansas, one in the Gunnison, and four in the Yampa/White Basins. As shown in Figure 7.8, seven of these entities noted that they experienced impacts during the drought of 2002 in one or more of the following categories:

- Limited new construction
- Loss of reliable water supply
- Loss of operations revenue
- Loss of system flexibility

Figure 7.8 1999 – 2003 Drought Impacts to the Industrial Sector



Loss of system flexibility was reported to be an impact by 75% of all the entities surveyed (most notably in the Arkansas Basin and Gunnison Basin). Limited new construction was reported by five of the eight entities, and loss of operations revenue and loss of reliable water supply were both reported by four entities. Overall, mining in the Gunnison Basin had the greatest occurrence of impacts. Similar to the power analysis summarized in Figure 7.7, these findings are informative because, although all mining professionals surveyed for the DWSA reported some negative impacts related to drought, few could cite drought impacts affecting them significantly in the long-term.

Another relevant Colorado specific study is the SWSI (SWSI 2010 and SWSI Update). Although it did not specifically focus on drought as the DWSA did, the SWSI process was funded and directed by the CWCB to understand existing and future water supply needs and how those needs might be met through various water projects and water management techniques. The SWSI also used a statewide and basin-level view of the water supply conditions in Colorado and created basin roundtables as a forum for collecting and sharing information and ideas.

In SWSI, the Energy Sector was included in the self-supplied industrial (SSI) category, which included coal-fired and natural gas power generating facilities that consume significant quantities of water, snowmaking facilities, and other identified industrial facilities with significant water use such as brewing, manufacturing, and food processing. The SWSI process estimated baseline and projected water use to 2050 for SSI. The SSI sector was divided in the following sub-sectors: large industry, snowmaking, thermoelectric power generation, and energy development. Where applicable, water demands were presented for each sub-sector under low, medium, and high growth scenarios to illustrate the range of possibilities given the uncertainty in their future development (CWCB, 2010). With respect to the Energy Sector discussed herein, the thermoelectric power generation and energy development sectors were updated in 2013 with new data (e.g., water demands, population) to reflect expected energy development scenarios in the northwestern portion of the State, but as of this report the SWSI Update projections were not ready for use.

Although the SWSI and associated 2050 M&I water use projections did not specifically address drought impacts to the Energy Sector, they identify areas in the State that use water for industrial purposes that may be more vulnerable to a water supply shortage in times of drought. Future work could build on these findings by incorporating Energy Sector growth scenarios into the vulnerability assessment methodology while analyzing future drought vulnerability scenarios.

In addition to the reports referred to above, the CWCB funded another Colorado-specific study on energy development and associated water needs in the northwestern portion of the State. Phase I of the Energy Development Water Needs Assessment, performed for the Colorado, Yampa, and White River Basin Roundtables Energy Subcommittee, estimated the amounts of water required to support the operations of natural gas, coal, uranium and oil shale industry within those basins. The study used a series of energy production scenarios for near-, mid-, and long-term planning horizons to develop water demands for each energy sub-sector (CWCB, 2008).

The second phase of this project focused on refining estimates for the water needed for oil shale development. Water requirements for natural gas, coal, and uranium mining developed in Phase I were unchanged in Phase II. These refined water use estimates for the oil shale industry were also broken down into components to allow water use to be disaggregated spatially as required by water resources modeling. For example, location, priority, and amount of physical and legally available water supplies were considered when investigating various scenarios (CWCB, 2011b). This information provides not only a spatial context for water use related to energy development, but also the timing of the water use. Due to the potential magnitude of water development in northwestern Colorado associated with energy development, this detailed information can assist stakeholders in understanding potential impacts during any hydrologic condition, including drought, so that appropriate water management techniques can be employed.

Drought and its implications on Colorado's energy sector were also investigated in the 2016 Colorado Energy Assurance Emergency Plan (CEAEP), prepared by the Colorado Energy Office in conjunction with the Colorado Department of Regulatory Agencies (Public Utilities Commission and the Colorado Division of Emergency Management). In the CEAEP hazards ranking, drought ranked 15th out of 16 natural hazards affecting the energy sector (meaning that its impact on the sector was categorized as negligible). However, the level of impact can vary considerably depending on the electric power mix and a range of other factors in the impacted area (Colorado Energy Office, 2016). One event that tested the effectiveness of the CEAEP was wildfires. During the 2013 wildfires in Colorado, the CEAEP successfully enabled enhanced communications, coordination, and situational awareness that may not have been otherwise possible. In addition to wildfires, the CEAEP provides guidance during, among other hazards, flash drought events across the state.

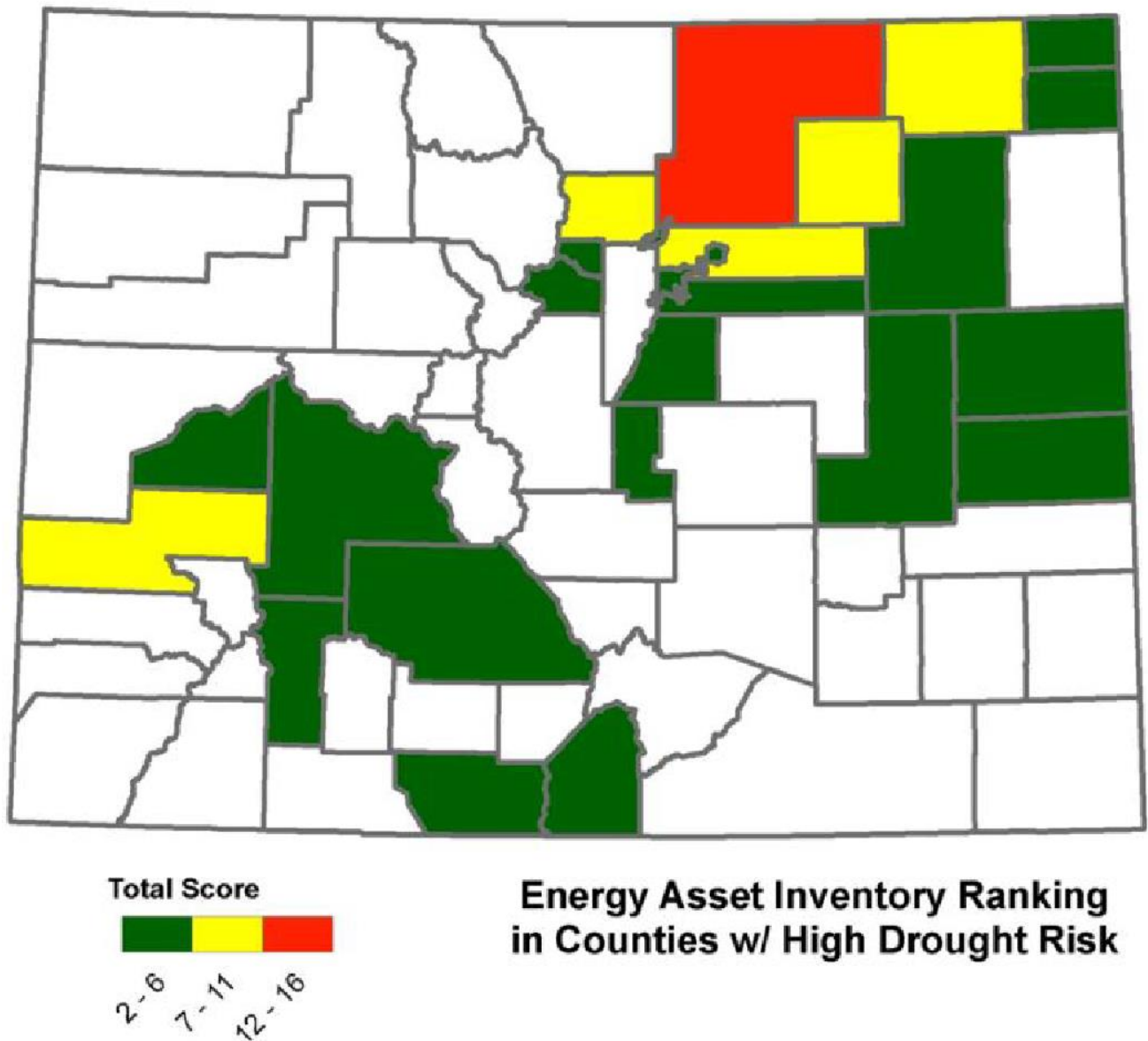
As discussed above, generating capacity can be lost during drought due to decreased water supplies for various processes, namely for thermal power plants and steam turbines. Droughts that occur during the peak summer electrical demand period can produce additional impacts on the energy sector (e.g., increased power costs). Having flexibility in generating output during drought periods is an important mitigation tool. Relying more heavily on renewable energy resources can alleviate some negative effects during drought, particularly if utilizing sources that require little to no water to create power (e.g., solar panels). Switching to energy generation using natural gas, which requires less water than coal-fired plants, nuclear, or hydroelectric generation, can also be used to cover the load during dry periods. This may cause shortages or increases in natural gas and electric prices, but provides a region with the ability to compensate and meet power needs. Recognizing that not all loads may be transferable to natural gas generating plants during drought is important, but interruptible supply agreements can also be obtained to cover water supply at existing plants. As mentioned, supply agreements also benefit other sectors such as agriculture, as it may receive revenue from temporarily selling its water supplies during times when the agricultural conditions are not optimal to plant crops. The CEAEP ranked twenty-five counties at risk for drought by comparing their energy asset inventory to their drought risk ranking. As shown in Table 7.3 and Figure 7.9, Weld County has the highest hazard score for inventory related to energy assets out of these high drought risk counties.

Table 7.3 Energy Asset Inventory Ranking by High Drought Risk County

County	Drought Risk	Transmission Score	Pipeline Score	Substation Score	Plant Score	Hazard Score
Weld	High	4	4	4	4	16
Adams	High	2	2	3	3	10
Logan	High	2	1	2	2	7
Montrose	High	2	1	2	2	7
Boulder	High	1	1	2	3	7
Morgan	High	2	1	2	2	7
Denver	High	1	1	2	2	6
Arapahoe	High	2	1	2	1	6
Douglas	High	2	1	2	1	6
Lincoln	High	2	1	1	2	6
Washington	High	2	1	1	1	5
Kit Carson	High	2	1	1	1	5
Phillips	High	1	1	1	1	4
Sedgwick	High	1	1	1	1	4
Delta	High	1	1	1	1	4
Gunnison	High	1	1	1	1	4
Clear Creek	High	1	1	1	1	4
Cheyenne	High	1	1	1	1	4
Conejos	High	1	1	1	0	3
Saguache	High	1	1	1	0	3
Broomfield	High	1	1	1	0	3
Teller	High	1	1	1	0	3
Gilpin	High	1	1	1	0	3
Costilla	High	1	0	1	1	3
Hinsdale	High	1	0	1	0	2

Source: Colorado Energy Office, 2016

Figure 7.9 Energy Asset Inventory Ranking in Counties with High Drought Risk



Source: Colorado Energy Office, 2016

7.3 Assessment of Impacts and Adaptive Capacities

In this section, specific impacts and adaptive capacities are covered in more detail separately for power production and mining. Impacts are further differentiated by activity, where vulnerability differences are sufficient to warrant this distinction.

7.3.1 Potential Impacts and Adaptive Capacities of Mining

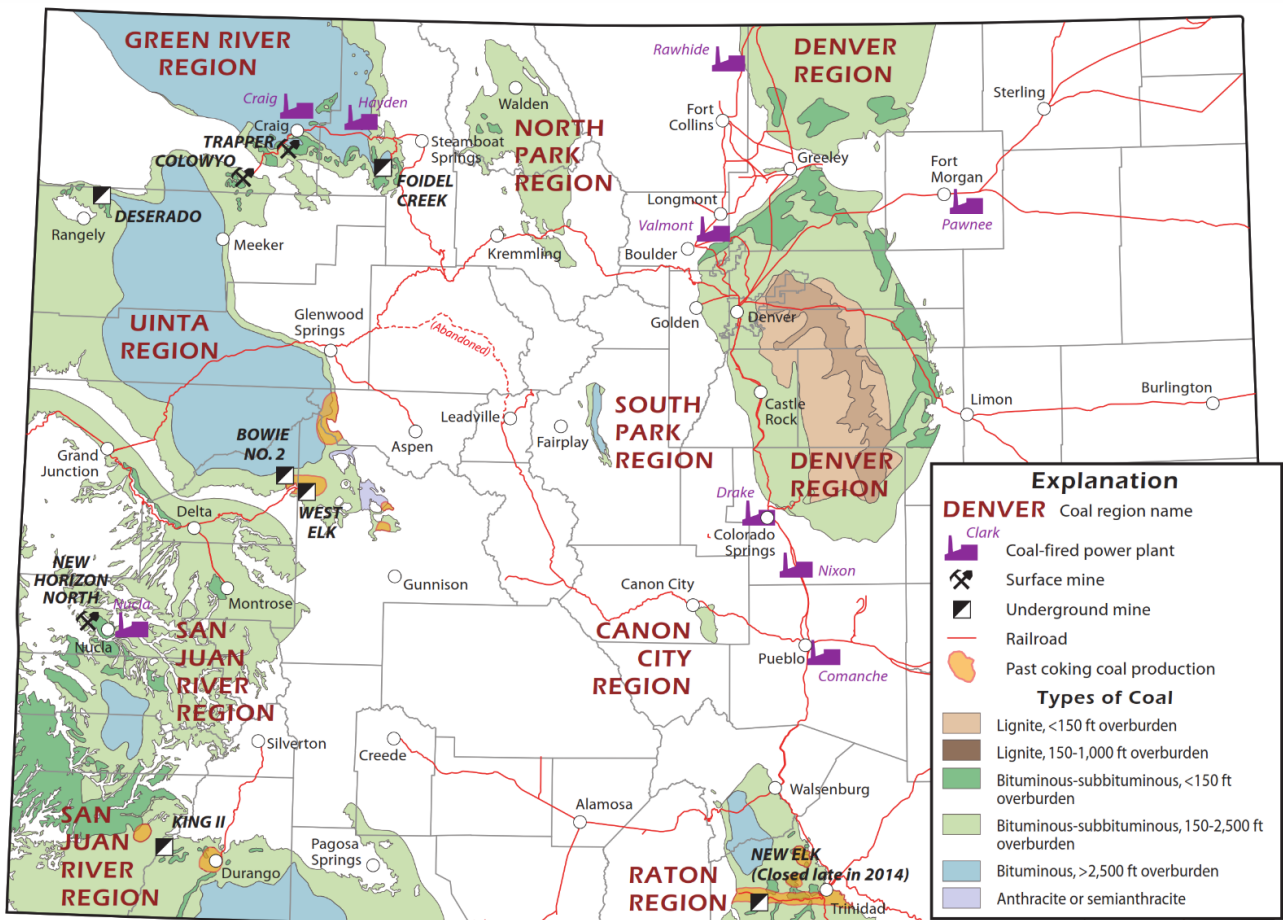
Mines use water for quarrying, dewatering, milling, and other site preparation. Data on additional water used to process the raw materials such as oil refining and slurry pipelines are not available

and hence not included as part of the mining water use estimates. In 2014, according to the Colorado Division of Reclamation Mining & Safety, Colorado had 110 active hardrock mines. In addition, there were 86 coal mine permits in areas where other mining activities might be taking place. Water withdrawals from hard rock mines could account for over 10,000 gallons per day (GPD), according to a previous study conducted by the USGS (USGS 2010).

In 2005, roughly 1,150 sand, gravel, and construction aggregate operations produced 47 million tons of material (USGS, 2010). These operations run almost exclusively on groundwater and it is estimated that the total water use for these combined operations was approximately 4.6 million gallons per day (MGD) (USGS, 2010). Gravel operations reuse water for 100% consumption in the aggregate washing process and evaporation from settling ponds. Given the increased number of hardrock and coal mines active in 2018, groundwater use by the industry has likely increased from the 2005 estimate.

Colorado is second only to Illinois in bituminous coal reserves but is the leader in clean air compliant coal reserves (Burnell, Carroll, and Young, 2008). As of 2016, about 4,276 Coloradans had employment in the mining sector, outside of oil and gas extraction. Another 11,130 citizens worked in industries that directly support activities for the mining sector (Colorado Department of Local Affairs, 2018). In particular, coal mines employed 1,331 people in 2016 (U.S. Department of Labor, Mine Safety and Health Administration, 2016). Figure 7.10 shows the location of coal reserves, mines, and coal-fired power plants across the State as of 2015. Coal mining requires water for cutting in underground mines, dust suppression for surface activities, and reclamation and revegetation in the post-production phase. Average water requirements for mining activities range from 10 to 100 gallons per ton of coal mined (Cameron et al., 2006). Coal mining specifically was estimated to use a total of 2.66 MGD in 2005 (USGS, 2010). Water pumped from a mine is often used for cutting. Excess process water is often contaminated and requires treatment via settling ponds or other processes, meaning that it cannot be easily reused or repurposed.

Figure 7.10 Coal Mining in Colorado



Source: Colorado Geologic Survey, 2015

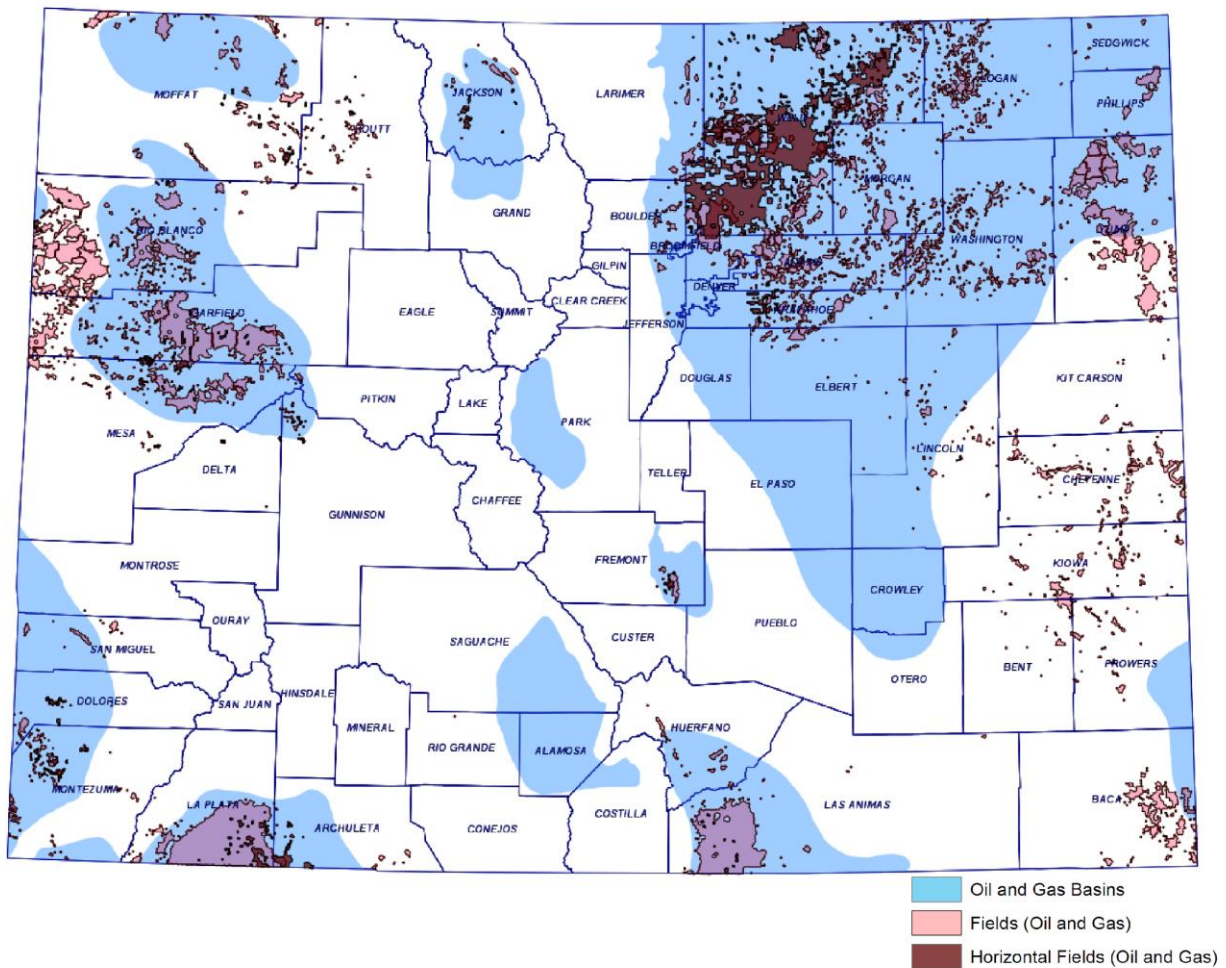
NOTE: The Valmont power plant in Boulder stopped burning coal in 2017. Other gas-fired generation at the plant continues as of 2018.

Figure 7.11 shows the major oil and gas producing regions in the State, and Figure 7.12 displays the permit locations for oil and gas wells. These permit location points represent spots that are approved for drilling and/or recompletion as of 2018. The majority of the permitted locations are in Weld County. Figure 7.13 shows the total yearly sales from oil and gas (i.e., coalbed methane, natural gas, carbon dioxide, and oil) in 2017, by county. There are four counties in Colorado with an estimated production value greater than \$100 million. Combined, these counties represent 87% of the statewide production value (COGCC, 2018).

Oil and natural gas production tends to be a net producer of water. Coalbed natural gas production in the San Juan Basin is about 8 gallons of water per barrel of oil equivalent (boe) (Cameron et al., 2006). Water use for natural gas extraction is negligible. Oil extraction requires 5 to 13 gal/boe, though. The biggest water requirement for oil and gas is enhanced oil and gas recovery. In this process, water is injected down recovery wells in order to move oil and gas to nearby wells. Enhanced oil recovery can require anywhere from 81 to 14,000 gal/boe (Cameron et al., 2006). Water used for enhanced recovery is often recycled production water. In 2010, the USGS estimated

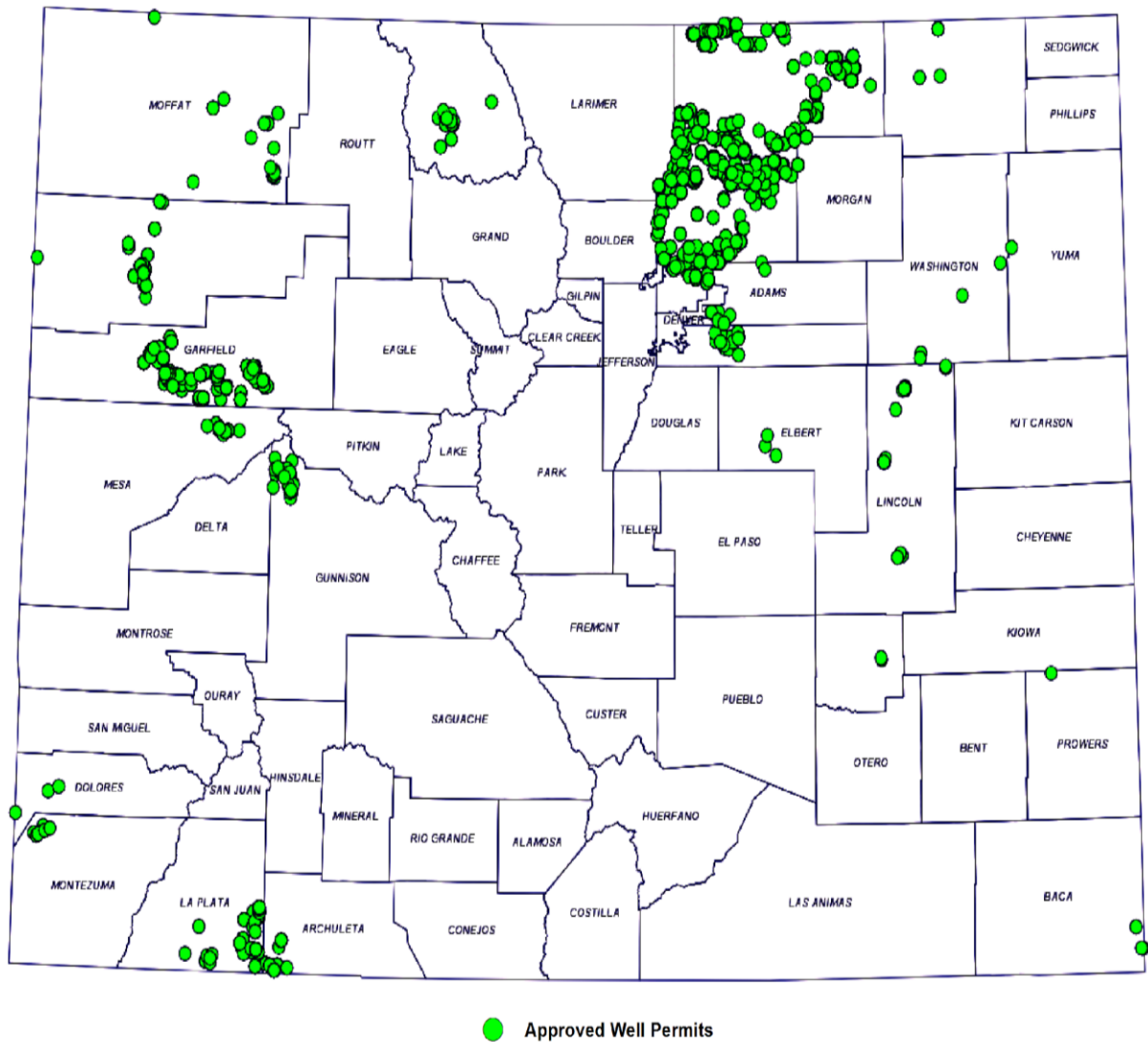
that 19.42 MGD of saline water was withdrawn in Colorado in total, most of which ended up reinjected for oil and natural gas production (USGS, 2014). Possible future oil shale production is not included in these numbers.

Figure 7.11 Oil and Gas Production in Colorado



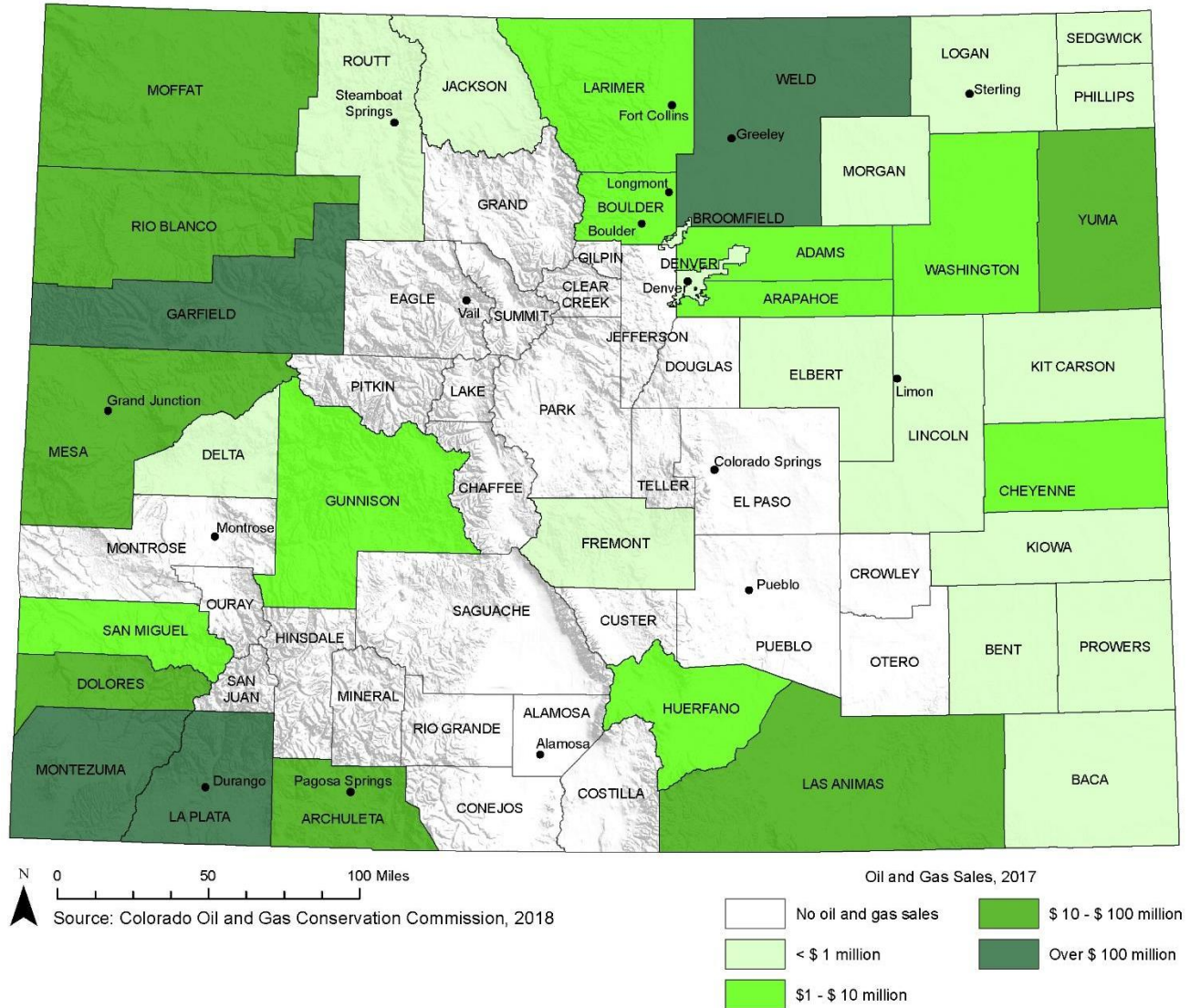
Source: Colorado Oil and Gas Conservation Commission, GIS Online application, 2018

Figure 7.12 Oil and Gas Permit Locations



Source: Colorado Oil and Gas Conservation Commission, GIS Online application, 2018

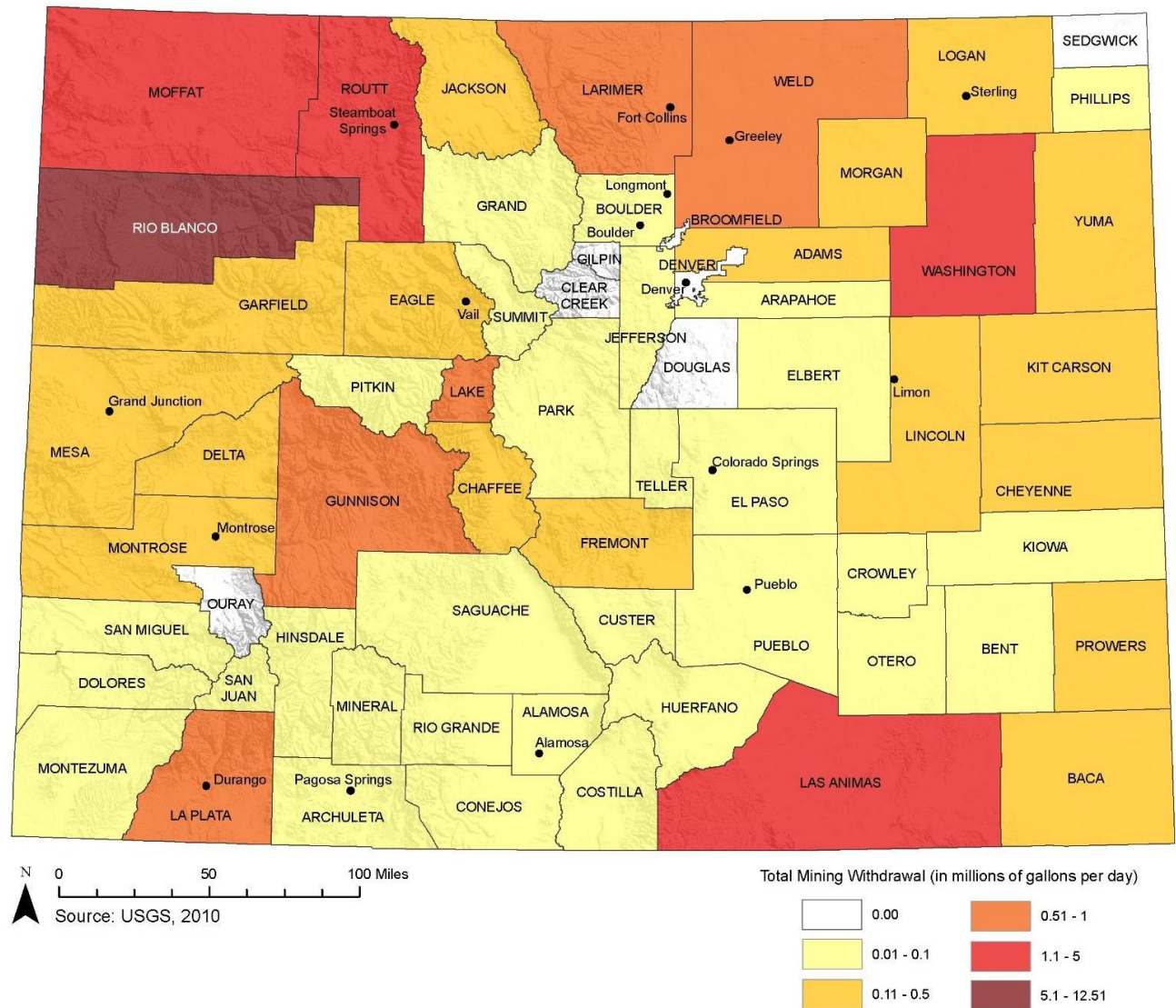
Figure 7.13 Oil and Gas Sales by County



Source: Colorado Oil and Gas Conservation Commission, 2018

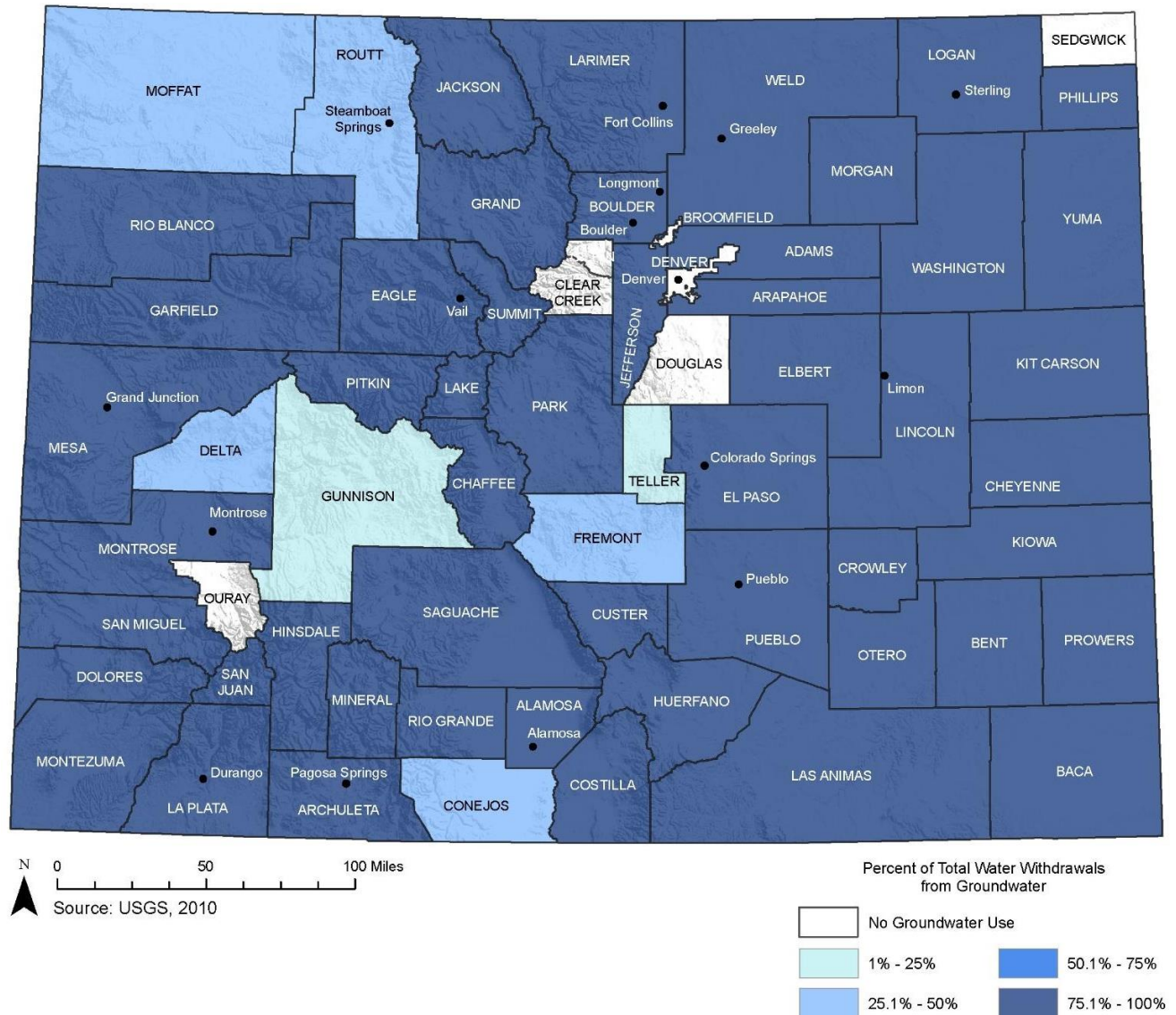
Figure 7.14 shows the total estimated water withdrawals for all mining activity in 2010 (using the most recent data available, from the USGS study published in 2014). Water use for mining activity is distributed across the State but generally higher along the northern edge. Figure 7.15 shows the proportion of these withdrawals that come from groundwater. There are only three counties in the State that get less than 75% of their mining water from groundwater. It is clear that, without water, mining activities in the State would not be able to operate. However, there is no comprehensive analysis examining the impacts of drought on mining operation costs and production rates. Mining experts throughout the State are consistent in stating that drought does not impact them dramatically because they purchase water rights far in advance of starting operations. No person interviewed could cite any specific damage incurred in the 2002 drought. Even without specific impacts to cite, there are still ways for mines to improve their adaptive capacity for future, more severe droughts. Mining operations can invest in technology or choose methods that will decrease their reliance on water. Also, they can diversify their water rights holdings and purchase conditional leases that would take effect during a drought. As noted in Section 7.2.1, drought vulnerabilities for mining are subject to change based on future mining resources and techniques. If oil shale becomes an economically feasible option, water needs may change significantly.

Figure 7.14 Total Water Withdrawals for Mining in 2010



Source: USGS water use study published in 2014, using data from 2010

Figure 7.15 Percentage of Mining Water Use Originating from Groundwater, 2010



Source: USGS water use study published in 2014, using data from 2010

7.3.2 Potential Impacts and Adaptive Capacities of Power Production

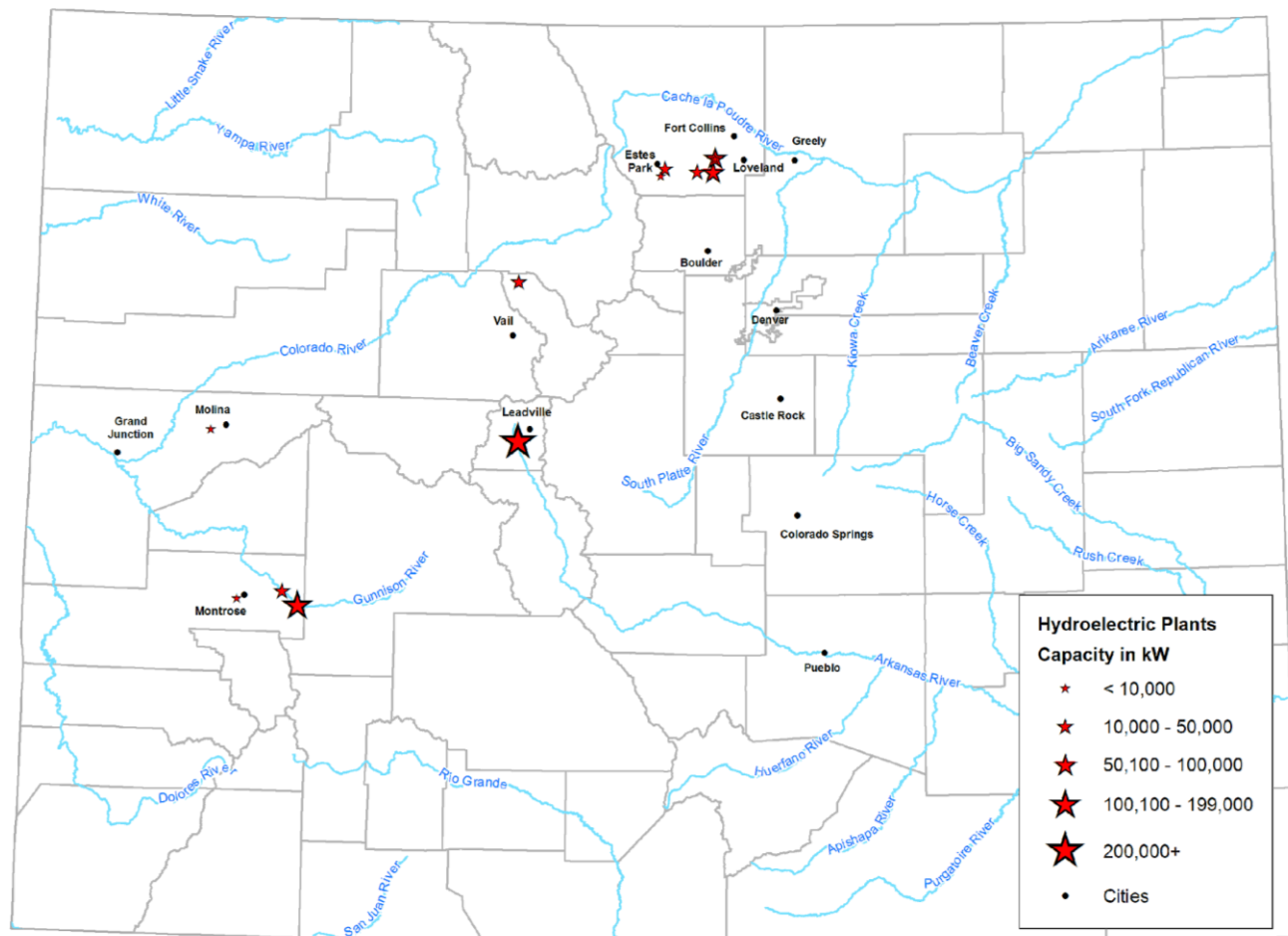
The vast majority of Colorado's power is produced by coal or natural gas fired thermoelectric power plants. These plants can run off fuel sources such as nuclear, oil, and biomass (see Figure 7.2). Regardless of fuel source, all thermoelectric plants use steam to drive a turbine generator, and require cooling to condense the steam and the turbine exhaust. Open-loop ('once-through') plants, which are becoming more uncommon in Colorado as they close, use a method where water is withdrawn for cooling and then directly discharged after heating. These plants generally have very large water withdrawals but evaporative losses are only about 1% (i.e., consumptive use is low) (Cameron et al., 2006). When the 2010 USGS report was published, Colorado had five 'once-through' plants (USGS, 2010). The Cameo plant closed in 2010 and the Valmont plant, while still

active for gas-fired generation, stopped burning coal in 2017 (Daily Camera, 2017). However, the Platte River Power Authority Rawhide station uses reservoirs for cooling and does not need the continuous, high-volume replacement of water that is typical of ‘once-through’ facilities.

Most plants installed since the 1970s use closed-loop systems, where cooling is achieved by evaporation, and these end up withdrawing less than 5% of the water withdrawn by open loop systems. Nevertheless, almost all of this water use for closed-loop systems is consumptive (Cameron et al., 2006). Colorado had 14 closed-loop thermoelectric plants, as of the 2010 USGS publication.

Colorado currently has 12 active hydroelectric plants, and these generate about 2% of the State’s power demand (see Figure 7.16). The amount of water that flows through hydropower plants is much larger than thermoelectric plants; however, this is primarily non-consumptive water. The main consumptive use of hydropower generation is the evaporation of water from reservoirs, which are typically also used for other purposes, such as municipal water supply storage.

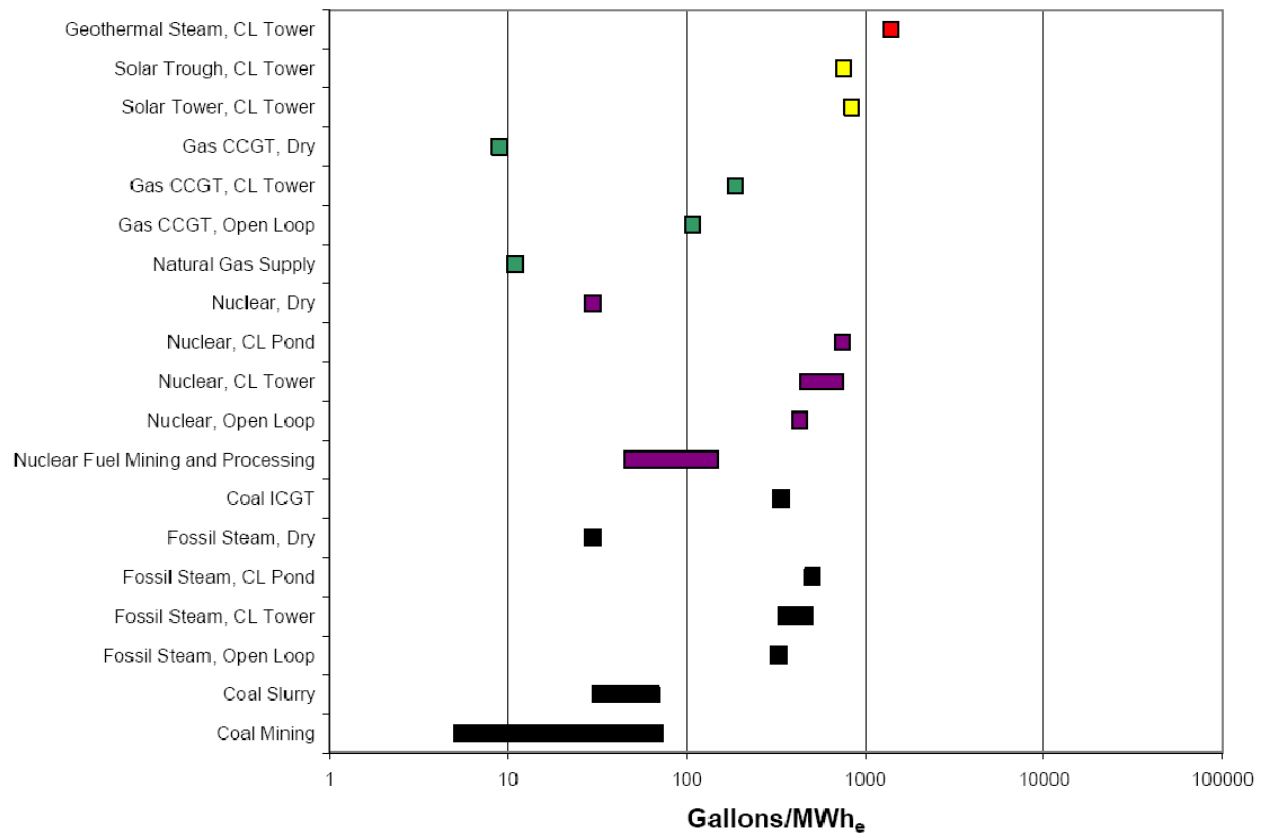
Figure 7.16 Hydroelectric Power Plants 2017



Source: U.S. Bureau of Reclamation, 2017

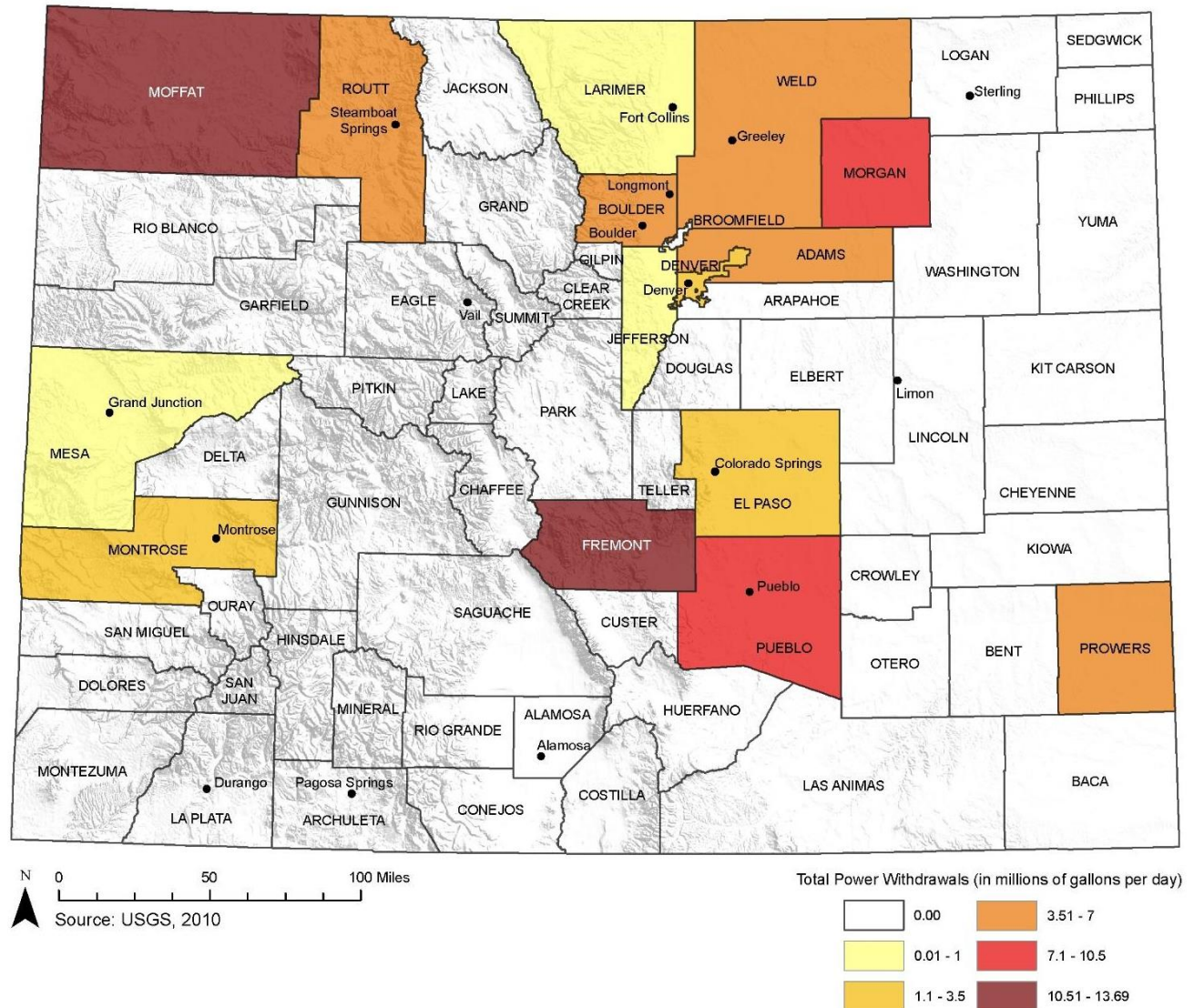
Figure 7.17 shows the water consumption for various power generation methods (where CL stands for ‘Closed Loop’). This shows that closed-loop cooling methods generally have the highest consumption rates. Figure 7.18 displays total water withdrawals used for power production by county in. This map shows that both power generation and its resulting water use takes place statewide; that is, hydropower is prevalent in the western half of the State but does not account for large generation capacity, and the counties with the largest generation capacities generally have no (or little) contribution from renewable resources.

Figure 7.17 Water Consumption for Power Generation



Source: Cameron et al. 2006

Figure 7.18 Total Water Withdrawals for Power Production by County



Source: USGS 2010

Drought impacts to power producers are potentially devastating although at this point still hypothetical. Without adequate water for cooling, Colorado's thermoelectric dominated power supply could be threatened (refer to Section 7.2.1). However, based on interviews with power experts across the State, power providers do not seem to be all that sensitive to drought and there were no energy generation curtailments during the 2011-2013 and 2002 droughts. Power plants tend to have senior water rights and the ability to purchase additional rights if necessary. However, power providers acknowledge that, had the 2002 drought continued longer, they could have been in trouble. After this experience many providers purchased additional water rights and conditional lease agreements. Even though power producers in Colorado have historically not been heavily impacted by drought, it is important to remember that the impacts in Table 7.2 are still applicable. As Colorado's population and power demands expand, and climate changes, construction of new

power plants may prove more difficult and drought impacts could become a much larger issue. However, new energy generation can be added without increasing the overall water demand on the providers' supply portfolio. For example, Xcel's Fort St. Vrain Station in Platteville was originally built as a 356 MW nuclear power plant, but was converted to a 1,000 MW natural gas facility in 1989. Because the water demand was therefore reduced, those supplies have been integrated with other Xcel facilities to provide a more robust, flexible water supply.

The lack of drought-related impacts to the Energy Sector speaks to the strong adaptive capacities already in place. Power providers can further increase their adaptive capacity by continuing to purchase additional water rights, creating partnerships to join efforts with regards to sharing resources and maintaining infrastructure in times of need, and overall engaging in drought planning. Another step is to continue to decrease water consumption. This can be accomplished with conventional fossil fuels by converting to combined cycle turbines or dry cooling systems. Another option is to switch to renewable, non-water dependent production methods. With its mandate of 30% renewable energy by 2020, Colorado is already improving its adaptive capacity to drought. Much of the renewable resources that will be developed are wind and solar PV, which require very little water. In 2016, Colorado produced 79.26% of its renewable-sourced energy from wind, 15.13% from hydropower, and 4.61% from solar. In terms of solar energy potential, Colorado ranked 11th in the nation in the same year (Colorado Energy Office, 2018). Figure 7.19 shows the future development areas for wind and solar resources that were identified by the Colorado Energy Office in 2007. As shown in the figure, the eastern plains of Colorado provide the most potential for wind energy, and the south-central portion of the State for solar.

Colorado has experienced steady growth in the renewable energy industry, particularly wind energy, since 2005. Despite the economic hardships in recent years that were coupled with lower electrical demand, new systems have come online, and wind resources (being the largest percent of renewable generation) comprised over 17% of the total electricity generated in the State in 2016. This statistic particularly illustrates the continually promising future the renewable energy industry has in Colorado for years to come.

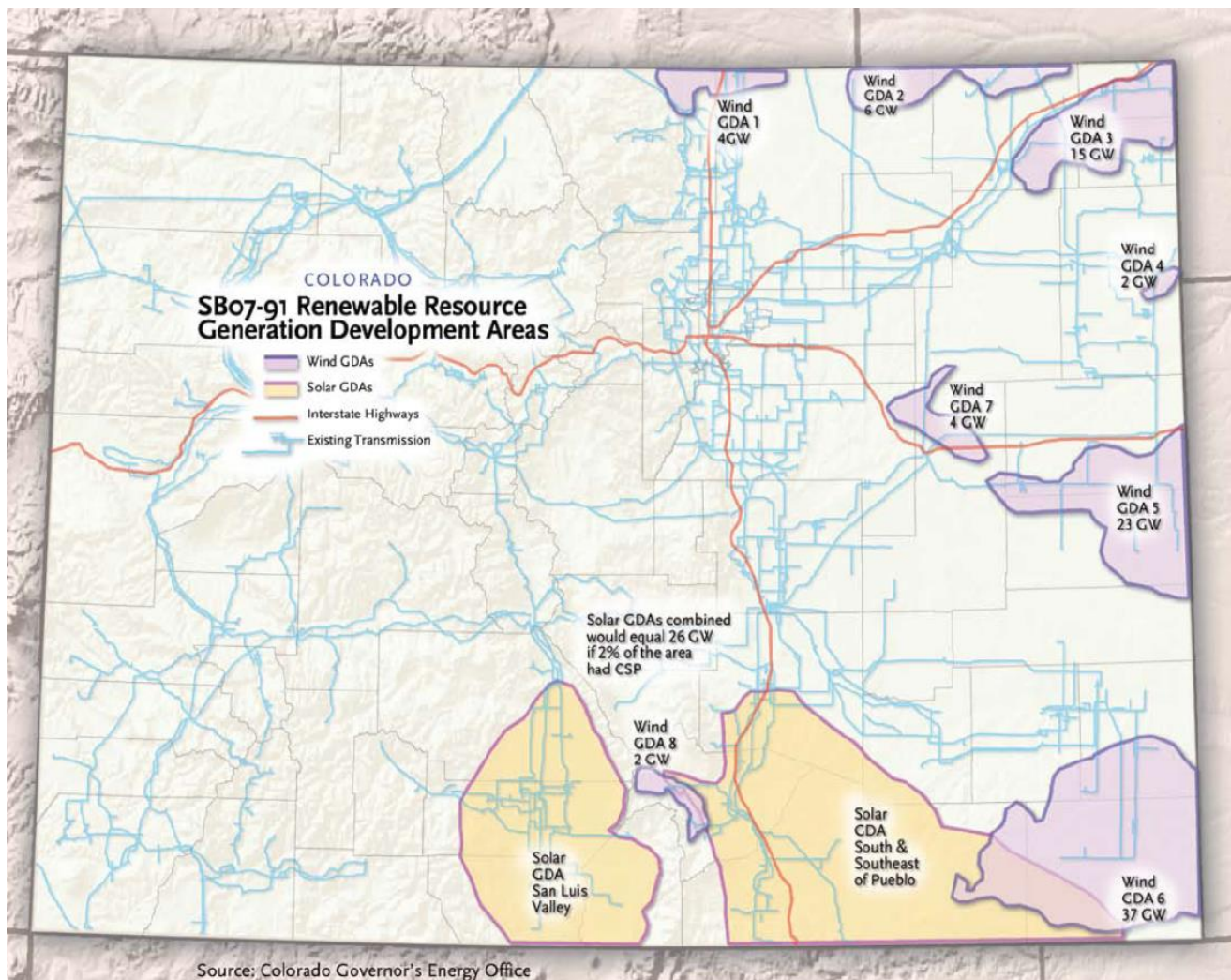
In 2012, a significant year for the addition of wind energy in Colorado, Xcel Energy began purchasing 400 MW from the Limon I and II Wind Energy Centers. In Lincoln and Elbert Counties, the 252 MW Cedar Point Wind Energy Project began operations in September 2011 using turbines manufactured in Colorado. At its full build-out potential, this is enough renewable energy to meet the annual power demands of approximately 80,000 Colorado households. The 30,000 acre Cedar Creek 2 Wind Farm in Weld County was completed in June 2011 and generates 250.8 MW of renewable wind power (Colorado Energy Office, 2010b). In November 2010, Tri-State Generation and Transmission Association, Inc. completed its first major wind acquisition. Their 51 MW Kit Carson wind project northwest of Burlington sits on a 6,000-acre site near I-70. Another endeavor, a 300 to 600 MW wind project by Tradewind Energy in Cheyenne Ridge (about 15 miles north of Cheyenne Wells), began construction in 2016 and is scheduled to cover about 100,000 acres of land. It straddles the border between Cheyenne and Kit Carson Counties, and has the potential to produce power for approximately 180,000 Colorado homes (Tradewind Energy,

2018). As of 2017, Xcel Energy was in the works for investing several billion dollars in wind power across seven states (from Minnesota to New Mexico), hoping to comprise nearly 35% of their total power portfolio from wind. That would mean a near doubling of the company's 19% share in this energy source from 2016 (Denver Business Journal, 2017). Xcel-Energy Colorado, specifically, is in the works to finish the Rush Creek Wind Project in 2018, another 600 MW wind project spanning Cheyenne, Kit Carson, Elbert, and Lincoln counties, and with the potential to produce enough energy for 325,000 homes (Xcel Energy 2018).

The solar industry in Colorado also experienced notable growth starting in 2012. The 30 MW San Luis Valley Solar Ranch, located in Alamosa County, began commercial operation in March of 2012. The 220-acre site was formerly farmland but now holds approximately 110,000 PV panels. Xcel Energy purchases all of the solar energy produced there, enough to power 7,500 homes (Iberdrola Renewables, 2013). Construction for the Hooper Solar project located in Mosca, CO began in 2014 and finished June 2015. This site can generate energy to power 13,500 households (with about 64 MW of electricity generation potential) (Mortenson, 2018). In 2016, Comanche Solar completed a photovoltaic project near the City of Pueblo, large enough to power over 31,000 Colorado homes. With its 156 MW potential, this has become the largest solar project east of the Rockies (Community Energy Solar, 2018).

Although some new systems can use existing transmission lines, as was the case with the Kit Carson wind system, Colorado should work to improve transmission line capacity in conjunction with new renewable power capacity. This infrastructure will help support new power supplies and add versatility to the system.

Figure 7.19 Renewable Resources Development Areas



7.4 Measurement of Vulnerability

The Energy Sector was divided into two impact groups ('power' and 'mining') for the numerical vulnerability assessment. For each impact group a spatial density metric was defined along with several impact metrics. Each metric is described in detail below. Refer to Section 3.1 of Chapter 3 (Annex B) for a general description of the vulnerability assessment tool and methodology.

Although the vulnerability to the Energy Sector was performed on a county-by-county basis for consistency with the methods utilized for the other sectors of this vulnerability assessment, it is important to note that energy production is regional, i.e., it is distributed over a grid which covers the entire western United States. Generally, the energy sector is fairly resilient to drought impacts due to the broad spectrum of drought preparedness utilities, which can range from diverse water

rights portfolios, to contracting supplies from municipalities, and availability of renewable energy sources which are less reliant on water.

7.5 Vulnerability Metrics

The metrics described in Section 7.5.1 for ‘Mining’ regard the spatial density datasets (total mining jobs and population) and the actual impact datasets (total water use, and percent of water use that is from surface water) that were applied to calculate the overall vulnerability statistics, by county. For Section 7.5.2, ‘Power,’ the spatial density metrics used are: power generation capacity by county. The three impact variables include total water use in the industry, percent of water use contributed from groundwater, and renewable energy development potential.

7.5.1 Mining

Spatial Density Metric

Total mining jobs

The total number of people employed in mining jobs is broken up per county, and sources from the 2015 industry base analysis data produced by the Department of Local Affairs’ Demography Office¹ (DOLA, 2016).

Impact Metrics

There are two metrics for measuring mining vulnerability. The total water use by county in the industry, and the percentage of water used that is surface water (versus groundwater). For the overall mining impact calculation, total water use was weighted 75% and the contribution of groundwater was weighted 25%. Additional uncertainty flags were added for Rio Blanco and Garfield Counties because of the possibility of future oil shale development.

Total water use

Total water use, broken up by county, is based on both surface and groundwater extractions for mining purposes as estimated in a USGS study containing data from 2010 and published in 2014 (USGS, 2014). While it is very difficult to get accurate data on the production value and methods by county for the wide range of mining activities in Colorado, these total water use summaries reflect the overall water dependence of mining activities without requiring in-depth data on mining practices. Refer to the USGS study for details on the assumptions made for the water use calculation. Note that a newer (more updated) study is coming out later this year, containing water use estimates from 2015, but unfortunately those results are not fully available yet. Given the

¹ Colorado Department of Local Affairs, State Demography Office:
<https://demography.dola.colorado.gov/economy-labor-force/data/jobs-by-sector/>

relative insensitivity of the mining industry to drought, thresholds were adjusted so that no scores of 4 would be assigned for this impact category. This is to reflect the fact that even mines using significant amounts of water are generally not shut down during drought.

Percent of water use that is surface water

Most mining activities use only groundwater, but there are some that rely on surface water or a combination of surface and groundwater. Based on the experience of other water users across the State, it is assumed that mining activities relying on surface water will be more vulnerable to drought. Surface water withdrawal data from 2010 came from the USGS study mentioned previously (USGS, 2014), and is compared to groundwater use and overall totals. The thresholds for scoring were broken up into equal bins, using non-zero water use values. A score of 1 means no surface water use, and 4 corresponds to the highest percentages of surface water use. No previous work on drought as related to the mining industry had specifically considered the impacts to surface water-supplied versus groundwater-supplied mines. This impact metric was therefore assigned an uncertainty flag.

7.5.2 Power

Spatial Density Metric

Power generation capacity

Power generation capacity by county was calculated using data from the U.S. Energy Information Administration's Preliminary Monthly Electric Generator Inventory, with results from the January 2018 report (based on Form EIA-860M) (U.S. Energy Information Administration, 2018). After calculating power generation capacity by county, it was noted that nearly one-third of all counties had zero generation. The large number of counties with no generation makes the typical thresholds for spatial density scores invalid; therefore, thresholds were adjusted to create equal bins for the non-zero dataset.

Impact Metrics

There is one impact metric and two adaptive capacity metrics for power generation. Similar to mining, the impact metric is overall water use by county for the power generation industry. The two adaptive capacity metrics are groundwater contribution and renewable energy development potential. Overall adaptive capacity was calculated by weighting renewable energy 75% and groundwater contribution 25%. Groundwater contribution was weighted less because further investigation is needed to determine the impact groundwater has on a case-by-case basis beyond that it may decrease vulnerability compared to reliance on surface water. The final power impact score was calculated by dividing the impact score (i.e., total water use) by the overall adaptive capacity score.

Total water use

Total water use was extracted from the 2010 USGS study mentioned in the Mining section 7.5.1 (USGS, 2014). For Power, this metric reflects the water that is extracted for use within the power generation industries across the counties. Counties already using less water dependent generation techniques will have lower overall water use. As with the generation capacity, data threshold percentiles were adjusted to account for the fact that many counties had zero water withdrawals. A value of 1 was assigned to all counties not withdrawing water for power production. The rest of the data were divided into three equal groups or bins.

Groundwater contribution

Water supply sourced from groundwater increases adaptive capacity. Groundwater contribution percentages were calculated using data from the 2010 USGS study (USGS, 2014). Counties on 100% groundwater were given an adaptive capacity score of 3 and counties with some groundwater capacity were given a slightly lower adaptive capacity score of 2. There are only four counties that use groundwater for power production. Kit Carson and Morgan Counties were given a score of 3 for using 100% groundwater, Adams and El Paso Counties were given a score of 2 for having some groundwater capacity. The groundwater contribution metric is assigned an uncertainty flag because it is not certain that the use of groundwater will decrease vulnerability. Groundwater sources may be impacted or overdrawn during drought, which could negatively impact uses by the energy sector. The ability to increase pumping rates during drought and the operation of augmentation plans need to be investigated on a case by case basis to determine how much adaptive capacity groundwater rights actually provide.

Renewable energy development opportunities

In a report by the Colorado Energy Office submitted to the State governor as well as the General Assembly in 2009, several renewable resource generation development areas (GDAs) for wind and solar power generation were identified (Colorado Energy Office, 2009). Using a map of GDAs (see Figure 7.19), counties with either a wind or a solar GDA were given a higher adaptive capacity score than counties with no GDA opportunities, and counties with both were given the highest adaptive capacity score (meaning they are least likely to be negatively impacted by droughts). This metric is assigned an uncertainty flag because several developments for both wind and solar are still in progress, and many more from other regions in the State could come online in the next few years. As of the end of 2017, 3,104 MW of wind generation capacity had been installed in Colorado, with a total of 25 online projects and a few others to come online soon (American Wind Energy Association [AWEA], 2018). Furthermore, there were 374 MW of solar capacity installed in the State as of the end of 2016 (Solar Energy Industries Association [SEIA], 2017), with this number likely to have grown by 2018 thanks to efforts such as the recent Governor Executive Order D2017-015 supporting the state's clean energy transition.

7.5.3 Results

Figure 7.20 and Figure 7.21 show the overall impact scores for power and mining respectively, along with their spatial density metrics. The shading represents the impact rating, and the size of the grey circle indicates the size of the sub-sector in a given county. Impact ratings greater than 0 but less than 1 are considered to be net adaptive capacities and are shaded in green. Impact ratings greater than 1 are shown in increasingly darker shades of red. For power, the spatial density metric used to display sub-sector size is the total Megawatt generation capacity (nameplate capacity) and for mining it is the number of mining jobs. Figure 7.22 shows the overall vulnerability scores combining power and mining results. Discussion of these maps is included in the following section.

Figure 7.20 Power Inventory and Impact Scores by County

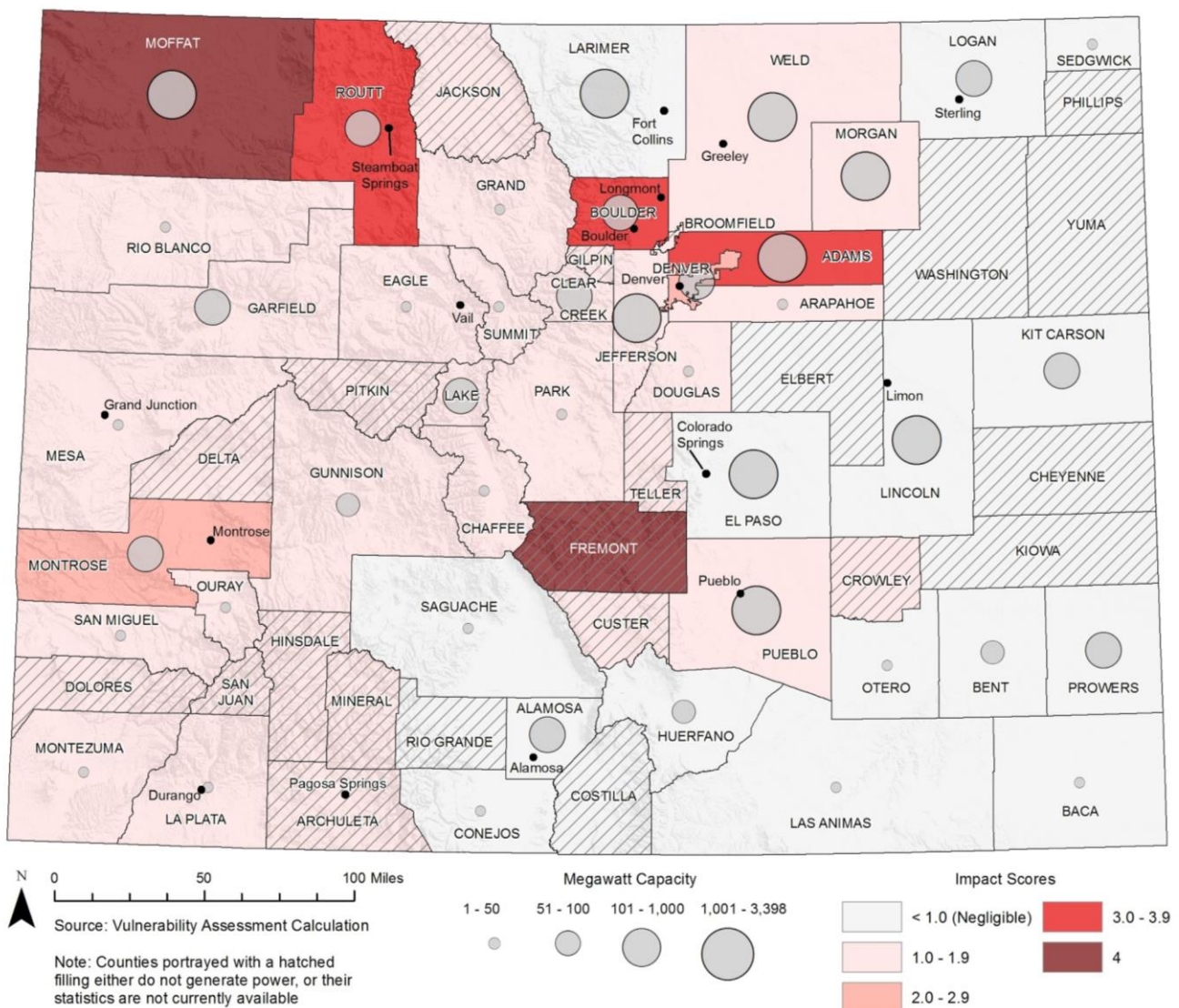


Figure 7.21 Mining Inventory and Impact Scores by County

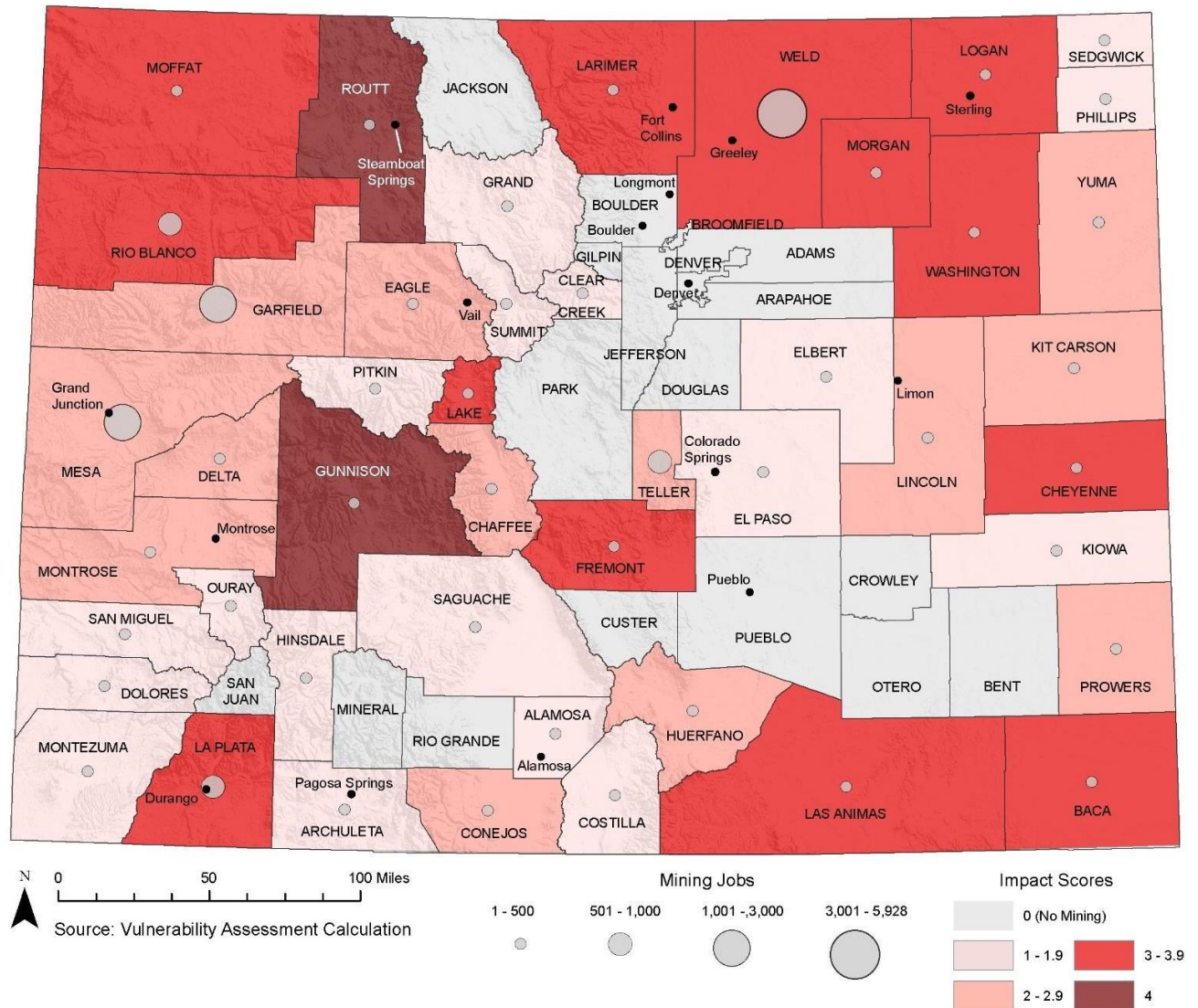
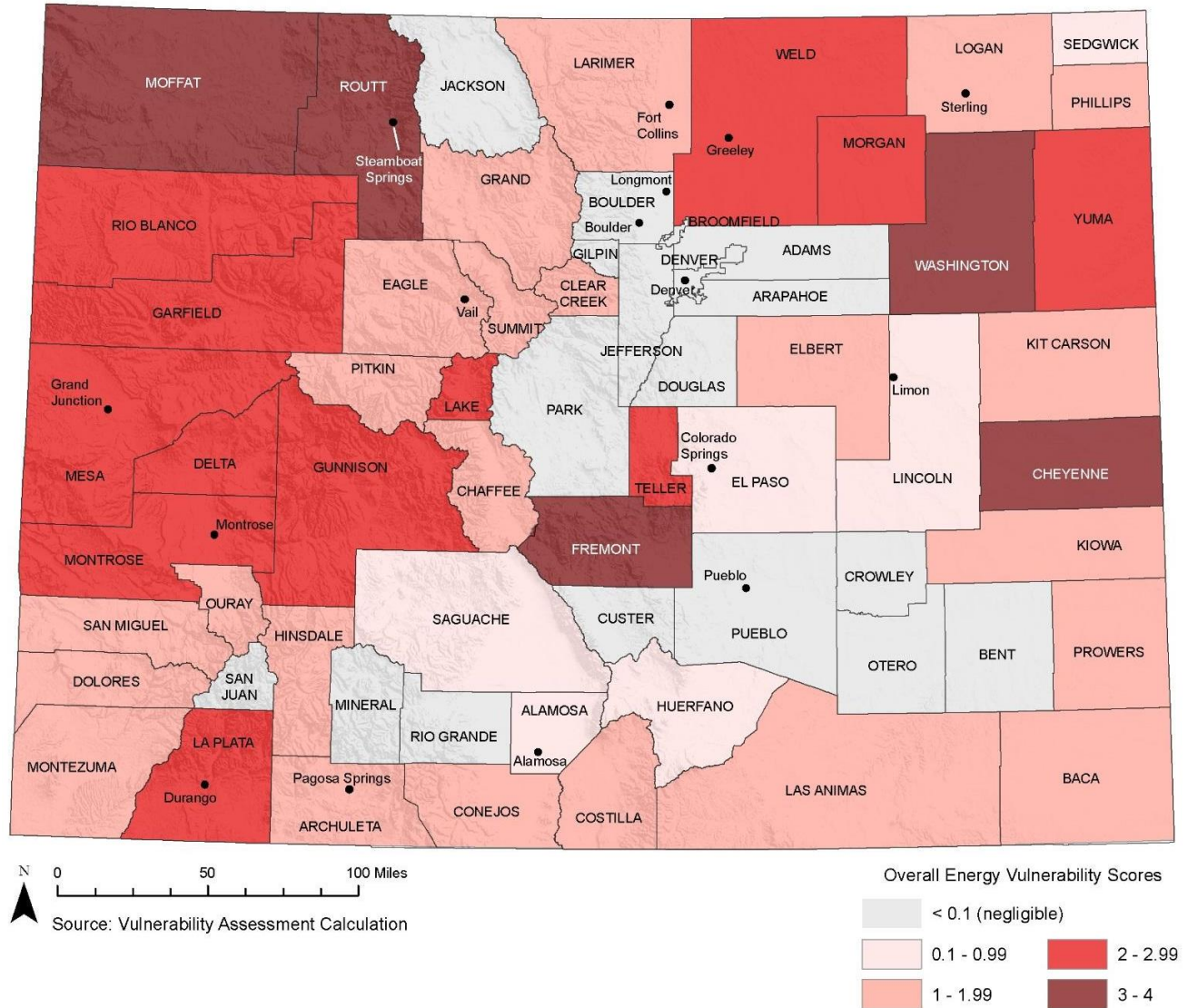


Figure 7.22 Overall Energy Vulnerability by County



7.5.4 Spatial Analysis

Vulnerabilities in the power sub-sector are highest in the counties of Moffat and Fremont (with scores of 4), followed by Routt, Boulder, and Adams Counties, which received scores of 3-3.9 (Figure 7.20). This is a result of a number of counties using significant amounts of water for power generation, coupled with the lack of wind or solar development plans that can serve as adaptive capacities in these areas. Other power producing counties in the Denver Metro area, e.g. Jefferson County, simply do not use as much water for their production. Fremont and Moffat Counties, in particular, are highly vulnerable because of their reliance on large amounts of surface water for power generation. Other counties such as Pueblo, on the contrary, have adaptive capacities to offset their vulnerability due to their solar and wind GDAs, even when they also heavily rely on surface water resources for power generation. Alamosa, Powers, and Lincoln Counties are examples of areas that produce large amounts of power (having over 100 MW of production capacity), but do

not utilize any water resources to generate or process such power, and instead maximize renewable sources; these aspects lower their vulnerability ranking.

High impact scores in the mining sub-sector indicate counties where large volumes of surface water are used for mining production (Figure 7.21). Routt and Gunnison Counties both have high surface water use, but the number of mining jobs associated with the areas is small (500 employees or fewer). Counties like Weld, Rio Blanco, or La Plata have high vulnerability rankings (based on water use) coupled with a high number of jobs dependent on mining. While there are 15 highly vulnerable counties that score 3 or above for the mining industry, 18 others do not have any mining operations or mining-related jobs currently, and are hence not likely to prove vulnerable in future drought events.

Overall, the five counties with the highest vulnerability scores for the Energy Sector (ranking 3 and above) are: Moffat, Routt, Washington, Fremont, and Cheyenne. This is due to their high vulnerability scores with respect to the power industry, mining industry, or both (as is the case with Moffat and Fremont, for example). While counties such as Washington or Cheyenne do have diverse water sources and a number of renewable resources which increase their adaptive capacities, their final scores were high due to the uncertainty flags assigned to groundwater use and renewable energy GDAs. All counties with power production or potential renewable energy development have at least one uncertainty flag. This flagging mechanism reflects the need for further investigation into water rights vulnerabilities and future renewable power development for the Energy Sector, as it affects the final ranking some counties receive, even when realistically they could prove to be rather adaptive against drought.

For comparison purposes between this Plan's Energy vulnerability results and the previous version published in 2013, the following counties are noted as changing the most drastically with regards to their overall vulnerability scores (either by having become more or less vulnerable than before): Adams, Boulder, Cheyenne, Fremont, Prowers, Teller, Yuma, Broomfield, Gilpin, Rio Grande, and San Juan. The first seven have higher vulnerability scores than in the previous Plan's assessment (particularly Adams and Cheyenne, which have increased by 200% and 225%, respectively), while the latter four have lowered in vulnerability, by either decreasing their impact or increasing their adaptive capacities (by a factor of 100%).

7.5.5 Compound Impacts

As previously noted, the Energy Sector is closely tied with the M&I Sector. One of the most critical compound impacts is the relationship between power generation and water supply as shown in Figure 7.5. Beyond this there are compound impacts between power producers and the mining industry, as most of the current power generation in the State is still fossil fuel based. Any impacts to the mining industry can, in turn, impact power providers, and the effects will cascade back to water providers, mining, and society as a whole. The list below outlines some of the key interconnections between Energy Sector impacts and the rest of society. This list is not exhaustive but does cover the general categories of impact.

-
- Impacts from power outages
 - Public health and safety concerns
 - Disruption of water supply for municipal providers
 - Disruption of well pumping
 - Economic impact for businesses unable to operate without power
 - Impacts from changes in power generation mix
 - Fluctuations in energy prices
 - Environmental impacts and possible increased emissions
 - Large shifts could change demand for various resources, locally affecting mineral prices
 - Impacts from decreased mining activity
 - Loss of mining jobs
 - Impacts to mining related industries
 - Impacts to mining communities and related economies/tourism
 - Decreased supply could locally affect resource prices
 - Positive impacts of “new energy economy”
 - Drought mitigation steps can indirectly affect society in a positive light, by creating jobs and generating funding for investment in new technology. The solar energy industry held over 6,000 jobs in Colorado as of 2016, and the wind energy sector supported between 6,000 and 7,000 (direct and indirect jobs) as of the end of 2017 (SEIA 2017; AWEA 2018)
 - Environmental conservation and cleaner natural resources often stem from these renewable energy economies and generation opportunities

7.6 Recommendations

7.6.1 Adaptation to Drought

The Energy Sector does not seem to be very highly vulnerable to drought. They have escaped with relatively minor impacts during previous droughts and tend to have senior water rights portfolios which will help protect them during future droughts. However, the Energy Sector is highly water dependent and should take drought mitigation very seriously. Future population growth, increased water demand, and potential impacts from climate change could put a larger strain on the Energy Sector and significantly alter drought vulnerability.

Power providers can reduce vulnerability without changing their generation technology by purchasing additional senior water rights and drought-contingent leases. They can also diversify their water sources (e.g., with renewables), reduce overall water use, and implement water reuse practices during the electric cooling process. The fracking industry can also investigate ways to recycle and reuse produced water. The best solution is generally to decrease the water required for power generation. In the case of traditional fuel sources, this can be achieved by implementing dry

cooling and combined cycles technology. Renewable resources like wind and solar require almost no water for generation.

At the State level, government has already moved to support less water dependent power generation with the 30% renewable energies by 2020 mandate. Further government support of water-independent technology will lower drought vulnerability. Also, improving transmission line capacity increases the ability of the State to react and fill deficits if power generation is curtailed as a result of drought. Increasing transmission line capacity to other states will provide additional flexibility to import power if necessary.

It is not clear whether the mining industry considers drought vulnerability in their operations. However, in the future, mines may have more trouble obtaining adequate water rights, even far in advance. Currently, there is not sufficient data available to analyze the impact of drought on the ability of the mining industry to obtain water rights, or the price of those rights. At the very least, mining companies should start considering drought vulnerability in their long-term planning process.

Another important consideration for the mining industry is Colorado's vast oil shale reserves. This mining activity was not investigated in detail as part of this assessment, since it is not yet technologically and economically feasible. However, significant research is currently being conducted on this topic and any assessment of oil shale extraction feasibility should take into account drought vulnerability. Similarly, hydraulic fracturing and its drought vulnerability should also be investigated as data on water use and water supplies, specifically in times of drought, become available.

7.6.2 Improving Vulnerability Assessment

One of the key data gaps for the Energy Sector is an analysis of water right holdings. In this analysis it is assumed that mines and power providers who are more reliant on surface water are more vulnerable to drought than those reliant upon groundwater. While this is a reasonable assumption, there are certainly differences in the reliability of groundwater and requirements for augmentation plans. Furthermore, it is likely that water right seniority plays a bigger role than the groundwater-surface water relationship. This is very difficult to analyze because most large power providers have a complex portfolio of water rights with a range of seniority dates. Future assessments should consider the seniority of water rights, the amount of surplus water held, and drought contingent leases.

The spatial density metric for mining was the number of mining jobs by county. A better metric might be the total mine production value by county. While these data are readily available for several individual resources like coal and natural gas, data on total production value of all mined resources were not easily found. Future assessments should incorporate these data, if possible, and test their use as a density metric for mining.

The water withdrawal data used to estimate impacts for both power and mining came from estimates made by the USGS based on 2010 data. Future assessments should update these data if revised numbers are available. Also, the USGS was forced to make many assumptions in their calculations because not all water use by the Energy Sector is reported. More accurate reporting techniques would improve the quality of these analyses.

The list below outlines data collection tasks identified through this study that could improve future vulnerability assessments. In some cases, these data may already exist but requires additional manipulation to be used for these purposes, or is not freely available to the public. This is by no means an exhaustive list, but is intended to be a starting point for future work. As future investigations are completed, changes to vulnerability metrics and data collection tasks will likely need to occur.

Mining

- Total mining production value by county for all resources
- Projected production value by county
- Actual reliance on various water resources (surface vs. groundwater) for mining extraction and processing purposes
- Current and projected water use for mining activities obtained directly from mines
- Water rights volumes and priority dates for operating mines
- Water rights yield analyses under a range of drought scenarios for mining operations

Power Producers

- Similar analysis of total water rights portfolio yield on a plant by plant basis for power providers
- Quantification of surplus water rights held and drought contingent rights for power providers
- Verification of the water use estimates done by USGS

8 ENVIRONMENTAL SECTOR

Key Findings

- Colorado's natural environment is diverse and drought vulnerabilities are expected to vary spatially based on ecology and existing precipitation regimes.
- During the 2018 and the 2011-2013 droughts as well as in 2002, Colorado Parks and Wildlife (CPW) reported severe impacts to several fish populations and was even forced to relocate some populations to fisheries or protected stream reaches for protection. The lessons learned from these major droughts should be carefully analyzed to better prepare for, and hopefully prevent, such negative impacts from occurring in future events.
- Increased wildfires and beetle infestation are common secondary drought impacts. While the occurrences of these are well documented, the resulting impacts to forest species are not thoroughly quantified.
- During the 2018 and 2011-2013 droughts, sedimentation of aquatic habitat, resulting from wildfires, was reported in several instances as being particularly damaging to fisheries, including fish kills from severe ash run-off during the monsoon months of July and August.
- The 2018 and 2011-2013 droughts impacted many wildlife species by decreasing available water, habitat, and population recruitment.
- Monitoring resources are limited, and comprehensive impact information, even for the most recent drought, is not available.

Environmental impacts cause compound effects in other sectors directly tied to the different natural resources available (e.g., decreased revenue from the Recreation and Tourism sector from lower visitation rates, increased management costs from different State departments to respond to drought events).

Key Recommendations

Some of the following key recommendations were originally developed in previous Plan versions but continue to be relevant in 2018.

- Continue the use of irrigation water rights to maintain and enhance wetlands
- Recommendations by the Water Availability Task Force highlight the need for identification of critical areas and additional monitoring.
- Agencies should approach monitoring in a collaborative fashion to decrease redundancy and increase the amount that can be achieved with limited resources.
- While the need for additional monitoring and impact measurement is great, previous studies should not be overlooked. There is a considerable amount of publicly available data of all sorts for Colorado that, with additional analysis, may be useful in improving drought preparedness and response. In future assessments, additional variables and perspectives should be considered to enhance current work.
- Future work should, where possible, build on the foundation of previous studies that have been conducted.

-
- As additional data becomes available, the drought vulnerability metrics used in this analysis should be updated.
 - Promote wildlife populations and maintenance of their habitats: e.g. beavers and beaver dams, which are proven to enhance stream flows during dry periods. In addition, promote stream and environmental restoration techniques that mimic those of successful species (e.g. beaver dams).

Local and regional governments and agencies should be cognizant of the compound effects to other sectors of the economy and society hidden behind environmental impacts, and work together or in sync to better study, prepare for, and mitigate drought.

8.1 Introduction to Sector

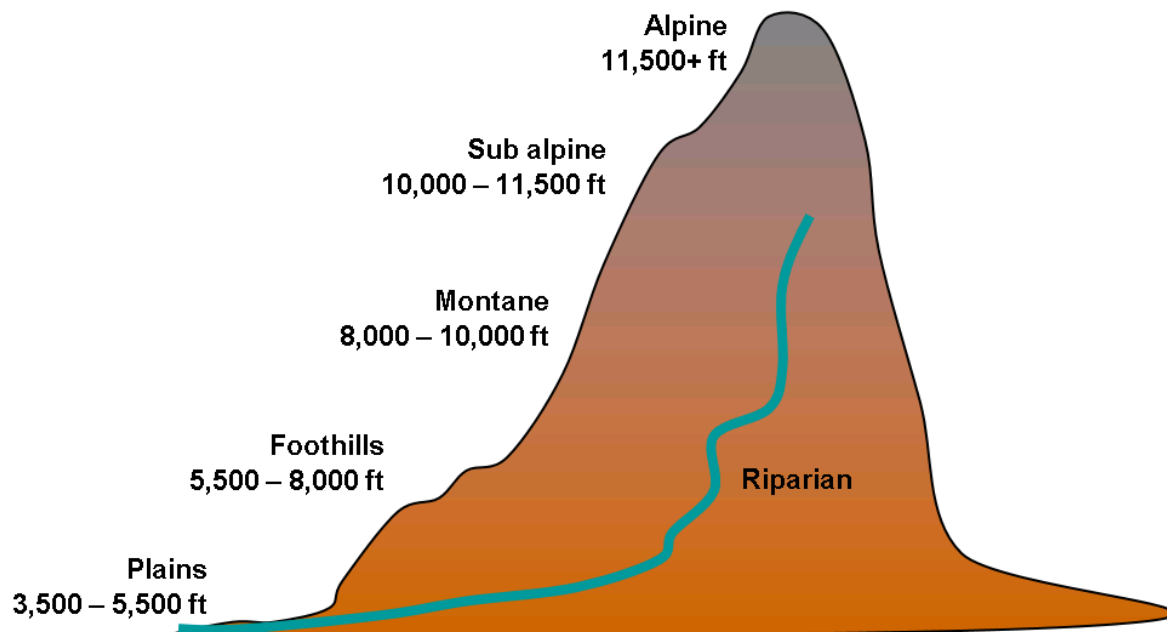
Colorado has an exceedingly diverse environment, with elevations ranging from 3,300 ft. at the Kansas border to over 14,000 ft. in the Rocky Mountains. The State is home to over 960 wildlife species (CPW, 2013) and many more plants, insects, and other organisms.

While it is impossible to assign monetary value to Colorado's environment, it is important to acknowledge the role it plays in our economy. Colorado attracts tourists and residents with its outdoor recreation opportunities, physical beauty, and high quality of life. Total direct travel spending in Colorado was estimated to bring over \$19.7 billion dollars into the State in 2016 (Dean Runyan Associates, 2017). This included lodging, food and gas. Wildlife species in the State attract tourists and residents who enjoy wildlife viewing, hunting, and fishing. The scenic beauty of aspen trees and the Rocky Mountains are another big attraction to the State.

The success of all the other sectors discussed in this assessment is linked to environmental quality to varying degrees. For example, the recreation and tourism industry is driven by Colorado's scenery, undeveloped lands, and array of outdoor activities, and relies on the environment in Colorado to attract visitors to parks and generate revenue. Socioeconomically, the condition of the environment contributes to the overall quality of life of people who live in the State.

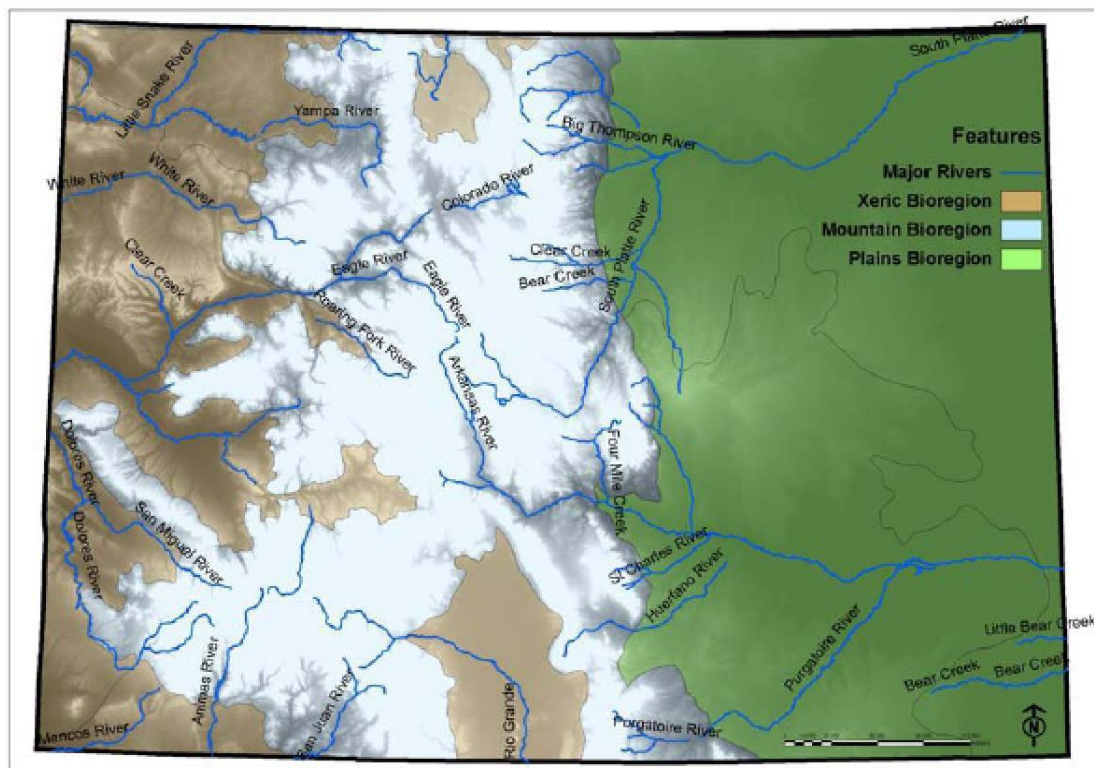
Given the diverse nature of Colorado's environment, accurate analysis is difficult and requires division into assessment categories. Previous work has created ecological groups based on elevation (so-called "life zones"), bioregion, watershed, and forest type, to name a few. Division by major river basins has also been used in other studies, such as the Non-Consumptive Needs Assessment (NCNA) (CWCB, 2011). The figures that follow graphically illustrate Colorado's ecological diversity and various categorization approaches. Figure 8.1 shows life zones in Colorado as determined by elevation. The Colorado Department of Public Health and the Environment's (CDPHE) Ecological Monitoring and Assessment Report delineated the three main bioregions show in Figure 8.2. The Natural Resource Ecology Laboratory (NREL) at Colorado State University (CSU) mapped seven ecoregions across the State (Figure 8.3). Forest types are mapped by the Colorado Division of Forestry in Figure 8.4.

Figure 8.1 Bioregions and Life Zones



Source: Adapted from NREL 2009

Figure 8.2 Bioregions and Major Rivers



Source: CDPHE 2007

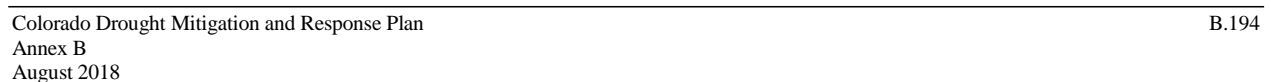
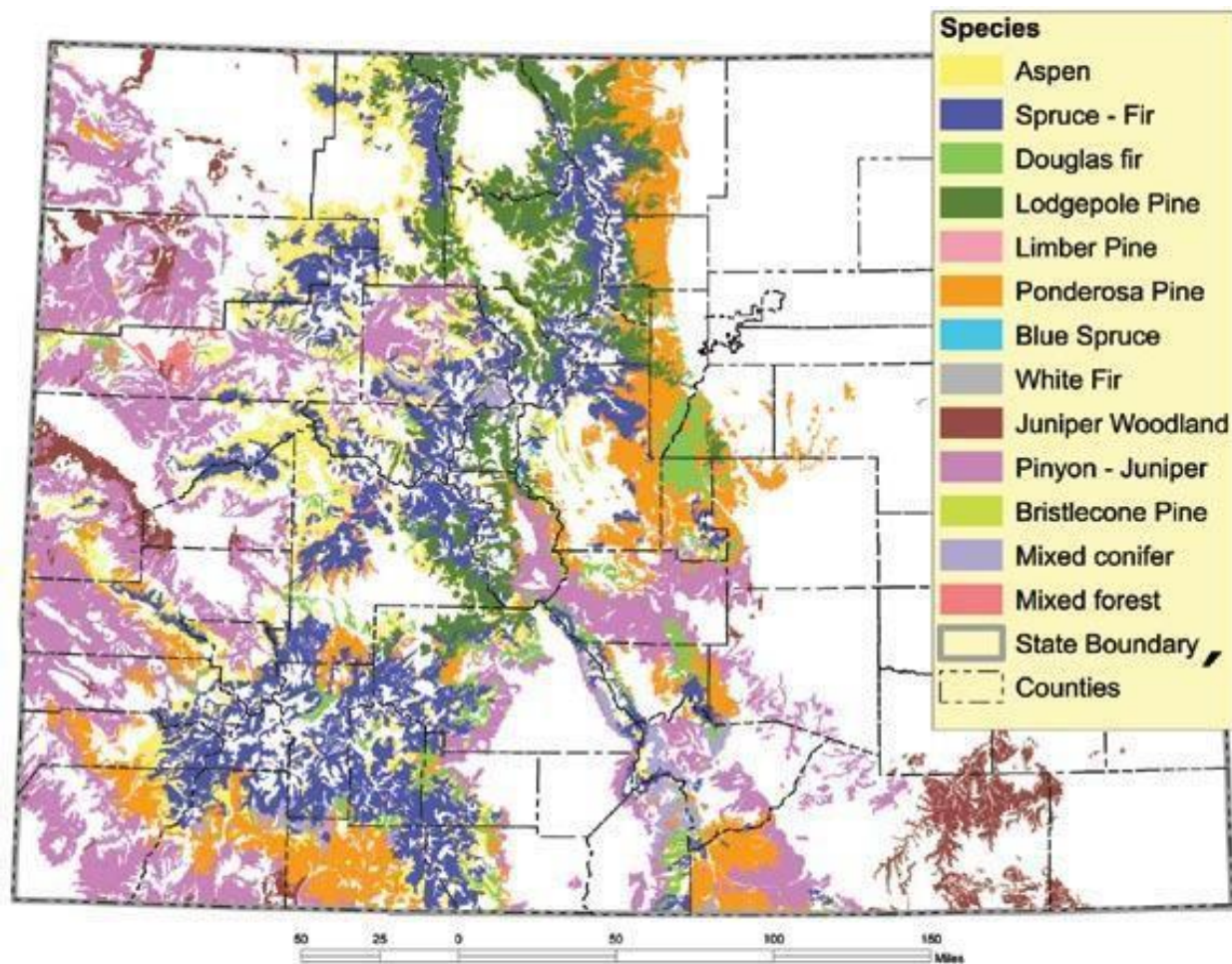


Figure 8.4 Forest Types in Colorado



Source: Colorado Division of Forestry 2001

From these four figures, a clear distinction can be seen between the eastern and western halves of the State as the plains transition into the Rocky Mountains, and the Continental Divide at the crest of the mountains creates a barrier to moisture transport (McKee et al., 2000). The eastern portion consists of the plains bioregion and ecoregion. This area is generally not forested, has less surface water, and is considerably flatter than the western half. Closer to the mountains, forests become more prominent and varied, and the topography becomes significantly more rugged. This is also reflected in the change of bioregions and ecoregions. On the western half of the State considerably more surface water is present and there appears to be a greater variety of forest and ecoregion types. Although not shown in these figures, plant, and animal species vary greatly depending on water availability, forest type, elevation, and topography.

Precipitation around the State averaged 16 inches in 2017 (NOAA, 2018), but can vary widely from 7 inches annually in the middle of the San Luis Valley to over 25 inches in most areas above 10,000 feet (McKee et al., 2000). More than 70% of the precipitation above 10,000 feet falls as snow (McKee et al., 2000), while on the Front Range and the eastern plains a large portion of

precipitation comes during spring and summer rain and hail storms. The wettest time of year for much of the Front Range and northeastern Colorado is early March to early June. On the west side of the divide, the wettest period is late fall through early spring. Precipitation patterns are naturally correlated with natural ecology but should be noted because the severity of drought impacts will vary depending on local precipitation regimes.

The combination of environmental and climatological diversity described above makes an accurate high-level vulnerability assessment challenging. Numerical assessment is further limited by the lack of usable data. Although a vast array of environmental studies has been conducted in Colorado, the majority could not be incorporated within the scope of this project. This was generally due to the following factors: 1) data analysis was not carried out relative to drought; 2) the studies did not cover the entire state; and 3) underlying data was not available in the appropriate resolutions (e.g. spatial, temporal) or would require significant spatial manipulation. As such, environmental vulnerability is not assessed according to the classification systems described above. Instead, vulnerability is calculated for the environment as a whole. Particular attention is paid to riparian areas because of their direct dependency on streamflow and their importance. Riparian areas, which are the land-water interface, are found throughout the State, and roughly 75% of the wildlife species known or likely to occur in Colorado are dependent on these areas for a portion of their life cycle (Natural Diversity Information Source [NDIS], 2004). Although this assessment recognizes other areas are impacted by drought (for example, snow- and groundwater-dependent habitats), riparian areas were chosen due to the availability of data and because these areas are widespread throughout the State. A secondary focus is on the existing quality and health of the region, such as existing forest health and water quality. This assessment is intended to be a starting point for future assessments and provide a template for data collection and analysis efforts. As additional data becomes available, the assessment should be updated. For a general description of the vulnerability assessment approach refer to Chapter 2 of Annex B.

8.2 Vulnerability of Environmental Sector to Drought

8.2.1 Aspects of Vulnerability

Drought impacts the natural environment in many ways. One of the factors that can influence an area's vulnerability to drought is land use. Human modification to a land area can exacerbate drought impacts, such as when livestock are allowed to graze on over-stressed pastures. Competition between municipal, industrial, and agricultural users can further impact an area that is already experiencing negative impacts due to drought.¹ For wildlife, a species' ability to relocate to areas that are not as impacted by drought influences their adaptive capacity. Animal mobility

¹ Ongoing planning by the CWCB is focused on identifying environmentally and recreationally important waterways and providing the maps and tools necessary to avoid conflict over these areas in the future. More discussion on this is provided in Section 8.2.2.

can be aided or encumbered by land use and human activities that either encourage, discourage, or prevent the migration of wildlife.

Some examples of drought impacts are listed below:

- Reduction in the spatial extent of flooded wetlands
- Reduction in irrigation water rights available for flooding wetlands
- Stress and die-back of riparian vegetation (e.g. cottonwoods and willows)
- Aquatic habitat can be impacted by lower streamflows, and mountain vegetation that wildlife depend upon for forage and cover in all habitat types can be impacted by reduced soil moisture in the spring and summer.
- Fish populations may decline as a result of limited wintertime habitat for mature fish. Wintertime habitat is a limiting factor to species proliferation, and lower wintertime streamflows can decrease the available habitat for adult fish.
- Late summer is also a limiting time period for fish, particularly in times of drought. Both flow and temperature can become detrimental, especially for cold-water species.
- Increased human wildlife interactions can occur when planned forage becomes less abundant as a result of decreased moisture. Elevated wildfire risk and subsequent wildfires can further increase habitat stress.
- More large-scale fires, continued insect and disease epidemics, and changes in species dynamics and range can result from drought conditions exacerbated by warm temperatures (CSFS, 2008). Continual grazing, fire exclusion, and drought are possible contributing factors to lack of regeneration noted around stands of aspen in the western half of the State (CSFS, 2008).
- During a drought, already-stressed systems can become further impacted by increased pollution, surface water diversions, and groundwater depletions. Low elevation riparian systems are often subject to heavy grazing and/or other agricultural use.
- As overall temperatures are on the rise with climate change, effects to the environment from drought events are projected to continue negatively impacting sensitive systems, particularly those already dry and/or highly susceptible to temperature variations (e.g., montane and alpine regions). Longer summers, hotter seasonal peaks, lack of precipitation, and prolonged drought events, among others, may put these types of environments at extreme risk of losing key biodiversity.

Adaptive capacities largely depend on human willingness to effectively manage wild areas or leave them undisturbed. Management decisions that have been implemented in past droughts include: forest management that allows for natural forest fires; closing sensitive lands to grazing when carrying capacity decreases; and maintaining instream flows at a level sufficient for aquatic life survival. Maintaining the natural environment at a high level of integrity during non-drought times helps ensure that, when a drought does occur, there are fewer areas already in a state of stress and therefore more susceptible to damage.

8.2.2 Previous Work

A number of studies have been conducted for specific subsectors of the Colorado environment. These reports were reviewed for information on negative environmental impacts with respect to drought. Table 8.1 outlines the findings of this literature review.

Table 8.1 Impacts from Literature Review

Topic	Impacts	Source
General environment	Impact: Extreme climate events can interact with other disturbances (e.g., catastrophic wildfire, insect outbreak, grazing, erosion) to drive semi-arid ecosystems past ecological thresholds, leading to changes in vegetation, degradation, and desertification.	Enquist et al. 2008
Mountain environment	Impact: Montane and alpine ecosystems are particularly at risk of added stress to already sensitive and vulnerable species, or even losing diversity. The American Pika, for example, thrives under specific conditions at high elevations and has been suffering from increasing temperatures, longer warm seasons, and ephemeral precipitation and snow pack. The report warned that the Pika could become endangered or extinct if these conditions worsen over the years (as they have in other western states such as California and Utah).	NPS, 2017
Mountain pine and other bark beetle	Impact: Extreme cold temperatures are a key factor to controlling the spread of beetle populations. The spread of mountain pine beetle can be exacerbated through warmer temperatures that often accompany drought, and because trees that are weakened by lack of water are more susceptible to infestation.	Leatherman 2007
Aquatic environment	Impact: In 2002 Antero Reservoir's fishery was lost, mostly due to draining of the reservoir.	DWSA, 2004
	Impact: Decreased water levels in Tarryall Reservoir, Spinney Mountain Reservoir, and Elevenmile Reservoir also resulted in significant aquatic impacts.	DWSA, 2004
	Impact: The lower South Platte River reservoirs experienced the loss of fishery resources.	DWSA, 2004
	Impact: In the San Luis Valley, the Home, Smith, Mountain Home, Million, and La Jara reservoirs were all drained dry with a total loss of fish.	DWSA, 2004
	Impact: Wildfires in the South Platte, Animas, La Plata, Los Pinos, and Mitchell Creek Watersheds, and their aftermath, resulted in serious loss of quality habitat in these watersheds.	DWSA, 2004
	Impact: Sediment and ash from wildfires impacted fisheries in Trinidad State Park, Lake Dorothy State Wildlife Area, the Poudre River, Marcos River, Sand Creek, and Piedra Rivers.	CPW, 2012
	Impact: Low water levels, high temperatures and low dissolved oxygen levels contributed to fish kills in the Las Animas Hatchery, Williams Creek Reservoir, and created stressful conditions for many fish species in streams throughout the State.	CPW, 2012
	Impact: A fish kill was observed in the Colorado River above Dotsero after a monsoon event transported a large amount of sediment into the river.	CPW, 2012
	Impact: Waterfowl production in breeding areas such as North Park, San Luis Valley, and the Yampa River was generally poor in 2012 and the same is expected for 2018.	CPW, 2012 and 2018

Extreme wildfires	Impact: Reports from the summer of 2002 indicate that elk were incinerated, watersheds were at risk, streams were choked with ash and sediment, and reservoirs that were already low were at risk of filling up with ash and sediment.	Holsinger, 2002
	Impact: The 2002 fire season was heightened by extended drought conditions that caused well below average fuel moistures in wildland fuels. This resulted in increased potential for fire starts and more intense fire behavior. Wildfires are a separate hazard from drought, but the dry and hot conditions accompanying a drought exacerbate the wildfire problem.	DWSA, 2004
	Impact: Debris flows that result from wildfires deliver large amounts of sediment to stream channels. The sedimentation of the channel deteriorates habitat vital for aquatic life. This impact is observed along the Poudre River, downstream of the 2012 High Park fire.	CPW, 2012
Noxious weeds/plants	Impact: Noxious weeds and plants can proliferate when native vegetation is stressed by lack of water due to drought. Impact: They also create heightened competition for water, which in a drought can damage surrounding vegetation by consuming excess soil moisture.	CSFS, 2008

In addition to the works cited above, environmental impacts due to drought were included in the 2004 Drought and Water Supply Assessment (DWSA), and its 2007 Update. The CWCB conducted the original DWSA in 2004 to determine the State’s preparedness for drought, and to identify limitations to better prepare for future droughts (DWSA, 2004). It entailed a survey, or opinion instrument, where 537 responses were received statewide on specific impacts experienced during the drought years of 1999-2003. In both the original version and the later update, various entities were surveyed including power, industry, agriculture, municipal, state, federal, water conservancy and conservation districts, and other entities such as tribes and counties. Although the survey did not include any groups directly related to the Environmental Sector, the DWSA did mention drought related impacts (noted in Table 8.1) regarding extreme wildfires and the aquatic environment. Additionally, the DWSA identified the need to thin or remove moisture-competitive trees and brushes in watersheds in order to increase yields for streams and aquifers. This task falls on the U.S. Forest Service (USFS), Colorado State Forest Service (CSFS), and the Colorado Department of Natural Resources (DNR). The eradication of the invasive tamarisk plant was one of the identified goals in an Executive Order to the Governor in 2004; the DNR was responsible for developing a plan to eliminate the tamarisk tree from all public lands within 10 years, and many environmental, restoration, and sustainability agencies are actively collaborating on this eradication endeavor (e.g., Tamarisk Coalition).

The CWCB, in 2010, also sponsored the Statewide Water Supply Initiative (SWSI) update (from the original in 2004). Due to its importance to the State economy and quality of life, and because population growth is expected to place competing demands among many water uses, the Environmental Sector had a prominent role in the SWSI process. One of SWSI’s water management objectives was to “Provide for Environmental Enhancement.” Similar to the Recreational Sector, a detailed assessment of how drought may impact the Environmental Sector was not performed in the first phase of SWSI. However, the SWSI process identified many environmental resources on a statewide basis that are potentially vulnerable as a result of population growth and the subsequent

strain on water resources. Further, the upcoming SWSI Update in 2018/19 will incorporate additional efforts related to the environmental sector, including scenario planning and gap analysis methodologies, population projection and effects methodologies, and water supply and finance methodologies that can assist future efforts and studies assess water related changes and impacts.

The resources pertaining to the Environmental Sector include the following (as presented in the SWSI from 2010):

- Gold Medal fisheries/lakes
- Colorado Water Quality Control Division (CWQCD): Monitoring and Evaluation List, 303(d) List
- Audubon important bird areas
- Colorado Natural Heritage Program
- Instream flows

Data associated with these resources were collected, delineated, and summarized in GIS coverages as part of SWSI 2010. The data and associated tools are available to decision makers to prioritize environmental areas and ensure these resources are considered when establishing water management strategies throughout the State. Additionally, SWSI 2010 recommended that preservation of environmental resources needs to occur when water development projects are being considered, to avoid conflict between water providers and the environmental and recreational community.

The CWCB completed the work started in SWSI with a Non-Consumptive Needs Assessment (NCNA) Focus Mapping report (CWCB, 2010). This report covers non-consumptive water uses in the nine basin roundtable areas of Colorado (eight major river basins and the Denver metro area). The NCNA expands upon the existing set of environmental and recreational attribute maps that were developed through the process to update SWSI in 2010 and develops aggregated maps of Colorado's critical waters based on environmental and recreational qualities. The maps are intended to be a guide for water supply planning, so that future conflicts over environmental and recreational water needs can be avoided.

The data resources used in the NCNA assessment include the following:

Environmental and Recreational GIS Shapefiles from SWSI 2010 Arkansas darter

- Audubon important bird areas
- Bluehead sucker
- Bonytail chub
- Boreal toad critical habitat
- WQCD 303(d) listed segments
- Colorado pikeminnow
- Colorado River cutthroat trout
- CWCB instream flow rights
- CWCB natural lake levels
- CWCB water rights where water availability had a role in appropriation

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- Flannelmouth sucker
 - Gold Medal trout lakes and streams
 - Greenback cutthroat trout
 - Humpback chub
 - Rafting and kayaking reaches
 - Rare riparian wetland vascular plants
 - Razorback sucker
 - Recreational in-channel diversions
 - Rio Grande cutthroat trout
 - Rio Grande sucker
 - Roundtail chub
 - Significant riparian/wetland communities

 - Additional Environmental and Recreational GIS Shapefiles
 - Additional fishing, greenback cutthroat trout waters, and paddling/rafting/kayaking/flatwater boating
 - Bald eagle winter concentration, active nest sites, summer forage, and winter forage
 - Brassy minnow
 - Colorado birding trails
 - Colorado outstanding waters
 - Common garter snake
 - Common shiner
 - Ducks Unlimited project areas
 - Educational segments
 - Eligible/suitable Wild and Scenic rivers
 - Grand Mesa, Uncompahgre, and Gunnison wilderness waters/areas
 - High recreation areas
 - Least tern
 - National wetlands inventory
 - Northern leopard frog locations
 - Northern redbelly dace
 - Osprey nest sites and foraging areas
 - Piping plover
 - Plains minnow
 - Plains orangethroat darter
 - Preble's meadow jumping mouse
 - River otter confirmed sightings and overall range
 - Rocky Mountain Biological Laboratory (scientific and educational reaches)
 - Sandhill crane staging areas
 - Southwestern willow flycatcher
 - Stonecat
 - Waterfowl hunting areas

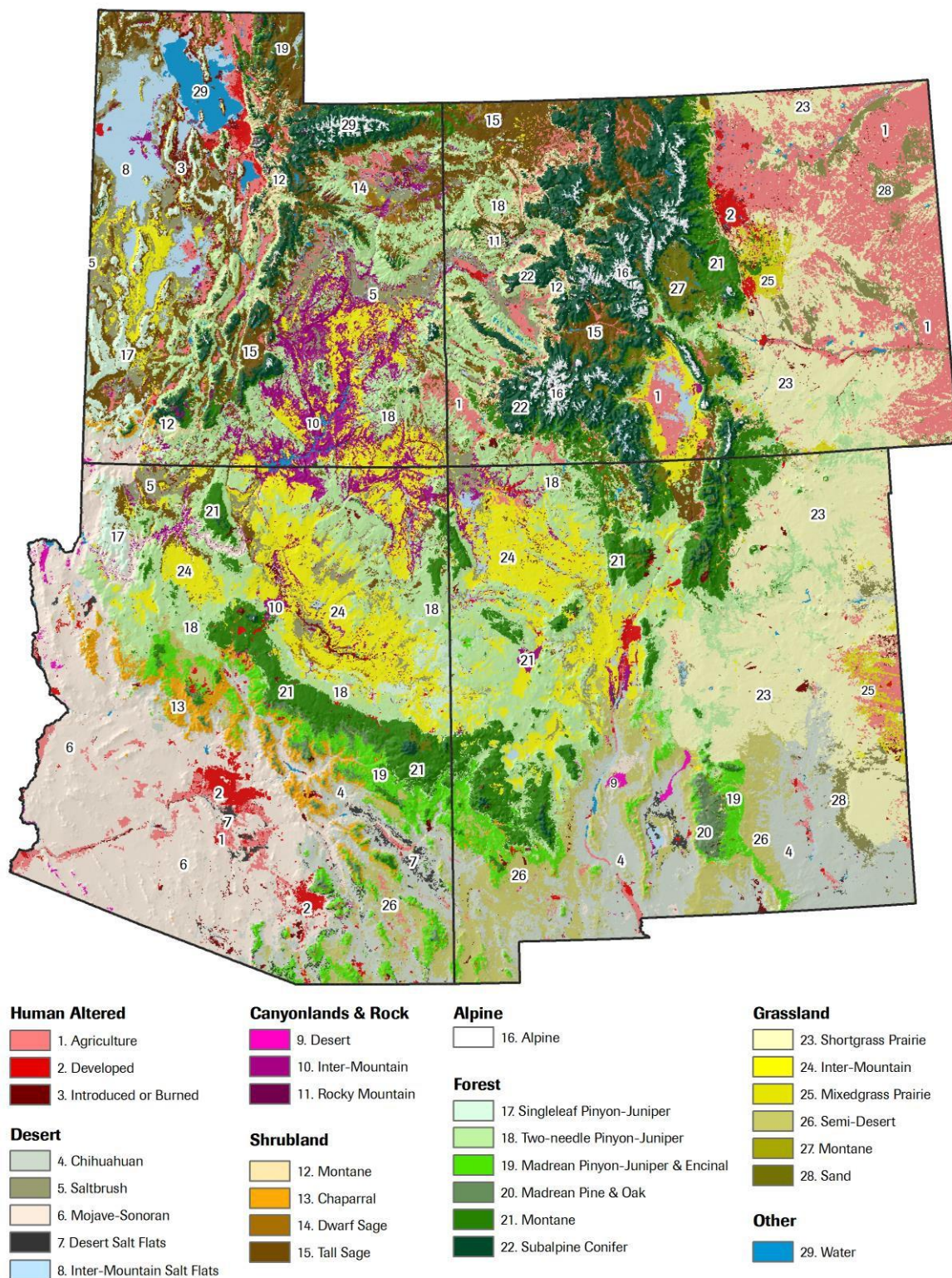
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- Wild and Scenic study rivers
 - Wildlife viewing
 - Yellow mud turtle

As can be noted by the extensive list above, the NCNA was an expansive undertaking that provides valuable aquatic ecosystem data aggregation. While it does not speak to drought vulnerability specifically, the data gathered and resulting stream reach designations are a useful environmental inventory metric. However, in the NCNA process, basins could produce different maps based on their selected mapping technique and priority data layers (CWCB, 2010). The methodology for the Drought Vulnerability Study was developed to facilitate analysis that could be consistent across watershed and county boundaries in Colorado, this requiring selection of categories and data types that were available and comparable at the county level. In contrast, while data developed for the NCNA analysis was often rich in terms of the number and types of data used, the data are variable across basins. This precluded extraction of this information in a manner that would have facilitated direct use of the NCNA results. Furthermore, all of the NCNA analysis was done with respect to sub-basins and stream reaches. Significant analysis is required to convert these findings into county designations that could be incorporated into this methodology. Although numerical integration is not possible at this time, the applicability of this data for future analysis is unquestionable. Additional work should be supported to build on the NCNA findings.

Finally, there are many recent and ongoing environmental studies by various groups in Colorado that are attempting to, for example, analyze watershed health and restoration efforts, and even classify local and regional bioregions and assess vulnerabilities, primarily related to climate change.

Figure 8.5, provided by The Nature Conservancy (TNC), is modified from a regional study conducted by NatureServe in 2009 to classify habitats in the southwest of the United States. Habitats were determined using a GIS dataset of vegetation units called “macro groups.” Macro groups are groups of plant communities with a common set of growth forms and dominant plants that share a broadly similar geographic region, regional climate, and disturbance regime (TNC, 2010). This classification unit is broader than ecological systems and has been included in the most recent version of the U.S. National Vegetation Standard. As with NCNA the results of this study, while informative, are not (as of 2018) in a form that is readily usable for the vulnerability assessment methodology of this project. Information like this may be beneficial in future drought vulnerability work and is a good candidate for additional analysis.

Figure 8.5 Southwest Region Macro groups



Source: NatureServe, 2009 and TNC 2010

8.3 Assessment of Impacts and Adaptive Capacities

While there is a significant body of work concerning the ecological diversity of Colorado, comprehensive drought impact information is not available. Specific impacts to vegetation, aquatic species, and wildlife have been noted in previous droughts, but not in a systematic way. The primary sources of this information are CPW and the Water Availability Task Force. Many of the impacts noted here relate to riparian areas and secondary impacts to forest health (wildfires and beetle infestation). Particular attention is also paid to endangered species. Relevant information is presented in this section. However, it should be noted that there is a general lack of information about drought impacts to the environment as a whole and to species and areas that are not heavily managed. Therefore, the specific impacts discussed here may be more heavily weighted towards managed species and areas.

8.3.1 Potential Impacts

The following list outlines the experiences reported by CPW staff during the 2002 drought and these same types of impacts occurred again in 2012 and 2018. Many of the comments highlight aquatic species and riparian areas' direct vulnerability to drought.

- Increased tillage of playa wetland basins within croplands in eastern Colorado.
- Statewide decrease in forage for wildlife; in some cases resulting in increased conflicts between humans and bears.
- Aquatic impacts due to low stream levels and significantly higher water temperatures. Salmonid populations were affected in several low-water streams. Voluntary angling closures were employed on some streams to minimize impact to already-stressed salmon. Both voluntary and mandatory angling closures have been implemented during the summer of 2018.
- Several endangered fish species were threatened and had to be transferred to a protected stream reach or hatchery. For example, greenback cutthroat trout were pulled from Como Creek and roundtail chub from La Plata and Mancos Creeks.
- A baseline condition for the majority of native aquatic wildlife species had not been established prior to 2002, therefore it was impossible to accurately describe the impact of the drought on these species.
- Monitoring resources are limited and it was not possible to track impacts to some native wildlife resources, including fish, birds, small mammals, and amphibians.

Since the multi-year drought have that occurred state-wide since the 2011-2013, Colorado in general was relatively drought free until 2018. The southern portion of the state has been particularly struck with drought since early 2018. As of the update of this plan in late June of 2018, 8.81% of the state was falling under the exceptional drought category based on the US Drought Monitor portal, with another 27.65% categorized as extremely dry, 15.85% being in severe drought, 14.59% in moderate drought, 11.76% in abnormal drought, and the rest not seeing any drought conditions.

CPW observed various impacts associated with the latest major drought events of 2018 and 2011-

2013, some of which could repeat or worsen the systems summarized below. The impacts mentioned are similar to those observed for the 2002 drought event.

- Significant decreases in forage, water, food, cover, and habitat stressed populations, creating concerns about the health and survival of game species through the winter.
- Fish kills observed in reservoirs, lakes, ponds, and streams as a result of low water levels, high water temperatures, anoxic conditions, and sedimentation.
- Many CPW's 18 hatcheries were greatly impacted by reduced water supply that lead to early release of fish and an overall reduction in fish raised by the hatcheries.
- Black bears emerged earlier from their dens due to abnormally hot and dry conditions during the spring of 2012.
- Waterfowl production in breeding areas such as North Park, San Luis Valley, and the Yampa River was generally poor in 2012 and the same is expected for 2018.
- Pronghorn antelope herd distribution has changed significantly during 2011-2012 and experienced reduced recruitment. It is too soon to tell for the 2018 season.

A secondary impact of drought is increased incidence of wildfires, which can also negatively affect riparian areas. In 2002, the CPW reported impacts from the Hayman fire that included increased runoff from the burn areas and a corresponding increase in sediment load and deposition in the South Platte River. The increased sedimentation caused direct loss of aquatic habitat, negatively influenced macro-invertebrates, and degraded trout spawning habitat. As a result of these impacts the CPW had to increase stocking of fingerlings and sub-catchable (5 to 8 inch) trout to replace year class losses. They worked closely with water providers throughout the basin to implement sediment trap areas on tributaries that would increase opportunities for flushing flows to move the sediment bed load downstream and were involved in a variety of other stream and riparian habitat enhancements to restore watershed function (communication with Colorado DOW (now CPW), 2010). CPW staff note that the ecosystem is slowly recovering but impacts from the fire are still noticeable today.

Similar impacts were observed as a result of wildfires during the 2011-2013 drought. A fish kill at Lake Dorothy State Wildlife area was caused by high sediment loads from ash and sediment resulting from the 2011 Track Fire. Additionally, the health of the fishery in the Poudre River basin has been negatively impacted by the ash and sedimentation associated with the Hewlett Gulch and High Park fires.

Compound impacts are secondary, or indirect, impacts brought about by changes in sectors that are directly impacted. Given the strong inter-reliance between other sectors and the environment, compound impacts can be dramatic. As previously noted, Colorado's beautiful environment is a big attraction and is often cited as an important factor in the high quality of life for residents of the State. Loss of vegetation and drought induced wildfires can impact society as a whole. Furthermore, when drought puts stress on ecosystems that are the basis for recreational activity, the recreation and tourism industries suffer. For example, CPW has implemented voluntary recreational closures on portions of rivers during periods when high water temperatures stress fish (communication with Colorado's DOW [now CPW], 2010; CPW, 2013). Many of the preserved natural spaces in Colorado are controlled by government agencies. Responding to the

environmental impacts of drought can put stress on agencies like CPW and the State Forest Service. Both CPW and the State Engineer's Office reported increased cost resulting from additional manpower to manage environmental resources during the 2002 drought.

Aquatic species, especially fish, may be very sensitive to municipal and industrial wastewater effluent, particularly during low flow times when waters have diminished volume or flow with which to dilute pollutants. This can have detrimental effects on native fish species as well as lucrative sport species. The 2002 drought illuminated the inability of water quality and water quantity legislation to respond to drought coherently because they are managed in two separate arenas. For example, wastewater treatment operators were legally allowed to continue discharges into state waters experiencing very low flows even though discharge calculations were completed for flow levels higher than the flow levels at the time. When and where these situations actually occurred and whether such conditions impacted aquatic life was difficult to assess in real time, making monitoring a difficult and reactive task. Many new water transactions and management plans have been developed in recent years and impacts from future droughts will probably not parallel past experience. Colorado's water quality regulations do not provide a framework for overall review of water-quantity projects nor can they inhibit the exercise of water rights. Similarly, water-quantity regulations cannot incorporate literal water-quality considerations. As such, future planning and education efforts are needed to reduce the potential for water-quality impacts and conflicts².

8.3.2 Adaptive Capacity Actions

In May 2002, the Water Availability Task Force assembled a list of potential mitigation strategies for aquatic and terrestrial habitats as part of the Impact Task Force Drought Assessment and Recommendations, requested by then-governor Bill Owens. These strategies involved actions that government agencies and/or environmental groups could take to mitigate impacts during the drought, and which are still relevant. Many strategies, such as the identification of critical water features, were implemented to reduce the effects of drought; the positive impacts of some of those early actions can still be felt today (e.g. with instream flow rights that ensure certain flows in streams and lakes of concern remain). The mitigation strategies and actions table is reproduced below (Table 8.2). Note that the combination of CDPOR and DOW become the CPW in 2011, and as such, references to DOW and CDPOR now relate to the CPW.

² Stringent treatment standards could require extensive re-working of existing facilities and/or new facilities which may not be feasible for some entities. Such implications, in addition to water rights implications, would need to be evaluated on a case-by-case basis.

Table 8.2 Mitigation Strategies from the 2002 Water Task Force

Potential Mitigation Strategy	Agencies or Organizations Involved
Aquatic Habitat	
Identify critical stream reaches, lakes, and reservoirs. Critical stream reaches would be identified based on designated criteria such as species of concern, threatened and endangered species, recreational or historic importance, and instream flow reaches where senior water rights could help mitigation. Look for opportunities to maintain flows on the identified critical stream reaches.	DOW, CWCB, USFW, USFS, and Trout Unlimited (TU)
Develop processes to monitor critical stream reaches, lakes, and reservoirs. A process for monitoring flow rates, water levels, and temperatures needs to be developed. This process would incorporate citizens, schools, environmental/wildlife groups, and state and federal agencies. In addition, criteria would be set for emergency actions.	DOW, CWCB, CDPOR, DWR, CDPHE, USFW, USFS, TU, and citizen groups
Identify mitigation alternatives for critical stream reaches, lakes, and reservoirs where practical.	DOW, CDPOR, DWR, CWCB, CDPHE, USFW, USFS, and TU
Provide emergency instream flow protection. CWCB will work with the DNR, Governor's Office, DWR, SEO, DOW, and the public to provide emergency instream flow protection on streams where water rights may be temporarily made available for such purposes. In 2003, the general assembly revised the instream flow statutes to allow irrigators to temporarily "loan" unused water to CWCB for instream flow purposes at times when the Governor declared a drought (Colo. H. 03-1320, 64th Gen. Assembly, 1st Reg. Sess. [June 5, 2003]). In 2005 this section was again revised to allow for such loans in three out of every ten years, thus eliminating the requirement that the Governor declare an emergency (Colo. H. 05-1039, 65th Gen. Assembly, 1st Reg. Sess. [Mar. 25, 2005]).	CWCB, DWR, DOW, TU, and other water users
Develop process for enacting drought emergency closures, fishing restrictions, and fish salvage operations. Education and notification of the public on the process and the status of fisheries is also included under this strategy.	DOW
Monitor hatchery water levels and stocking conditions. Based on this monitoring, modify production levels and stocking procedures as needed.	DOW, USFW
Terrestrial Habitat	
Identify priority areas and monitor drought impacts on threatened and endangered species, and other species of concern.	DOW, USFW, and USFS
Continue to identify and assess how drought may impact predator and human interactions. This task includes public education.	DOW, USFW, and USFS
Evaluate process for compensating private landowners for game damage associated with drought issues. This task should include identifying lag effects on game damage.	DOW
Monitor waterfowl production impacts. Identify any local, hunting, or migratory impacts to waterfowl from drought.	DOW, USFW, and USFS
Aquatic and Terrestrial Habitat	
Evaluate and optimize state agency water use as necessary to best maintain habitat, stream flows, and reservoir levels. Includes development of water conservation measures for state-owned water rights.	DOW, CDPOR, CWCB, and DWR
Coordinate and research federal drought assistance funding, including research into whether federal drought relief money may be available to compensate irrigators and for CWCB to lease senior rights for instream flows.	DOW, CWCB, USFW and USFS
Educate water users on conservation practices to aid wildlife during drought and on what to expect during drought conditions.	DOW, CDPOR, DWR, CWCB, USFW, USFS, and TU

Abbreviations

CDPHE: Colorado Department of Public Health and Environment
 CDPOR: Colorado Division of Parks and Outdoor Recreation
 CDWR: Colorado Division of Water Resources
 CWCB: Colorado Water Conservation Board
 CWQCD: Colorado Water Quality Control Division

DNR: Colorado Department of Natural Resources
 DOW: Division of Wildlife
 DWR: Department of Water Resources
 TU: Trout Unlimited
 USFS: United States Forest Service
 USFW: United States Fish and Wildlife

In addition to the mitigation strategies assigned to specific agencies in Table 8.2, the impact task force also recommended: 1) statewide voluntary conservation measures intended to conserve water to benefit wildlife; and 2) coordinate public education and media releases to increase clarity and visibility of drought conditions and mitigation actions.

Many of the mitigation strategies discussed above involve identifying critical areas and monitoring impacts. This speaks to the lack of impact data noted in the previous section. It is difficult to develop specific mitigation strategies without a clear spatial understanding of impacts. For example, there are many wildlife species in dry regions of Colorado already adapted to drought and able to survive in dry conditions. Some may have the mobility to seek less stressful habitat elsewhere (communication with DOW [now CPW], 2010). Future monitoring and identification work should quantify qualitative observations like this. Only after drought impacts have been systematically observed can specific vulnerable areas and species be identified and targeted mitigation efforts designed.

In 2007, the Colorado Water Quality Control Commission (CWQCC) adopted revised surface water quality standards specific for protection of aquatic life. The standards included an acute standard (a two hour daily maximum temperature) for protection from lethal effects of elevated temperature and a chronic standard (a maximum weekly average temperature) for protection against sub-lethal effects on behavior. The standards also included seasonal adjustment for protection of spawning, accompanied by a narrative requiring that temperature maintain a normal pattern of daily and seasonal fluctuations and spatial diversity with no abrupt changes. Colorado's revised water-quality standards for temperature did not exist during the 2002 drought. Further, a low-flow exclusion allows for temperature exceedances when the daily streamflow falls below an acute low flow or when the monthly average streamflow falls below a chronic critical low flow. The basis of Colorado's temperature standards in species-specific physiological tolerances to elevated temperature suggests that the standards can provide a useful benchmark against which to evaluate whether elevated temperatures resulting from drought conditions are likely to contribute to deleterious effects on aquatic communities. The implementation of the temperature standards prompted an increase in temperature monitoring as well as a standardizing of action requirements, which have been facilitating better evaluation of the influence of drought-associated flows and elevated temperature on fisheries during drought conditions. The CWQCC continues to revise and/or make amendments to their water quality standards documents on a yearly basis, to provide up-to-date guidance based on current surface water conditions (CDPHE, 2018).

The Colorado Water Quality Control Division, which falls under the CDPHE, also publishes their Integrated Water Quality Monitoring and Assessment Report every two years (though the latest, presented in 2016, encompassed the studies carried from 2012 through 2016). This report summarizes water quality conditions across Colorado, along with some key new implementations. For example, the latest document version indicates that the CWQCD adopted a new database for tracking Integrated Report data (including National Hydrography Dataset [NHD] GIS datasets that increase the functionality and accuracy of the products), which enhances the division's ability to track, define, study, and make assessments from waterbodies in the State. Of additional interest is

the division's implementation of a new Assessment Unit IDs (AUIDs), which enable the study to better categorize and analyze water quality impacts to specific sectors, namely agriculture, aquatic life (cold and warm categories), domestic water supply users, and primary and secondary recreation users. Furthermore, the report summarizes efforts to monitor water pollution, define control programs to routinely sample and/or carry out special studies, acquire and approve additional funds as necessary, push out permits, facilitate cost/benefit assessments, and coordinate with agencies and governments to enforce requirements pertaining to water quality standards (CWQCD, 2016). This type of report enables the State to have a better understanding of knowledge gaps regarding environmental amenities affected by water sources. The document also supports data-driven decisions to protect species or habitats found to endure harsh conditions due to lack of water or degraded water quality, and hence improve the sustainability or adaptive capacity of those environments and species.

From 2011 to 2013, CPW implemented a number of response actions targeted at aquatic resources. Some of these included carrying out investigations and intensively monitoring different ecosystems to understand more exact circumstances. CPW has been closely recording data from stream flow levels, water temperatures, and dissolved oxygen levels in rivers and streams throughout the State. In 2016, CPW published their latest yearly Stream Habitat Investigations and Assistance report, outlining different fishery monitoring responses aimed at improving aquatic habitats, river restoration efforts, and other aquatic enhancement endeavors carried out in the studies (CPW, 2016). The project's efforts have been shown to have a positive impact on fish populations and have the potential to increase the carrying capacity of a stream after suffering from afflictions such as drought. Thanks to the measures taken, CPW has been able to implement fishing restrictions and/or closures when warranted. To support this action, CPW is encouraging anglers to monitor water temperatures and move to other locations if or when temperatures rise above 68 degrees Fahrenheit. This helps to reduce stress on cold-water species. CPW has also been collaborating with other agencies to obtain emergency releases of water when the conditions require increased flow for basic habitat needs, temperature moderation, dissolved oxygen, and for spawning migration. For example, in 2012, CPW was able to work with the CWCB and the Division of Water Resources to release water from Lake Avery to help maintain the White River fishery (CPW, 2012).

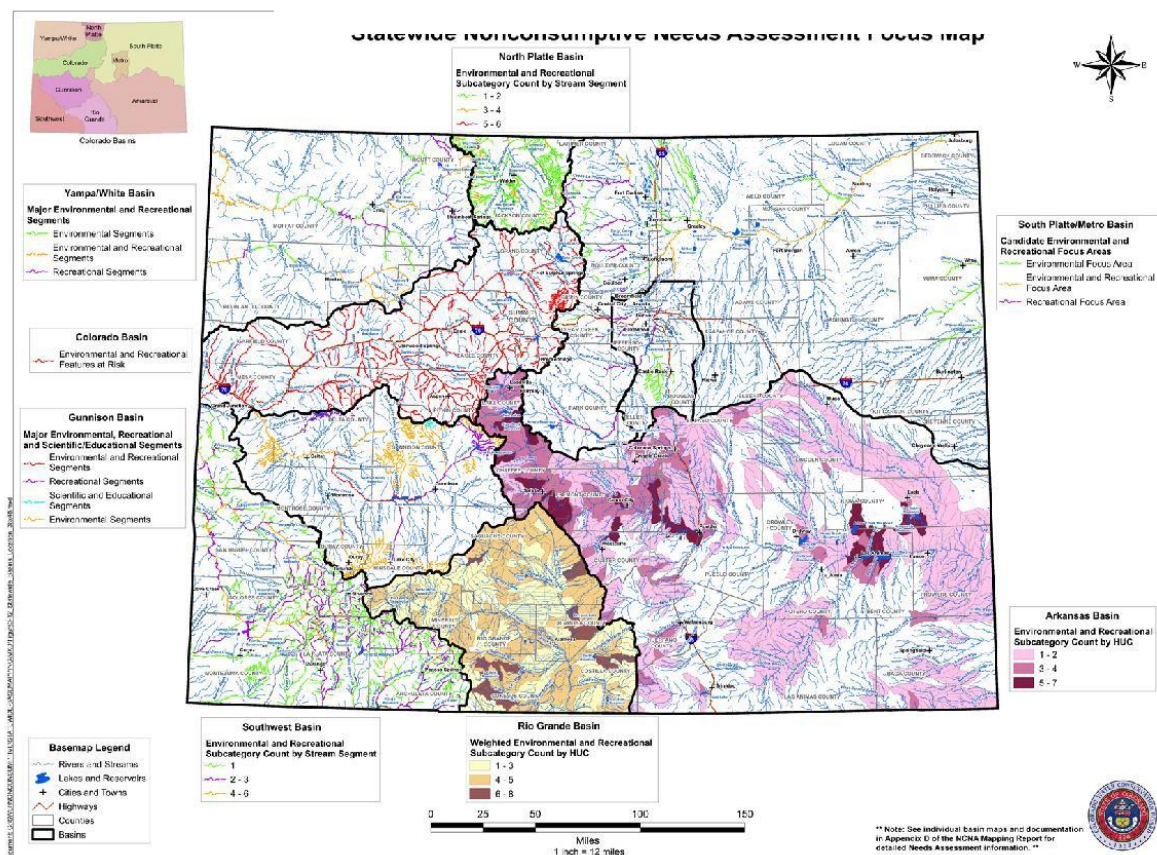
In response to the High Park Fire in 2012, CPW, along with other federal, state and county agencies, participated in the burn area emergency response effort to assess the impacts of the fire on the aquatic habitat and cold-water fisheries of the Poudre River (CPW, 2012).

CPW has also introduced response actions for wildlife and the terrestrial environment. Annual monitoring efforts provide information about overwinter survival, recruitment, population estimates, and pre- and post-hunt age and sex ratios for priority game species. In 2012 this monitoring effort was supplemented with aerial surveys to assess the pronghorn antelope, a species identified as being especially vulnerable to drought.

CPW implements herd management principles that account for drought and are ultimately flexible to changing weather conditions. For example, CPW made additional doe antelope licenses available in southeastern Colorado to help reduce the population to sustainable levels. CPW also participates in programs that aim to preserve and/or enhance habitat for a number of species (e.g., Wetland Wildlife Conservation Program, Colorado Wildlife Habitat Protection Program) (CPW, 2012) which may also assist in mitigating drought impacts.

The 2010 NCNA provides valuable identification information which is the necessary first step to future monitoring and impact tabulation. Figure 8.6 shows stream segments identified as critical for environmental and recreational reaches through each basin’s environmental and recreational analysis. It should be noted that the “critical” designation assigned in the NCNA process is a function of the environmental characteristics selected for analysis and does not denote drought vulnerability. Still, these results can be used to delegate limited resources by prioritizing areas for additional study and monitoring resources.

Figure 8.6 Statewide Non-Consumptive Needs Assessment Focus Map



Source: CWCB 2011 Revised for 2013 Update (no newer data available)

Instream flow rights owned by the CWCB are a drought mitigation strategy that is already in place. Instream flow rights are designed to maintain streamflows above critical levels even when water is scarce (refer to the State Assets section for a detailed discussion). A systematic analysis of the

impacts to instream flow protected reaches during the 2002 drought is not available; but it was noted by the CPW, after the 2002 drought, that maintaining existing stream habitat at a high level provides resilience against drought and sediment loads during and after wildfires. This includes maintaining the capacity for streams to pass increased peak flows and/or sediment loads (communication with DOW [now CPW], 2010). However, the instream flow program historically has been focused on maintaining streamflow rather than protecting habitat. Future studies of its effectiveness in protecting fish and other habitat would be beneficial to understand to what extent the instream flow program can be considered an adaptive capacity for drought-stressed areas.

Mitigation strategies are also in place for the spread of noxious weeds. As noted in the literature review, drought can increase the spread of weeds as native plants become stressed due to lack of water. Prevention seems to be the best adaptive capacity thus far for dealing with aggressive noxious weeds. A number of management techniques are used by the Colorado Department of Agriculture (CDA), United States Forest Service (USFS), United States Department of Agriculture (USDA) and other local government entities that focus on prevention, eradication and control of noxious weeds and other invasive plants. These programs also emphasize rehabilitation and restoration to help heal, minimize or reverse the harmful effects from invasive species (USFS, 2004). Rehabilitation actions are particularly important following wildfire to prevent the establishment of noxious weeds.

8.4 Measurement of Vulnerability

Considerations when addressing environmental vulnerability include:

- Criteria used to characterize the existing condition of the habitat or species
- Driving processes and exposure of a particular area
- Hydrologic regime and whether there is significant riparian presence
- How changes to the climate and precipitation patterns impact the region
- How stress is characterized

Before conducting a vulnerability assessment, the approach and vulnerability criteria need to be clearly defined. The existing lack of state-scale quantitative impact data is a limiting factor in this numerical vulnerability assessment. As such, the environmental sector is not divided into sub-sectors for analysis. The metrics described in Section 8.5.1 for the Environment regard the spatial density dataset (acres per county) and the actual impact datasets (stewardship status, impaired water streams/bodies, bark beetle extent, areas at threat for wildfire, instream flow rights, and riparian habitat). These vulnerability metrics were specifically chosen to reflect water-based ecosystems, impaired aquatic areas, and forest health hazard areas. The results are provided for each county in the State.

As future monitoring and impact assessment work is completed these metrics should be updated. The limitations of this approach and suggestions for future expansion are discussed in Section 8.6.

Refer to Section 3.1 of Chapter 3 (Annex B) for a general description of the numerical methodology.

8.5 Vulnerability Metrics

8.5.1 Environment

Spatial Density Metric

Acres per county

The spatial density metric for the environment is the total county area. This metric was chosen over protected or natural areas as a more accurate reflection of all natural and built environment areas (e.g., city parks) that can be at risk of drought. Future assessments will benefit from disaggregating based on wildlife, geography, and other defining factors and analyzing vulnerability for each subgroup individually.

Impact Metrics

The impact metrics chosen focus on protected area status, existing impaired waters (i.e., water quality), general forest health, and presence of riparian habitat. There are six vulnerability metrics, each weighted equally (16.67%) for the overall vulnerability score.

Southwest Regional GAP stewardship status

The Southwest Regional Gap Analysis Project (SWReGAP) began being conducted in 1998 (until about 2007) by the DOW (now CPW), University of Wyoming, and USGS Biological Resources Division and was a cooperative effort between DOW, the Natural Resource Ecology Center, and state, federal, and private natural resource groups in Colorado. Its major objectives were to: develop GIS databases to describe vegetation/land cover, terrestrial, vertebrate wildlife distributions, and land management status; identify land cover types and species that are not represented (or are perhaps under-represented) in long-term management areas; and facilitate development and use of the information to allow for effective stewardship of Colorado's natural resources. The information from this study is available online.³

The SWReGAP project determined “stewardship” statuses across the State. Stewardship status denotes a relative degree of management for biodiversity maintenance for a particular tract of land. It is a ranking of 1 through 4 of land ownership categories and their internal biodiversity management boundaries and policies. The status categories can be generally defined as:

³ <http://swregap.nmsu.edu/>

-
- Area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state;
 - Area like above, but which may receive use or management practices that degrade the quality of existing natural communities;
 - Area having permanent protection from conversion of natural land cover for the majority of the area, but subject to uses such as logging and/or mining; and
 - Area with no known public or private institutional mandates or legally recognized easements to prevent conversion of natural habitat types – generally allows conversion to unnatural land cover (Schrupp et al., 2000).

Status by county were tabulated to achieve an average ranking of 1 (least vulnerable) through 4 (most vulnerable) for the entire county.

Impaired streams and water bodies

These data were downloaded from the EPA's Reach Address Database (RAD) and are current as of May 2015. Impaired streams and water bodies were chosen as a metric based on the assumption that already-impaired water bodies are more apt to be negatively impacted by drought. The EPA's 303(d) Listed Impaired Waters program system provides impaired water data and impaired water features reflecting river segments, lakes, and estuaries designated under Section 303(d) of the Clean Water Act. Each state establishes "total maximum daily loads" (TMDLs) for these waters. The "impaired waters" layer does not represent all impaired waters reported in a state's Integrated Report, but only the waters comprised of a state's approved 303(d) list. Future analyses could expand the impaired water layer to include other state-recognized impaired waters. Some counties have no impaired waters. A large number of counties had no impaired streams or water bodies, making the typical percentile thresholds invalid. Therefore, thresholds were adjusted to create equal bins for the non-zero data set.

Bark beetle aerial extent

Bark beetle infestation is having a profound effect on the health of Colorado's forests. The Colorado State Forest Service (CSFS) and Colorado Parks and Wildlife have been forced to close campgrounds in the past, in order to clear beetle-damaged trees in danger of falling, and spray high-value trees in an attempt to protect them (Finley, 2010). As of the publication of the 2017 CSFS report on the health of State forests, over 200,000 acres of high elevation spruce trees were infested with spruce bark beetle (the most widespread and damaging pest in Colorado forests for the sixth year in a row). While there are efforts aimed at eliminating this bark beetle across Colorado, bark beetle continues to spread at an estimated 600,000 acres a year. Regional and national work to battle the beetle includes, among others, the use of pheromone treatments to repel attacks, and the implementation of the Western Bark Beetle Strategy in 2011 by the U.S. Forest Service, to identify response endeavors to combat bark beetles (by specifically addressing dead and down trees that pose hazards while providing for human safety).

Data for the extent of beetle infestation is available from the USDA Forest Service’s National Insect and Disease Risk Map portal. The latest published dataset contains beetle pest projections spanning from 2012 to 2027 (of basal area losses from forest pests and pathogens). The database was specifically queried for areas of all beetle infestation for the entire period of record/future projection (2012-2027). The percentage of total acres in a county that currently suffer (or are estimated to suffer) losses in basal area were used. A large number of counties had no beetle infestation, making the typical percentile thresholds invalid. Therefore, thresholds were adjusted to create equal bins for the non-zero data set.

Wildfire Threat Area

Wildfire threat data⁴ developed by the Colorado State Forest Service in 2010 was used to rank counties’ threat of wildfire. Threats were divided into six main categories: very low, low, moderate, high, very high, and none. To isolate the at-risk areas, moderate to very high zones were first extracted to give a ranking by county. The ranking method is useful provided that some counties did not have any significant wildfire threat acreage, so that a kind of normalization can be introduced. While this dataset is not the most current, wildfire threat analysis should still be applicable today, given there have not been any large scale, state-wide deforestation or natural environment modification projects (e.g., landscapes with high likelihood of wildfire risk).

Instream flow rights

The number and average priority date of instream flow rights per county was calculated using the primary county designation from the latest (October 2017) CWCB instream flow database. Reaches covering more than one county were assigned to their primary county designation with a spatial clipping mechanism. Nearly one third of counties have zero instream flow rights. Therefore, thresholds were adjusted to create equal bins for the non-zero data set. Instream flow rights historically have not been focused on protecting habitat; rather they ensure a minimum flow in a given stream. As such, future studies could be performed to assess the effectiveness of instream flows at protecting species and habitat that would otherwise be at risk. However, because instream flows often result in water being retained in a stream that may otherwise have been diverted, this metric is considered an adaptive capacity and is treated as such in the Vulnerability Assessment Tool.

Riparian habitat

Riparian habitat areas were obtained from the latest (as of January 2018) U.S. Fish and Wildlife Seamless Wetlands Dataset, part of the National Wetlands Inventory (which, in addition to riparian areas, contain historical wetlands, watershed boundaries, and other related information, by state). The riparian acreage was converted to square kilometers and summarized by county, to maintain consistency with the other metrics in this assessment. The counties with the highest riparian areas

⁴ <https://www.coloradowildfirerisk.com>

were considered most vulnerable, given their likelihood of containing more species and overall sensitive habitats, while counties with the fewest riparian habitat areas were considered least vulnerable to drought.

8.5.2 Results

The results of the numerical vulnerability assessment are presented here. The existing metrics used in the vulnerability tool are general indicators of environmental conditions and speak to broad areas that would potentially be impacted by drought. Vulnerability scores by county are presented in Table 8.3 and in Figure 8.7, and described in more detail below.

Table 8.3 Vulnerability Rankings

Counties	Overall Vulnerability Ranking
Costilla, San Juan	0.1 - 1
Pitkin, Yuma, Mineral, Alamosa, Phillips, Clear Creek, Jackson, Lake, Sedgwick, Gilpin, Hinsdale, Custer, Ouray, Teller, Dolores, Broomfield, Cheyenne, Conejos, Prowers, Summit, Gunnison, Montezuma, Baca, Elbert, Kit Carson, Rio Grande, Arapahoe, Archuleta, Bent	1 - 1.9
Denver, Kiowa, Lincoln, Chaffee, Douglas, La Plata, San Miguel, Boulder, Eagle, Huerfano, Saguache, Crowley, Otero, Park, Montrose, Jefferson, Rio Blanco, Routt, Morgan, Pueblo, Grand, Adams, Washington, Delta, El Paso, Fremont, Moffat, Logan, Las Animas, Garfield, Mesa	2 - 2.9
Larimer, Weld	3 - 4

Counties scoring between 0.1 and 1.9 (low) in overall vulnerability:

Many counties (30 total) fit this category. In general, a ranking of around 1 implies that a county has a mix of attributes that overall do not add up to high vulnerability. For example, there could be protected lands, the county has few impaired waters, there are instream flow rights, or other such aspects. The nature of the environmental analysis is that each metric is weighted equally (so that the six categories impact the overall score at about 16.67% each), so unless most or all of the metrics indicate high vulnerability (from a high impact score), the overall result will be rather low. Costilla and San Juan Counties ranked less than 1, indicating a net adaptive capacity and hence almost no vulnerability risk. In this 2018 update to the vulnerability study there are a few counties which gained adaptive capacity and/or reduced their vulnerability, so that their scores have decreased since the 2013 study, lowering from a 2 or above to below 2 ranks. The results of this 2018 vulnerability assessment update are displayed in Figure 8.7, and can be compared against the final ranks/results from the 2013 assessment portrayed in Figure 8.8 (although it should be noted that, in the 2013 map, the ranks were categorized different and as such the colors and results may vary slightly). These vulnerability changes involved 20% or more of a decrease. The counties are: Baca, Conejos, Elbert, Kit Carson, and Montezuma. These results are partially attributed to newly available data that updated certain categories. For example, instream flow rights results were very up-to-date when collecting data in late 2017, as were the impaired waters datasets. However, the

SWReGAP results remained the same as in the 2013 analysis, given no new studies or updates of that kind have been performed for Colorado since the original. The reduction in the number of impaired waters per county, and availability of updated details on instream flow rights are other key elements in the ultimate reduction in overall vulnerability scores as of the making of this 2018 Plan Update.

Counties scoring between 2 and 2.9 (moderate) in overall vulnerability:

The majority of counties (31 total) fell in this range of scores. These include some of the highest populated counties in the state, including Denver, El Paso, Adams, Jefferson, and Douglas. When comparing the 2018 results with the 2013 analysis, two counties in particular (Chaffee and Denver) have increased in vulnerability by a factor of 20% or more, making it into this category when before they had ranks of 1.9 or below. These results are due to a decrease in their adaptive capacity and/or environmental impacts, such as an increase in the amount of impaired waters present. As in the discussion above, the new scores are partially attributed to the availability of new data as well as general data revisions for some metrics. To achieve a vulnerability score of 2 or higher, a county must rank moderate to high in several of the impact categories. For example, Chaffee, which previously had a rank of 1.7, moved into this higher vulnerability category in part because the amount of impaired water went up since 2013, making the vulnerability slightly higher. Counties such as Crowley, Otero, and Morgan have remained in the same vulnerability category they previously had because of the lack of changes in their environmental metrics.

Counties scoring between 3 and 4 (high) in overall vulnerability:

Only two counties fit in this ranking category: Larimer and Weld. They remain with the same vulnerability scores they received in the 2013 version of this assessment, at 3.3 and 3.5, respectively. This is due to a lack of change in their related environmental metrics. Overall, they are found to be highly vulnerable because of their high amounts of impaired waters (both streams and lakes), as well as medium to high rankings in the wildfire index calculation. Furthermore, they both contain large areas of riparian habitat, making them more likely susceptible to negative impacts during drought events, and/or less able to adapt.

Figure 8.7 Overall Environmental Vulnerability Ranking

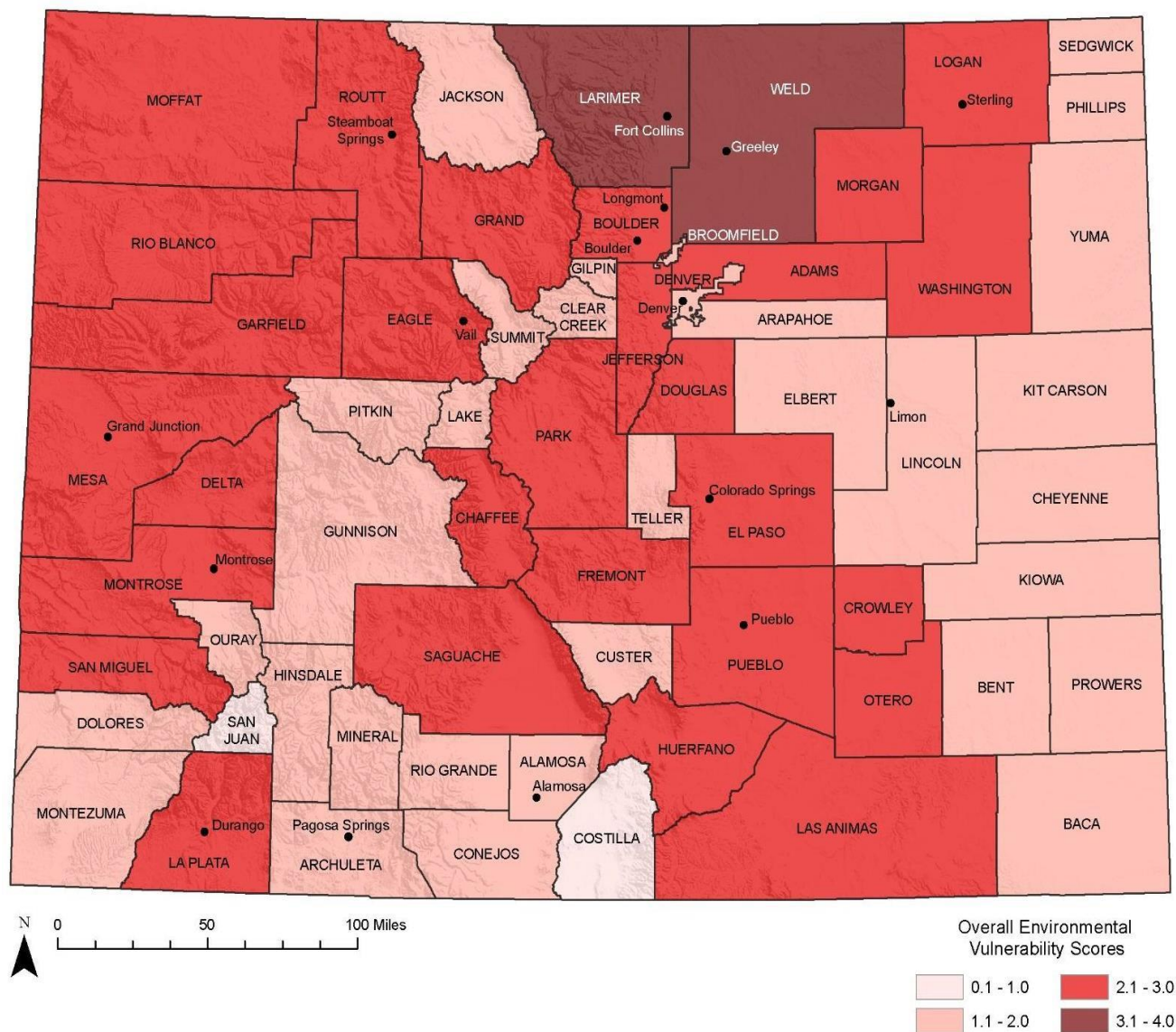
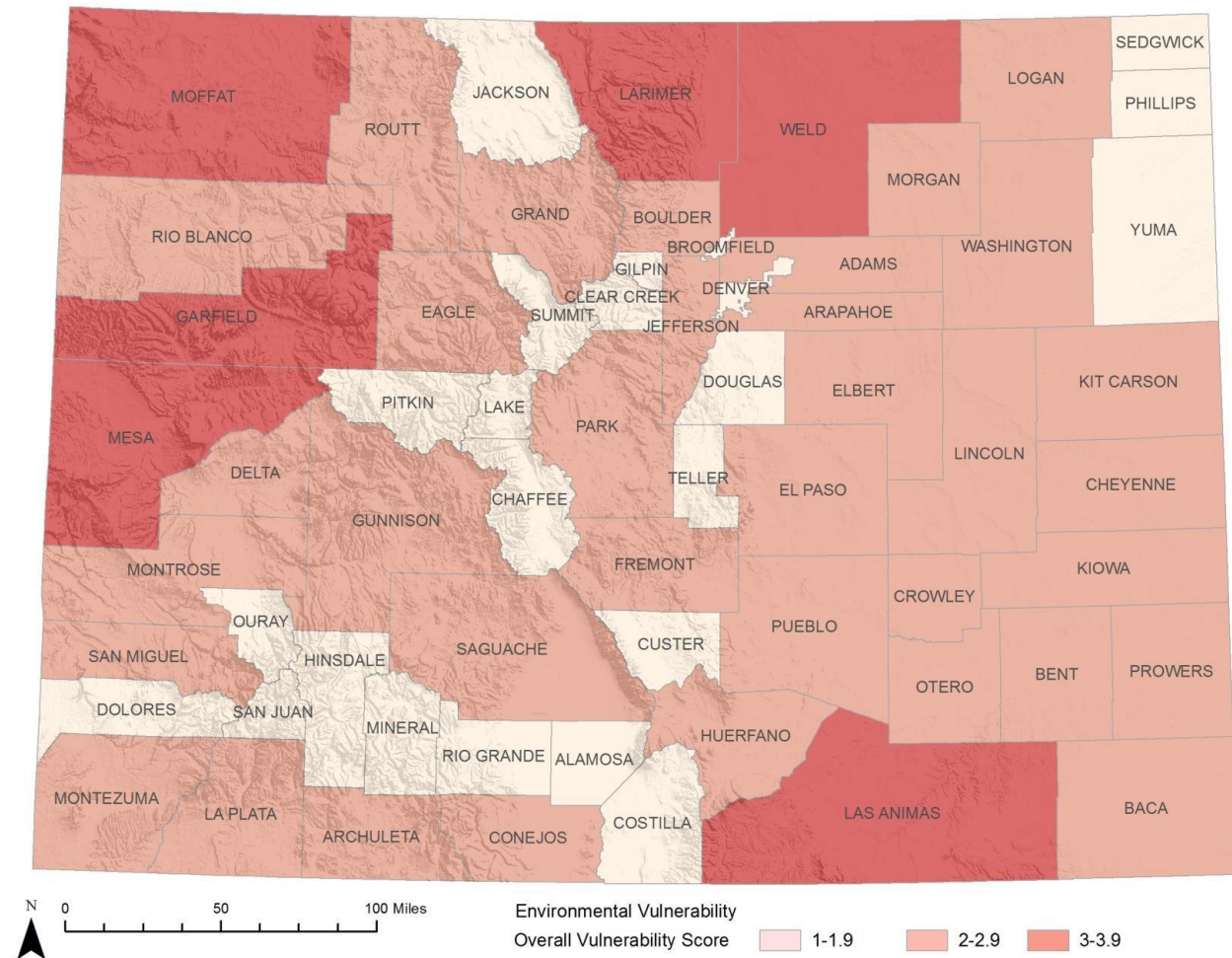


Figure 8.8 Environmental Vulnerability Ranking from 2013 Plan (for comparison)



8.5.3 Spatial Analysis

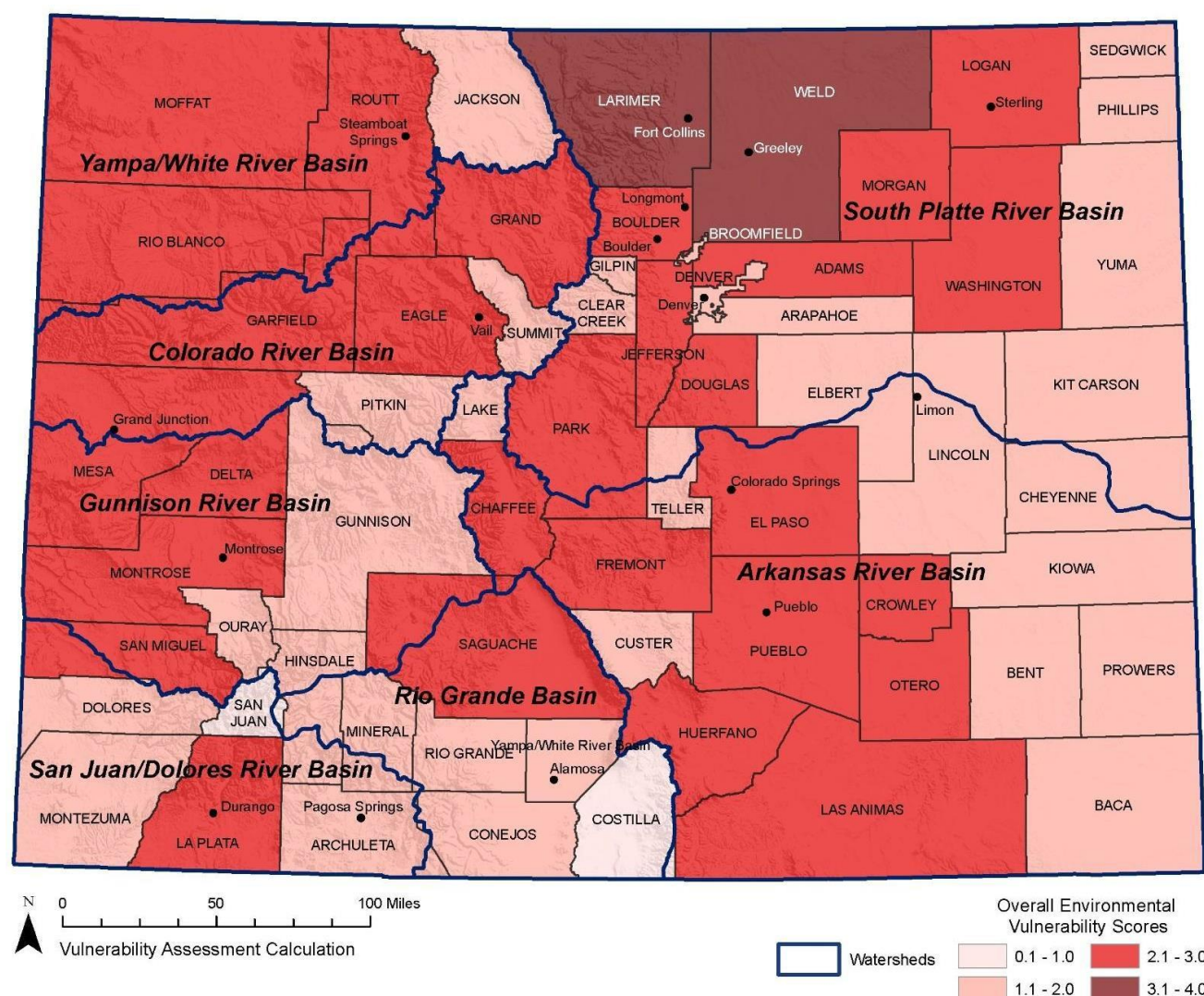
Spatially, it is difficult to identify specific trends in the vulnerability results, given the broad nature of the vulnerability metrics used and the fact that using counties can be too general (e.g., possibly a bit of an ecological fallacy case). Nevertheless, there are bands of lower vulnerability present in and immediately north of the San Luis Valley and in some eastern portions of the State. Most of the State falls into the category that ranks around 2, as seen in Figure 8.7. One interesting result of this analysis is that, unlike some of the other sectors, there are concentrations of lowest and highest vulnerability counties spread all about the State, with some lower vulnerability counties appearing in the northeast, southeast, the Rio Grande basin, and the south-center regions. In keeping with the vulnerability methodology of this project, all assessments were done on a county basis. However, in the case of environmental studies, political boundaries are probably less relevant than physical/natural ones. Future work could investigate the same type of analysis but aggregated on a basin or other natural region scale. While overlaying the basins on the results map (Figure 8.9) does not reveal a clear trend, recalculating the metrics using a watershed framework could alter the

vulnerability of the landscapes, revealing spatial trends hidden by the county framework.

The sensitivity of this analysis is also contained in the weighting given to the different vulnerability metrics. Without quantitative impact data throughout all the assessments it was determined that there was little basis for weighting some impact metrics more than others. As such, each factor was weighted equally to arrive at a combined vulnerability score. This approach has limitations in that most of the results show low to moderate vulnerability, and there is little distinction between aquatic factors like stream lengths, and land-based or even species-related vulnerability factors like bark beetle infestation. A suggestion for future analysis is to sub-divide the environment into aquatic and land-based flora and fauna and conduct a more detailed vulnerability analysis with metrics specific to the sub-sectors.

Additionally, further thought should be given to how the wildfire threat and beetle infestation layers are used. The wildfire threat layer is based on 2008 survey data and cannot include climatic or even or regionalized weather information, important variables controlling the ignition, spread, and behavior of wildfires (such as in Wildland-Urban Interface regions). The beetle infestation data contains the spatial extent of all the past six years of survey data available (2012-2017) in addition to projected estimations of spread (2018-2027), given no external variables are introduced to limit infestation rates (such as hormone spraying to prevent beetle reproduction). As such, it may or may not be appropriate to treat all years equally in the vulnerability calculation (e.g., without re-assessing adaptability after an area has been infested and perhaps cleared out of the pest completely), or include the projection estimates without more research about how future projections can alter the results.

Figure 8.9 Environmental Results with Watershed Divisions



8.5.4 Compound Impacts

Compound impacts occur when direct drought impacts cause additional effects themselves. The previous section presented the drought vulnerability ranking of the Environmental Sector as determined by the vulnerability tool. The condition of the environment extends to every aspect of the State, however, and impacts to this sector can compound across other sectors and/or state assets to magnify overall vulnerability. Climate change is an example of a process which can, throughout many industries and facets of Colorado life, contribute to compounding the Environmental sector impacts (by causing longer, warmer, and dry seasons for example).

Damage to the environment has broad impacts to the Recreation and Tourism Sector, which in turn affects regional economies by reducing visitation or substantially increasing costs for visitors. Indirectly, services such as hotels, restaurants, grocery stores, gasoline stations, and retail are also impacted. Socially, this can result in loss of jobs, localized recessions in recreation and tourism-

dependent counties, and overall hardship and economic depression. For other sectors in competition with the environment for water, drought can cause increased conflicts and other social tensions. A specific example is competition between the Agriculture Sector for irrigation water, the Recreation Sector for recreational use water, and the Environmental Sector for instream flows.

The operations of state assets, like Colorado Parks and Wildlife, are reliant on environmental conditions. If a drought causes degradation of the environment and loss of wildlife or native habitat, visitation to the parks and open areas may decline (as maintenance of amenities, entry charges, support to wildlife, and other factors may increase so substantially in cost that visiting recreation sites becomes unaffordable for many). State revenue can suffer if significant visitation and licensing decreases occur. Also during a drought, state agencies may need to increase their management effort and even park entry costs. Management efforts include introducing wildlife feeding programs or enhancing reservoir maintenance, all of which is related to lower water levels. These efforts require funding, which could be lower than average during a drought, further stressing the State's various departments.

8.6 Recommendations

8.6.1 Adaptation to Drought

One effective way to safeguard the natural environment from drought impacts is to maintain a high level of environmental integrity, so that when a drought occurs, areas are better able to withstand it. This applies to forest health, water quality, and wildlife. For example, CPW notes that streams designated as “gold medal” fisheries are expected to be less vulnerable to drought because of their strong ecological condition.

Other adaptive capacities include increased management on the part of state agencies (such as CPW) to identify areas that are experiencing environmental stress, followed by efforts to rehabilitate them in a timely manner. CPW and federal agencies did some of this in 2002 and during the 2011-2013 drought event.

CPW noted that threatened and endangered species were not severely impacted during the 2002 drought because so much attention was put on them from state and federal agencies. Where possible, stream levels were maintained for those endangered aquatic species, all in an attempt to help them survive the drought. Additionally, residual stock of these species is maintained in CPW hatcheries. Similar efforts could be expanded to other areas of the natural environment.

The first step to the adaptation process would be to identify areas already under stress that would benefit from increased state attention during future droughts. To accomplish this, a collaborative effort is recommended to identify these areas of environmental concern. The NCNA provides a good starting point for these efforts, as do metrics and assessments like those presented in this document. However, further work is needed to evaluate NCNA findings on a county basis across the State, and to incorporate drought specific information.

In the State Assets and Socioeconomic Sectors, it was noted that state agencies often incur additional costs during drought due to heightened management requirements. The resources required to achieve a collaborative drought analysis would require spending by the State, but the preparation efforts, especially if they result in increased awareness of existing support systems and linkages between agencies, could result in lower operating and management costs during times of drought.

8.6.2 Improving Vulnerability Assessments

It is difficult to put a dollar value on the natural environment, and possibly that is the reason environmental impacts from drought events have not been thoroughly quantified, except as related to man-made elements (for example, environmental costs that force a reaction, like sediment and ash in the water supply, forcing municipalities to clean a reservoir, or similarly degraded water quality in prime fishing streams, forcing management agencies to salvage the fish for future anglers). The approach of this document's assessment has been to use readily-available data to identify attributes of the environment that would indicate vulnerability to drought. Current datasets were used where applicable and when available in a useful format. While the need for additional monitoring and impact measurement is great, previous studies should not be overlooked. There is a significant amount of data available for Colorado that may be valuable given additional analysis, particularly with respect to drought and general climate change.

As of 2018, additional vulnerability indices are being developed by other organizations that may also be utilized in future analysis. For example, the Climate Change Vulnerability Index developed by NatureServe⁵ (with its latest update from 2015) is designed to identify plant and animal species that are particularly vulnerable to the effects of climate change. Since part of the tool involves a “climate wizard” that allows the user to specify the climate setting, the Climate Change Vulnerability Index tool could likely be adapted to drought-specific scenarios. Part of the NatureServe vulnerability study includes a rating of species with multi-factor criteria (e.g., dispersal methods, reproductive patterns, distribution and habitat, natural history factors, exposure), intended to help forecast whether a species will likely suffer a range contraction, population reductions, or from other negative impacts given climate change scenarios. This could also aid in identifying habitats more vulnerable to drought.

Because there are a number of ongoing studies to classify ecosystems and assess their vulnerability to various climatic stressors, stronger collaborative efforts to assess vulnerability of the natural environment to drought are recommended. This could include the CWCB, CPW, and any number of environmental groups such as The Nature Conservancy, NatureServe, and the Colorado Natural Heritage Program working together, or in sync to achieve common goals in studying droughts and related susceptibilities. An in-depth look at species vulnerability and habitat loss due to drought would provide a better statewide picture of vulnerable environmental species and habitats. The

⁵ Available at <http://www.natureserve.org/conservation-tools/climate-change-vulnerability-index>

“Species of Greatest Conservation Need” was identified by the CPW in their 2015 Colorado State Wildlife Action Plan, or SWAP (updated from the 2006 version) and is a good start to this effort. The report identifies over 960 native species and 20 major habitats and incorporates SWReGAP Analysis data for Colorado to map species extent and land use. These data could be used to begin an analysis of drought vulnerability. Another study recently conducted by NatureServe and The Nature Conservancy included a detailed look at habitat and vegetation as it is impacted by climate change in specific portions of southwestern states (Utah, Colorado, New Mexico, and Arizona). Findings and data from that research could be incorporated into a drought vulnerability assessment, given the interconnect in the matters. However, this analysis does not cover the entirety of each southwestern state. The basin-specific environmental subcategories identified by stream segment in the 2010 NCNA would also provide a geographic backdrop to any future vulnerability study.

Potential partners or stakeholders in environmental research were identified back in the 2006 Colorado Comprehensive Wildlife Conservation Strategy and Wildlife Action Plans (Colorado DOW [now CPW], 2006). Table 8.4, taken from that 2006 report, lists these organizations and the taxonomic group in which they would likely be interested, as they should still be relevant to this day.

Table 8.4 Potential Partners for Environmental Research

Potential Partners						
Organization or Type of Organization	Taxonomic Group(s)					
	All Taxonomic Groups	Invertebrates	Fish and Mollusks	Reptiles and Amphibians	Birds	Mammals
Federal Agencies						
USDA Forest Service	x					
Bureau of Land Management	x					
U.S. Fish and Wildlife Service	x					
National Park Service	x					
U.S. Geological Survey	x					
Natural Resources Conservation Service/Farm Service Agency	x					
Bureau of Indian Affairs	x					
Bureau of Reclamation	x					
U.S. Corps of Engineers	x					

Potential Partners						
Organization or Type of Organization	Taxonomic Group(s)					
	All Taxonomic Groups	Invertebrates	Fish and Mollusks	Reptiles and Amphibians	Birds	Mammals
Federal Emergency Management Agency	x					
Tribes	x					
State Agencies						
Colorado Division of Wildlife	x					
State Forest Service	x					
State Universities	x					
Department of Natural Resources	x					
Department of Agriculture	x					
Department of Transportation	x					
Department of Health and Environment	x					
CWQCC	x					
Colorado Natural Heritage Program	x					
Colorado State University Extension Offices	x					
Division of Parks and Outdoor Recreation	x					
Division of Water Resources	x					
Oil and Gas Commission	x					
Division of Minerals and Geology	x					
Water Conservation Board	x					
Great Outdoors Colorado	x					
Local Government						
Cities	X					
Counties	X					
Water Conservancy Districts	X					
State Agriculture and Ranching Associations (e.g., Colorado Cattlemen's Association, Farm Bureau, Colorado	X					

Potential Partners						
Organization or Type of Organization	Taxonomic Group(s)					
	All Taxonomic Groups	Invertebrates	Fish and Mollusks	Reptiles and Amphibians	Birds	Mammals
Wool Growers Association)						
Nongovernmental Organizations						
Rocky Mountain Bird Observatory					X	
Audubon (e.g., important bird area programs)					X	
The Nature Conservancy	X					
Colorado Natural Heritage Program	X					
Local land trusts	X					
Ducks Unlimited, Quail Unlimited, Pheasants Forever, Trout Unlimited, sport groups, etc.			x		X	x
Joint ventures (e.g., Playa Lakes)					X	
Bird Conservation initiative					X	
Partners in Amphibian and Reptile Conservation				x		
Colorado Weed Management Association	X					
Colorado Association of Conservation Districts	X					
Environmental Defense	X					
Southern Rockies Ecosystem Project	X					
Museums	X					
Zoos	X					
Biological professional societies (e.g., Colorado Herpetological Society, American Fisheries Society, The Wildlife Society)	X					

Potential Partners						
Organization or Type of Organization	Taxonomic Group(s)					
	All Taxonomic Groups	Invertebrates	Fish and Mollusks	Reptiles and Amphibians	Birds	Mammals
Private sector (e.g., land owners, pet shops, nurseries)	X					
Watershed groups and other local environmental groups	X					

Recruiting some of these stakeholders for future drought vulnerability assessments would have significant benefits. Management agencies could bring their knowledge of wildlife areas, and economic impacts to hunting, fishing, and camping revenue. These state and federal agencies are often on the forefront of environmental response, so involving them in this process could inform everyone about the resources available between agencies. Bringing expert biologists and ecologists into the process could enhance the quantitative assessment with specific details about different species and habitat. Together, government agencies, environmental groups, and local user groups would have the connections and expertise necessary to identify environmentally vulnerable areas of the State.

CPW has been engaged with the Colorado State University (CSU) to evaluate, among other things, the vulnerability of existing fish populations including cutthroat trout, mountain whitefish, sculpins, and wild spawning fish such as rainbow, brown, and brook trout. In-depth studies such as those arising from the collaborations between the two parties would benefit other subsectors of the environment.

Finally, the NCNA (CWCB, 2011) provides a detailed inventory of environmental water uses within each basin. This report contains valuable aggregated information on aquatic areas of environmental importance. As previously noted, this NCNA report can be used to guide future monitoring and impact assessment efforts. Also, given a revised spatial aggregation, these results could serve as the aquatic inventory metric in future disaggregated vulnerability assessments.

As additional data becomes available, it is recommended that environmental vulnerability be divided into assessment sub-sectors and further analyzed. One simple division would be to consider aquatic and terrestrial habitats separately. The type of division will vary depending on the additional data to be incorporated and could eventually become quite complex.

9 MUNICIPAL & INDUSTRIAL SECTOR

Key Findings

- Although M&I water use comprises less than 10 percent of Colorado’s overall water use (CWCB, 2015), it is vital to sustaining the urban economy (CWCB, 2004).
- An M&I provider’s vulnerability to drought depends on the reliability of a provider’s water supply system and their ability to effectively respond to drought.
- Through the process of developing Basin Implementation Plans (BIPs), each of the nine basin roundtables had an opportunity to address projected future shortages in water supply and propose methods to address the shortage. These “Identified Projects and Processes” (IPPs) may also directly or indirectly reduce drought vulnerability.
- Population growth stresses available supplies, as noted by the 2015 Colorado Water Plan (CWCB, 2015). This trend will continue in the future and is likely to exacerbate drought impacts.
- There are many complex factors, including water supply, water distribution, water demand, and adaptive capacity, that influence the overall reliability of individual M&I water supply systems and their ability to respond to a drought. Each of these factors are unique to individual M&I providers, and consequently water providers are affected in many different ways and magnitudes during a drought.
- A thorough statewide evaluation of M&I drought vulnerability would require a means to account for and incorporate the uniqueness of each M&I provider. Such an intensive effort is beyond the scope of this study. For the 2018 update, a qualitative assessment of M&I vulnerability at regional basin-wide level was deemed to be appropriate.
- CWCB has been actively engaged in several processes to enhance the ability to further assess M&I drought vulnerability in the future. This includes the development of a Municipal Drought Management Plan Guidance Document that informs M&I providers on how they may evaluate drought vulnerability and incorporate this information into their drought plans (CWCB, 2010), a Municipal Water Efficiency Plan Guidance Document that serves as a reference tool for water providers developing State-approved local water efficiency plans (CWCB, 2012); and collaboration on the Colorado Drought Response Portal (coh2o.co), a website of resources and information for citizens throughout the state.

Key Recommendations

- Continue to facilitate planning on a regional, collaborative level, as done in the BIPs and the Colorado Water Plan.
- Continue to provide technical and financial assistance to M&I providers for drought and climate change planning efforts as incentives for local planning and preparedness
- Ensure dissemination of CWCB technical information into drought, climate change, and water supply reliability studies (i.e. Colorado River Water Availability Study and the Joint Front Range Climate Change Vulnerability Study)

-
- Develop a means to characterize water supply reliability at a more local level (i.e. by water supplier) in future M&I drought vulnerability studies.
 - Continue to collaborate with the National Drought Mitigation Center (NDMC) in recording local impacts within the State by using NDMC's Drought Impact Reporter

9.1 Introduction to Sector

Although Municipal and Industrial (M&I) water use comprises less than 10% of Colorado's overall water use (CWCB, 2015), it is vital to sustaining the urban economy.¹ M&I water is used to meet domestic and residential needs, commercial uses including retail and professional services, institutional needs (i.e., schools and hospitals), and other industrial needs. Individual M&I providers are generally responsible for supplying their particular service area. The source of water supplies, reliability, and particular demands of a provider's customer base is unique to each individual provider.

In 2016, Colorado's population was approximately 5.54 million² with the majority of people living along the Front Range in the Arkansas and South Platte Basins between Fort Collins and Pueblo. This is shown in Figure 9.1. In the five years from 2012 to 2016, the state population increased by 6.7 percent and is projected to grow to 6.8 million people in 2030. The northern Front Range is the fastest growing region in the state with an average annual increase of 2.4 percent, compared to 1.5 percent state-wide.

¹ CWCB. 2004. *Statewide Water Supply Initiative (SWSI)*. Prepared by: CDM.

² The population estimates provided in this section are based on the 2016 population data provided by the Colorado Department of Local Affairs.

Figure 9.1 2016 County Population Estimates

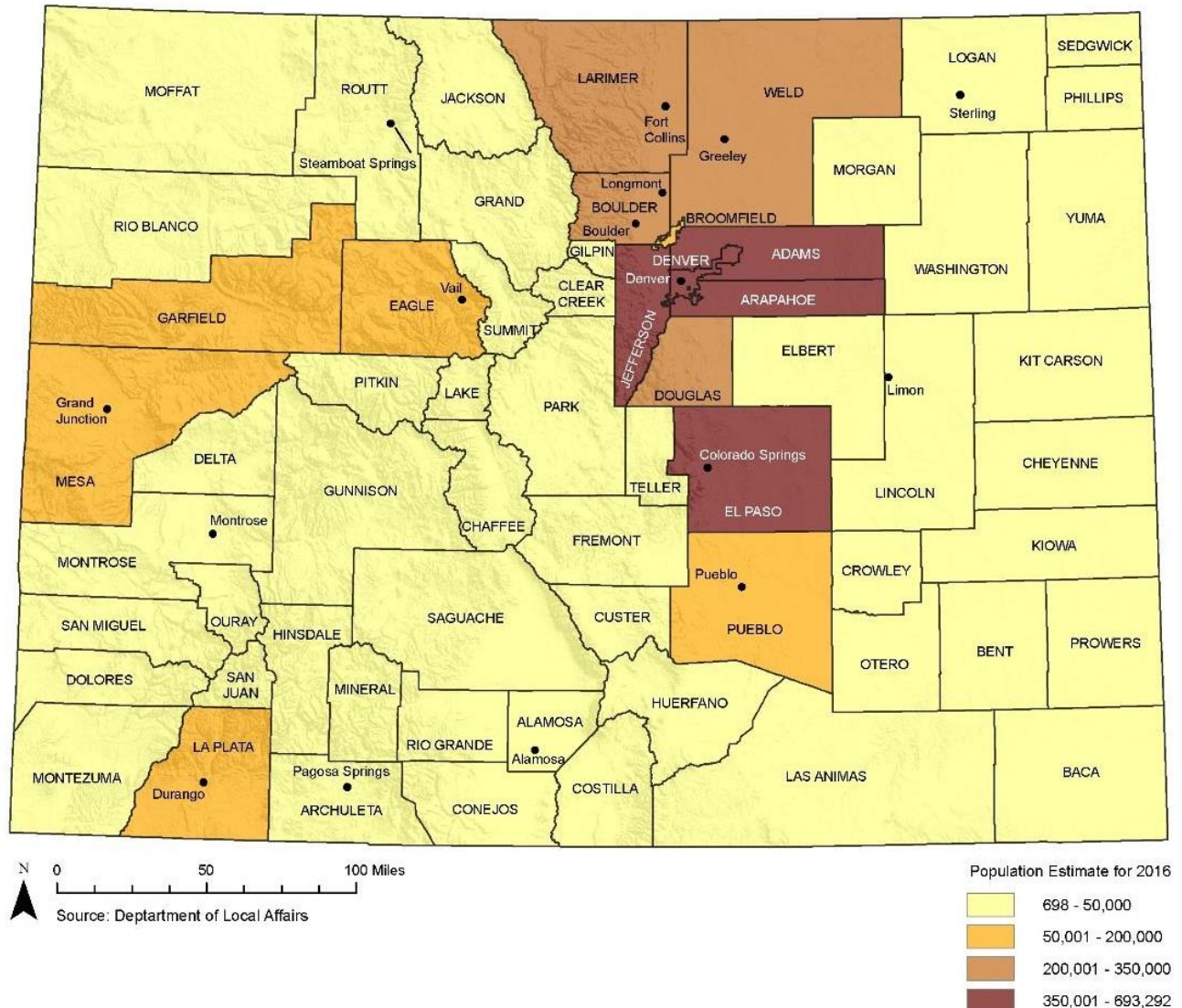
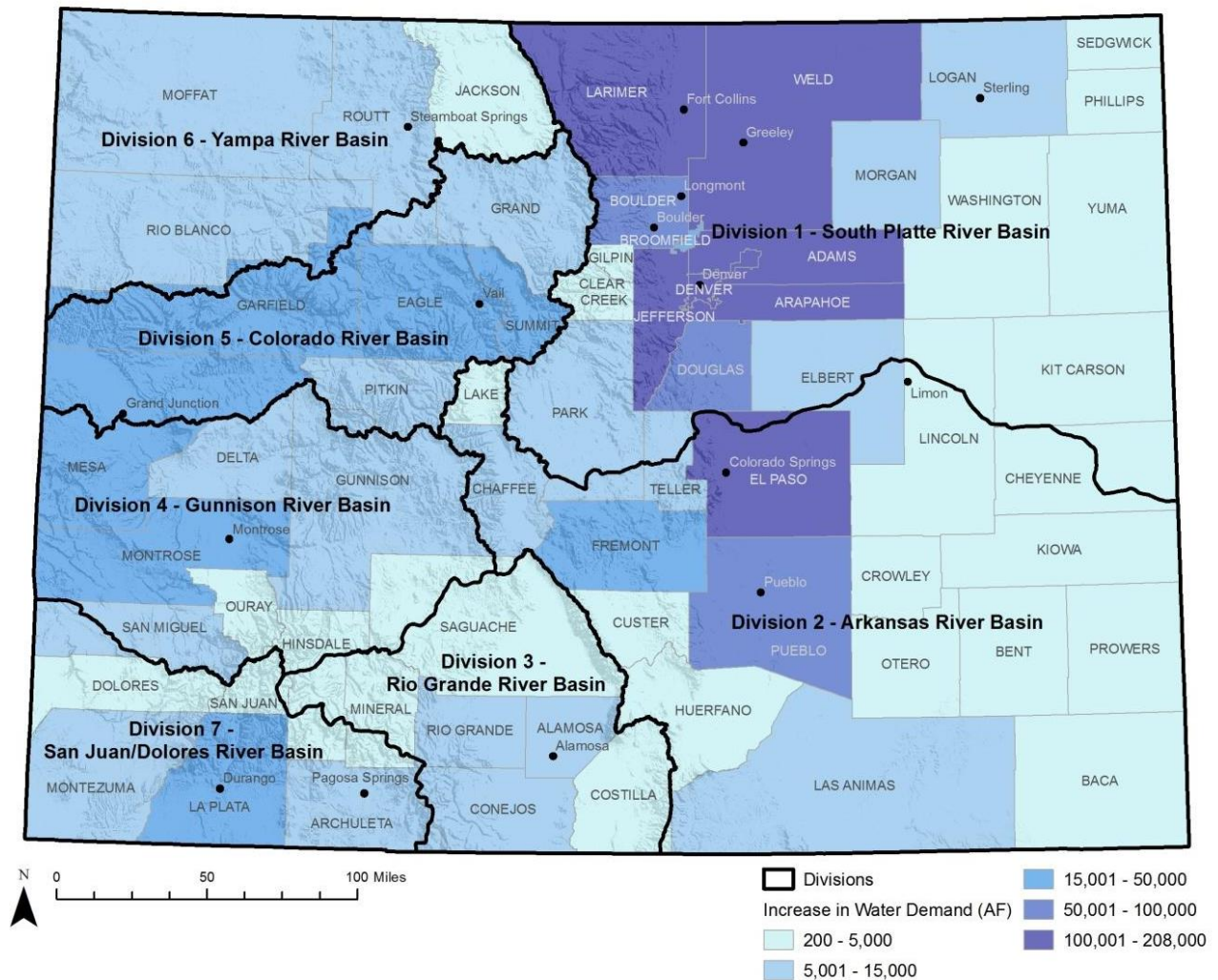


Figure revised for 2018 update.

Looking ahead to 2050, the future population within Colorado is difficult to accurately predict. For that reason, the State developed low, medium, and high population estimates that were used in the 2015 Colorado Water Plan (CWCB, 2015). In the high growth scenario, the State's population is could double by 2050 to over 10.0 million people; in the low growth scenario, the State's population would increase to approximately 8.6 million people (CWCB, 2015). Consequently, M&I water demands are projected to increase from 970,000 acre-feet in 2008 to between approximately 1.5 million acre-feet (low estimate) and 1.9 million acre-feet (high estimate) by 2050. Figure 9.2 shows that the majority of projected M&I water use in 2050 is likely

to occur in the South Platte, Arkansas, and Colorado River Basins³. This growth will place a greater demand on the State's limited water resources, especially during periods of drought.

Figure 9.2 Projected County Water Demands in 2050



Source: CWCB 2010, no change for 2018 update.

The vulnerability of the M&I sector to drought is an important consideration for water managers and planners. Given the complex nature of water rights portfolios held by many M&I providers, the costs associated with completing a comprehensive statewide analysis, and a lack of available data, it was determined that a high-level quantitative analysis of the M&I sector would not be feasible. Consequently, a series of surveys conducted in 2004, 2007 and 2013 (latest available), as well as basin-specific information from the Colorado Water Plan (CWCB, 2015) and the Basin

³ The data presented in Figure 9.2 is based on the Baseline M&I forecast for the medium 2050 growth scenario presented in *Final State of Colorado 2050 Municipal and Industrial Water Use Projections*.

Implementation Plans, were used to characterize impacts and adaptive capacities and qualitatively assess drought vulnerability.

9.2 Vulnerability of M&I Sector to Drought

M&I water demands in Colorado vary significantly throughout the year, therefore vulnerability to drought has a seasonal component. A significant portion of residential water use is for outdoor purposes, typically occurring during the summer months (June through mid-September).

Many M&I providers in Colorado rely on mountain runoff from snowpack during the spring to meet water demands. Consequently, M&I providers frequently monitor snowpack conditions from January through April for drought forecasting purposes, as this is when the mountain areas receive the greatest amount of snow. Reservoir levels and other drought indicator data are also monitored closely throughout the year in order to determine water supply conditions, and to help assess whether any level of drought response is necessary. Drought response may be more intensive during consecutive drought years as these can stress water supplies by decreasing providers' water storage.

9.3 Assessment of Impacts and Adaptive Capacities

This assessment relies on a variety of surveys and reports conducted and/or facilitated by the CWCB, as specified in Section 9.1. The earliest survey (DWSA, 2004) involved a comprehensive survey to evaluate the State's drought preparedness and identification of measures that could improve the State's future preparedness. A total of 241 municipalities responded to this survey providing information on impacts experienced during the 1999-2003 dry period.⁴ The follow-up survey in 2007 (DWSU, 2007) involved a comprehensive M&I provider survey of 200 municipalities. The 2007 survey focused on general information regarding municipal providers' water resources planning efforts (adaptive capacities) and drought awareness at a basin-wide level, rather than specific drought-related impacts as was the focus of DWSA, 2004. The latest survey occurred as a component of the 2013 State Mitigation Plan update, in which CWCB conducted an additional municipal drought survey in May of 2013 to characterize statewide M&I impacts, adaptive capacities, and vulnerability for the recent droughts that occurred in the early 2000s and in 2012/2013. Eighty-six survey responses were received statewide.⁵ Table 9.1 shows the number of 2013 survey responses for each of the seven major river basins of the State. This survey was not

⁴ The DWSA 2004 survey was developed with significant input, design, communiqués, rewrites, internal testing, before the instrument was finalized with the approval of the CWCB, GEO, and DOLA. Despite this comprehensive process, these data only provide a general indication of impacts. The perceived severity and interpretation of the listed impacts are subject to the interpretation of the provider being surveyed.

⁵ While 86 water providers responded to the survey, some providers did not respond to all of the questions.

intended to be statistically significant but rather to collect M&I drought related information that was previously not available.

Table 9.1 Survey Responses by Basin for the 2013 CWCB Drought Survey

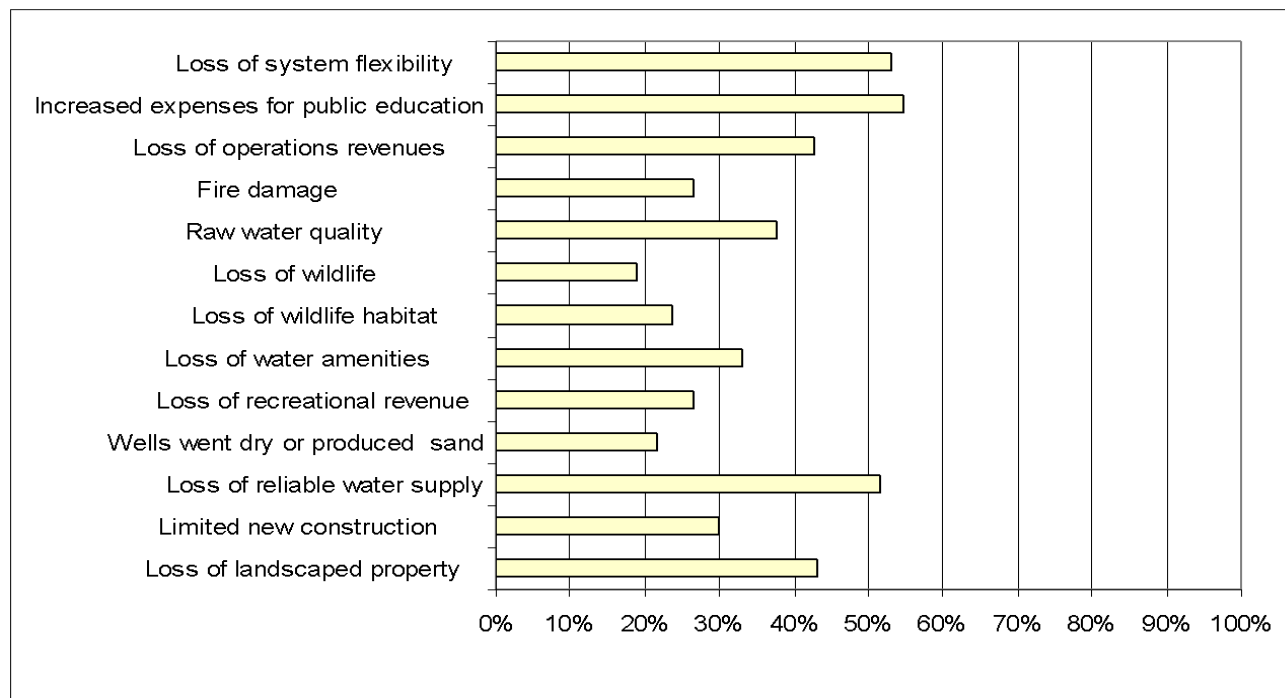
Basin	Response Percent	Response Count
Division 1 - South Platte Basin	48.8%	42
Division 2 - Arkansas River Basin	11.6%	10
Division 3 - Rio Grande River Basin	3.5%	3
Division 4 - Gunnison River Basin	8.1%	7
Division 5 - Colorado River Basin	12.8%	11
Division 6 - Yampa River Basin	5.8%	5
Division 7 - San Juan/Dolores River Basin	9.3%	8
Total Responses	100%	86

9.3.1 Potential Impacts

Municipalities may experience a variety of drought-related impacts. Figure 9.3 provides the percentage of surveyed M&I providers statewide that experienced specific, drought-related impacts from the 2004 DWSA survey. The loss of system flexibility, increased expenses for public education, and loss of reliable water supply were the most frequently experienced impacts statewide.⁶

⁶ The DWSA 2004 survey used the 5-point Likert Scale, with 1 representing no impacts and 2-5 reflecting the severity of the impact with a 5 being of greatest severity. All impacts data presented in this section reflects providers that gave an impact rating of 2-5.

Figure 9.3 2004 DWSA Survey M&I Statewide Impacts⁷



Source: DWSA 2004 survey data.

Additional impacts commonly experienced by M&I providers that were not included in the DWSA survey are:

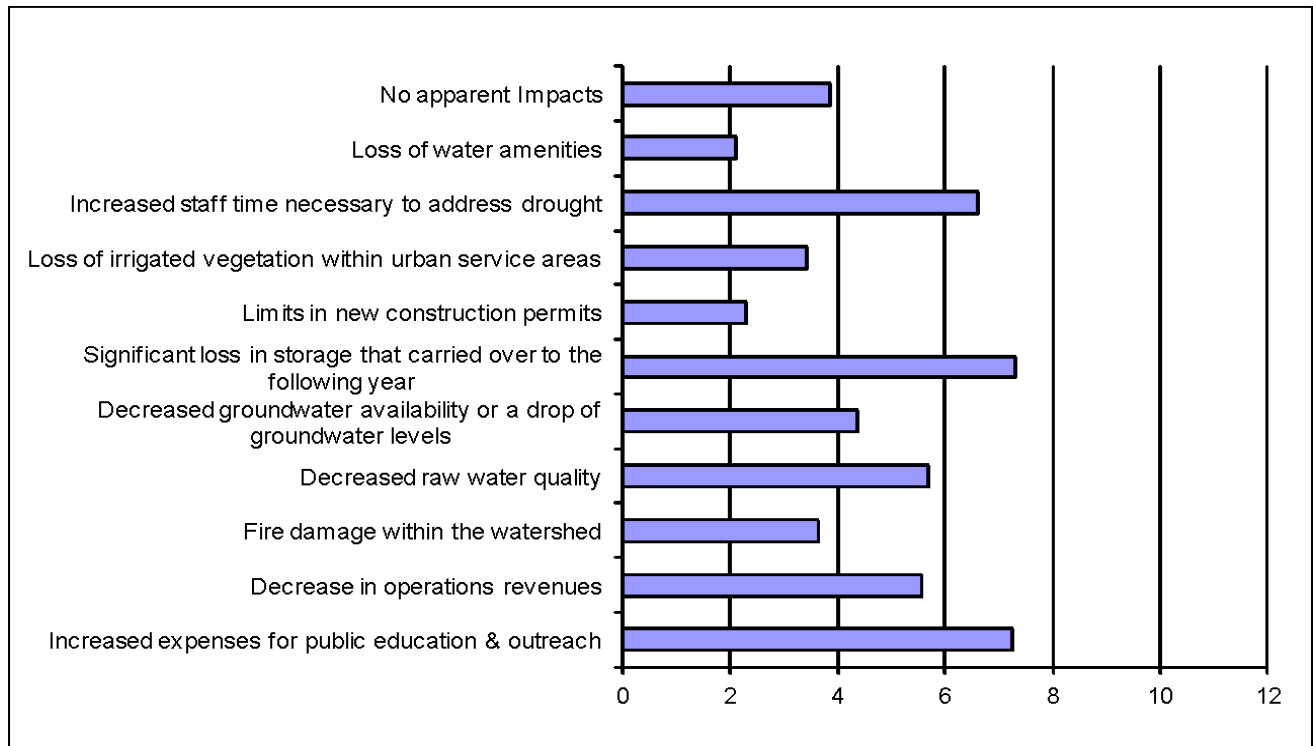
- Reduction in M&I well production and/or reduction in storage reserves
- Increased costs and staff time to implement drought plan and manage public perception of response to drought
- Disruption of water supplies
- Degraded source water quality and higher water treatment costs
- Sediment and fire debris loading to reservoirs following a wildfire
- Increased data/information needs to monitor and implement drought mitigation plan
- Costs to acquire/develop new water supplies
- Costs to increase water use efficiency
- Scarcity of equipment and other water-related services, e.g., contractors to repair wells

The 2013 CWCB drought survey addressed the frequency and relative level of M&I impacts that occurred during the 2012 drought, anticipated impacts in 2013, and the duration of residual effects from the 2002 drought. Figure 9.4 presents the frequency of drought impacts where a ranking of 12 designates the highest frequency and most severe of impacts and a 0 represents the lowest level

⁷ Note: A comprehensive review and internal testing process of the survey tool was conducted, yet it is important to recognize that these DWSA 2004 surveyed impact results are subjective. The impacts in the figure in many cases are a reflection of the DWSA's authors interpretation of the listed impacts.

of impact. The impacts with the highest ranking were 1) a significant loss in storage that carried over the following year and 2) increased expenses for public education & outreach whereas the lowest ranking impacts were 1) the loss of water amenities and 2) limits in new construction permits.

Figure 9.4 Frequency and Relative Level of Impacts During the 2012 Drought

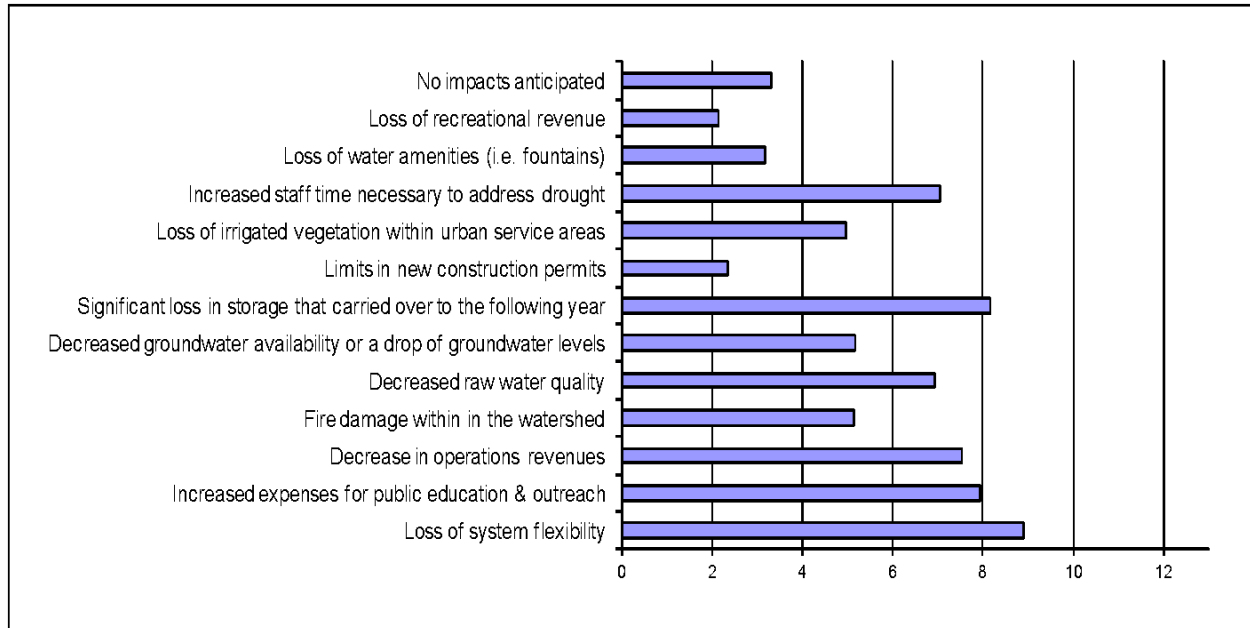


Source: CWCB 2013 drought survey data

Note: These results are based on 46 survey responses

Figure 9.5 presents the anticipated (at the time of the survey) impacts for 2013 statewide, where a ranking of 0 represents impacts of no concern and a ranking of 12 denotes impacts of highest concern. The loss in storage that carried over the following year was of greatest concern. Increased staff time necessary to address drought and increased expenses for public education and outreach were also among the higher rankings; this echoes the responses from the 2004 DWSA survey, where increased expense for public education and outreach was also cited as an impact. Loss of recreational revenue and limits in new construction permits were of least concern to those who responded.

Figure 9.5 Statewide Anticipated Impacts For 2013, per 2013 Survey

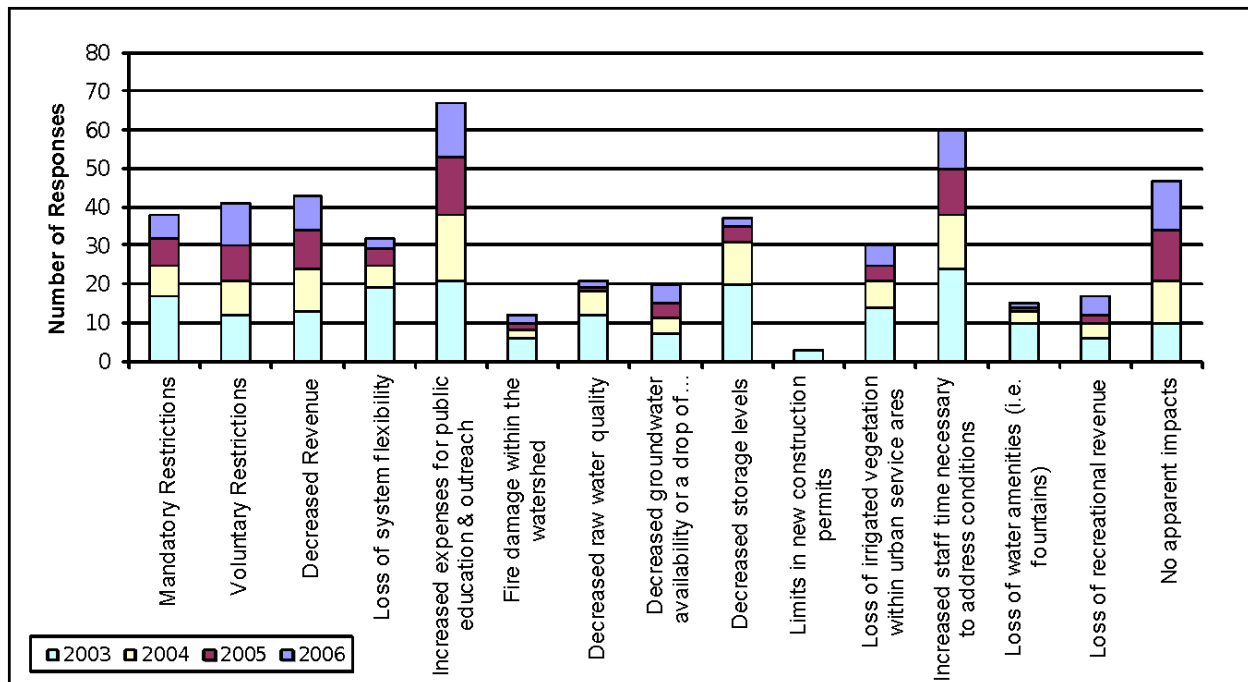


Source: CWCB 2013 drought survey data

Note: These results are based on 46 survey responses

Figure 9.6 shows the statewide residual effects of the 2002 drought from 2003 to 2006. Impacts experienced for the longest duration included the increased expenses for public education & outreach, followed by the increased staff time necessary to address conditions. The impact of shortest duration, limits in construction permits, was only experienced in 2003. Of the 46 respondents, an average of 12 (from 2003 to 2006) indicated that they did not experience impacts following the 2002 drought.

Figure 9.6 Statewide Residual Effects from the 2002 Drought



Source: CWCB 2013 drought survey data

Note: These results are based on 46 survey responses

Table 9.2 lists the highest-ranking impacts identified by the respondents of the 2013 CWCB drought survey by basin. Similar to the statewide results described above, the highest-ranking impacts were 1) loss of system flexibility, 2) significant loss in storage that carried over to the following year, 3) increased staff time necessary to address drought and 4) increased expenses for public education and outreach. Although additional studies (i.e. statistically significant surveys with a larger sampling pool size) would be necessary to confirm the results, it may be concluded from both the 2004 DWSA and 2013 CWCB drought survey that state and local efforts targeting the mitigation of these specific impacts could reduce M&I drought vulnerability throughout the State. Efforts could also focus on other high-ranking impacts identified at a basin-by-basin level. For instance, the loss of system flexibility was cited as the highest-ranking impact in the South Platte Basin. The Water Infrastructure and Supply Efficiency (WISE) partnership between 13 regional water suppliers is an example of one action that has been taken to mitigate this impact.

Table 9.2 Highest Ranked Basin Impacts

Basin	Impacts During 2012	Anticipated Impacts for 2013	Longest Residual Effects from 2002 to 2006
South Platte Basin	1) Loss of system flexibility 2) Significant loss in storage that carried over to the following year 3) Increased staff time necessary to address drought 23 <i>respondents</i>	1) Loss of system flexibility 2) Significant loss in storage that carried over to the following year 3) Increased staff time necessary to address drought 23 <i>respondents</i>	1) Increased expenses for public education & outreach 2) Increased staff time necessary to address conditions 3) Voluntary restrictions 23 <i>respondents</i>
Arkansas Basin	1) Loss of water amenities 2) Increased staff time necessary to address drought 3) Loss of irrigated vegetation within urban service areas 7 <i>respondents</i>	1) Loss of system flexibility 2) Significant loss in storage that carried over to the following year 3) Loss of recreational revenue 7 <i>respondents</i>	1) Decreased storage levels 2) Loss of irrigated vegetation 3) Increased staff time necessary to address drought 4) Mandatory restrictions 5) Increased expenses for public education & outreach 7 <i>respondents</i>
Rio Grande Basin	1) Decreased groundwater availability 2) Significant loss in storage that carried over to the following year 3) Loss of system flexibility 1 <i>respondent</i>	1) Loss of system flexibility 2) Significant loss in storage that carried over to the following year 3) Decrease in operations revenue 1 <i>respondent</i>	1) Loss of system flexibility 2) Increased expenses for public education & outreach 3) Decreased groundwater availability 4) Decreased storage levels 5) Increased staff time necessary to address drought 6) Loss of recreational revenue 1 <i>respondent</i>
Gunnison Basin	1) Loss of system flexibility 2) Significant loss in storage that carried over to the following year 3) Increased staff time necessary to address drought 3 <i>respondents</i>	1) Loss of system flexibility 2) Significant loss in storage that carried over to the following year 3) Increased staff time necessary to address drought 3 <i>respondents</i>	1) Loss of system flexibility 2) Decreased raw water quality 3) Increased staff time necessary to address drought 3 <i>respondents</i>
Colorado Basin	1) Decreased raw water quality 2) Loss of system flexibility 3) Increased expenses for public education & outreach 7 <i>respondents</i>	1) Increased expenses for public education & outreach 2) Loss of system flexibility 3) Decreased raw water quality 7 <i>respondents</i>	1) Voluntary restrictions 2) Mandatory restrictions 3) Increased expenses for public education & outreach 4) Decreased storage levels 7 <i>respondents</i>

Basin	Impacts During 2012	Anticipated Impacts for 2013	Longest Residual Effects from 2002 to 2006
Yampa Basin	1) Loss of irrigated vegetation within urban service areas 2) Significant loss in storage that carried over to the following year 3) Decrease in groundwater availability or drop of groundwater levels <i>2 respondents</i>	1) Loss of irrigated vegetation within urban service areas 2) Significant loss in storage that carried over to the following year 3) Decrease in groundwater availability or drop of groundwater levels <i>2 respondents</i>	No apparent impacts <i>2 respondents</i>
San Juan/Dolores Basin	1) Increase staff time necessary to address conditions 2) Limits in new construction permits 3) Loss or irrigated vegetation within urban service areas <i>3 respondents</i>	1) Limits in construction permits 2) Loss of irrigated vegetation within urban service areas 3) Loss of recreational revenue 4) Increased staff time necessary to address conditions <i>3 respondents</i>	1) Voluntary restrictions 2) Decreased revenue 3) Increased expenses for public education and outreach 4) Decreased storage levels 5) Increased staff time necessary to address conditions <i>3 respondents</i>

Source: CWCB 2013 drought survey data

Notes: The ranking is based on the frequency and perceived intensity of impact

In the 2014/2015 BIPs that fed into the 2015 Colorado Water Plan, each basin identified possible future impacts to M&I uses that they were planning to mitigate, and/or key challenges in the next 40 years. While most of them do not mention drought, it can be assumed that drought will exacerbate many of these impacts or relate to drought mitigation and adaptation. For each basin, these are:

- South Platte, Republican, and North Platte (Jackson County) River Basins
 - Conversion of agricultural water to M&I uses is expected to be an important option for meeting future M&I needs.
 - There is substantial competition for additional M&I water supplies, and in some cases multiple M&I suppliers have identified the same water supplies as future sources.
 - Increased M&I water-use efficiency is a critical step toward meeting future water needs, but it does reduce the quantity of water available for agricultural and ecological uses because of reduced return flows.
- Arkansas River Basin
 - Continued growth in groundwater-dependent urban areas will be a challenge.
 - The Arkansas River Voluntary Flow Agreement cooperatively integrates municipal, agricultural, and recreational solutions to support recreational boating and a gold medal fishery on the Arkansas River.
 - Rural areas have identified water needs but need resources and support from the basin roundtable and CWCB.
- Rio Grande
 - Residential growth of second homes and vacation homes is creating a need for additional water supplies.

- Groundwater management presents an on-going challenge.
- Gunnison
 - Growth in the headwaters region will require additional water management strategies.
 - The area between Ouray and Montrose is rapidly growing, and a rapid influx of retirees and growth in the Uncompahgre Valley may dramatically change the agricultural uses and other land uses in the area.
- Colorado
 - Water quality is a concern, particularly related to selenium and salinity.
 - There is a concern over a potential compact shortage during severe and sustained drought, and the potential effects to in-basin supplies.
- Yampa
 - The basin as a whole is not developing as rapidly as other parts of the state, leading to concerns that the basin will not get a “fair share” of water in the event of a compact call.
- San Juan/Dolores
 - The Pagosa Springs-Bayfield-Durango corridor is rapidly growing while experiencing areas of localized water shortages.
 - There is a need for new storage to meet long-term supply requirements in the Pagosa Springs area, as well as in Montrose County.

9.3.2 Adaptive Capacity Actions

M&I drought vulnerability can be reduced significantly through the implementation of adaptive capacity actions to mitigate drought impacts and respond to a drought. Mitigation refers to actions taken in advance of a drought that reduce potential drought-related impacts. Response actions are implemented to address drought when it occurs. Table 9.3 provides a list of long-term mitigation and short-term response actions that many municipal providers have incorporated into local drought plans. Many of these items may either be implemented as long-term mitigation or as short-term response actions.

Table 9.3 Adaptive Capacity - Long and Short-Term Mitigation Actions

Adaptive Capacity - Mitigation and Response Actions	Long-term Mitigation	Short-term Response Actions
Elements of a Drought Management Plan		
Establish drought response principles, objectives, and priorities	X	
Establish authority & process for declaring a drought emergency	X	
Develop drought stages, trigger points, and response targets	X	
Prepare ordinances on drought measures	X	
Evaluate historical drought impacts	X	
Monitor drought indicators (e.g., snow pack, stream flow, etc.)	X	X
Monitor water quality	X	X
Track public perception and effectiveness of drought measures	X	X

Adaptive Capacity - Mitigation and Response Actions	Long-term Mitigation	Short-term Response Actions
Improve accuracy of runoff and water supply forecasts	X	
Emergency Response		
Declare a drought emergency		X
Establish water hauling programs	X	X
Restrict/prohibit new taps		X
Identify state and federal assistance	X	X
Provide emergency water to domestic well users		X
Import water by truck/train		X
Public Education and Relations		
Establish a public advisory committee during drought planning and/or drought response efforts	X	X
Develop Drought Public Education Campaign with long-term and short-term strategies	X	X
Educate provider/municipal staff on how to save water	X	X
Provide instructional resources to business on developing an office/business specific drought mitigation and response plan	X	X
Provide acoustical meters to assist customers in identifying leaks	X	X
Water Supply Augmentation		
Establish drought reserves	X	
Draw from drought reserves		X
Increase groundwater pumping		X
Deepen wells	X	X
Develop supplemental groundwater/conjunctive use	X	
Reactivate abandoned wells		X
Flush existing wells to develop maximum flow rates	X	X
Blend primary supply with water of lesser quality to increase supplies		X
Rehabilitate operating wells	X	X
Employ desalination of brackish groundwater	X	
Increase use of recycled water	X	X
Utilize ditch water or treated effluent for irrigating landscaping/parks	X	X
Build new facilities to enhance diversion or divert new supplies	X	
Lower reservoir intake structures	X	X
Use reservoir dead storage		X
Acquire additional storage	X	
Build emergency dams	X	X
Reactivate abandoned dams	X	X
Cloud seeding	X	X

Adaptive Capacity - Mitigation and Response Actions	Long-term Mitigation	Short-term Response Actions
Water Rights Management and Cooperative Agreements⁸		
Call back water rights that others are allowed to use		X
Pay senior water user to not place a "call" on the river		X
Pay upstream water user to allow diversion of more water		X
Purchase water from other entities (e.g., neighboring cities, federal projects)		X
Arrange for exchanges	X	X
Lease irrigation rights from farmers		X
Lease private wells		X
Cancel M&I leases of water to farmers		X
Use irrigation decrees		X
Invoke drought reservations that allow reduction in bypass requirements		X
Negotiate purchases or "options"	X	X
Renegotiate contractually controlled supplies	X	X
Develop water transfers with other entities	X	X
Develop water bank to facilitate water transfers in times of drought	X	
Develop interconnects with other entities	X	X
Trade water supplies with other entities to increase yield		X
Improve Water Distribution Efficiency		
Conduct distribution system water audit	X	X
Repair leaks in distribution system	X	X
Reduce distribution system pressure		X
Replace inaccurate meters	X	
Calibrate all production, commercial, industrial, and zone meters	X	
Install meters at key distribution points to isolate areas of overuse and probable leakage	X	
Minimize reservoir spills	X	X
Change operations to optimize efficiency and distribution of supplies	X	X
Change pattern of water storage and release operations to optimize efficiency	X	X
Reduce reservoir evaporation (i.e., reduce storage in reservoirs with high evaporation rates)	X	X
Reduce reservoir seepage (i.e., reduce storage in reservoirs with high seepage rates)	X	X
Recirculate wash water	X	
Enhance efficiency of water treatment facilities	X	

⁸ Cooperative agreements are becoming increasingly important within Colorado, creating flexibility within the otherwise rigid prior appropriation system. Cooperative agreements provide the means to allow for temporary transfers of water between users, and allow for the more efficient use of water in periods of water scarcity. For example, agricultural users can utilize cooperative agreements to allow for the temporary lease, exchange and/or transfer of water to a needy municipal entity, when the limited availability of water may have impacted crop yield or production. In this way, the agricultural community can find sources of revenue while municipalities find emergency and/or short-term water supplies in dry and drought years.

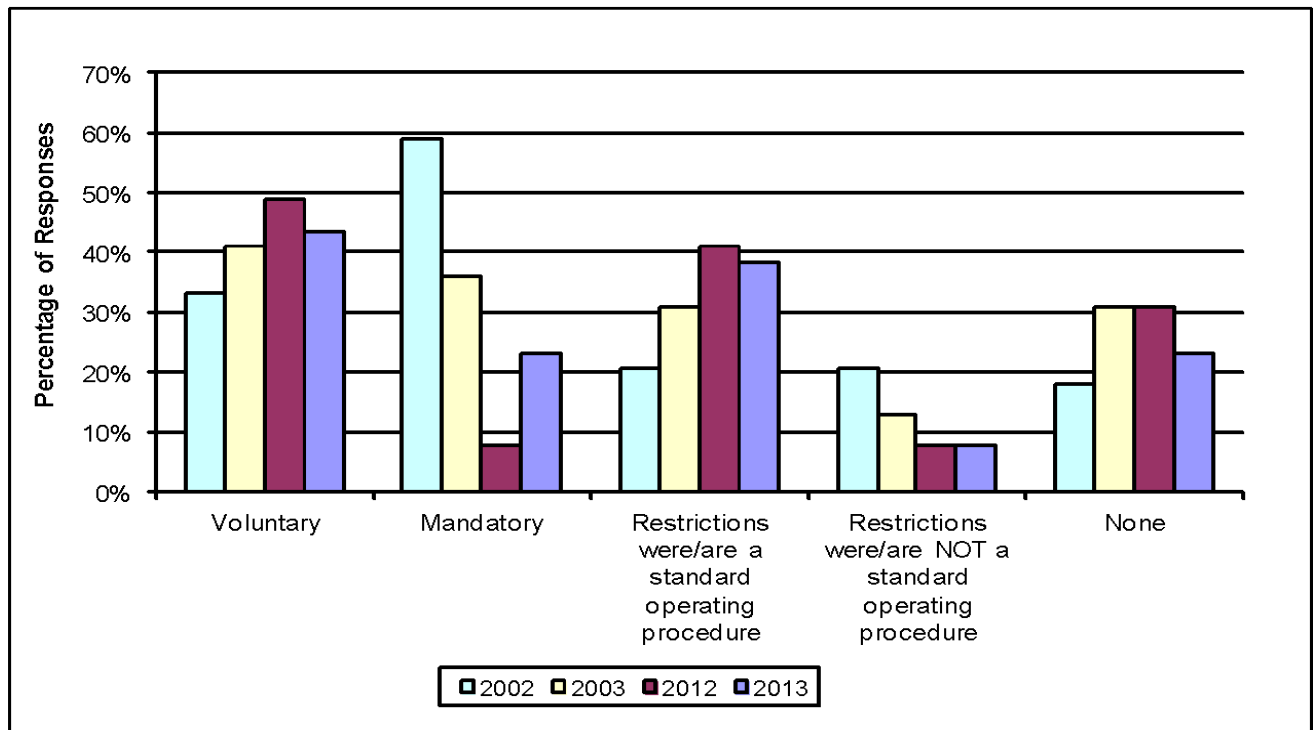
Adaptive Capacity - Mitigation and Response Actions	Long-term Mitigation	Short-term Response Actions
Demand Management		
Establish and enforce percent water use reduction goals	X	X
Identify high water use customers and develop water saving targets	X	X
Implement conservation measures that also provide water saving benefits during drought periods (i.e., water fixture rebates)	X	
Establish and enforce percent water use reduction goals	X	X
Identify high water use customers and develop water saving targets	X	X
Implement conservation measures that also provide water saving benefits during drought periods (i.e., water fixture rebates)	X	
Adopt a modified rate structure for drought periods	X	X
Implement drought surcharges		X
Provide historical monthly water usage on water bills	X	X
Restrict the issuance of new taps		X
Prohibit/limit use of construction water		X
Limit/prohibit installation of new sod, seeding, and/or other landscaping		X
Develop policy guidelines/limitations for installation of new sod and/or other landscaping	X	X
Conduct irrigation audits on parks and open spaces	X	X
Promote residential/commercial irrigation audits	X	X
Eliminate/reduce irrigation on municipal parks and other landscaping (i.e., street medians)	X	X
Enforce landscape watering restrictions	X	X
Limit outdoor watering to specific times of the day	X	X
Limit number of watering days per week	X	X
Set time limit for watering	X	X
Prohibit watering during fall, winter, and early spring		X
Promote/enforce conversion of sprinkler to low volume irrigation where appropriate	X	
Enforce restrictions on outdoor misting devices		X
Reduce/eliminate street cleaning, sidewalk, and driveway washing		X
Prohibit/limit non-recirculating fountains in buildings and parks		X
Turn off public drinking fountains		X
Limit/prevent washing of municipal fleet vehicles		X
Prohibit/limit residential vehicle washing		X
Prohibit/limit dealership washing of vehicles		X
Enforce water use restrictions on commercial car washes		X
Promote commercial car washes to install water recycling technology and/or other BMPs	X	X
Limit hydrant washing and flushing		X
Limit use of water for fire training		X
Prohibit/limit filling and use of swimming pools		X
Conduct/promote indoor water audits for commercial and residential sector	X	X

Adaptive Capacity - Mitigation and Response Actions	Long-term Mitigation	Short-term Response Actions
Enforce indoor water restrictions		X
Install water saving fixtures, toilets, and/or appliances	X	
Require water efficient fixtures and/or appliances on house resale or remodeling	X	
Promote/require graywater use	X	X
Promote/conduct indoor audits	X	X
Promote/enforce reduction of water-cooled air conditioning		X
Promote service of water in restaurants only upon request	X	X
Promote reduction in frequency of linen and towel washing in hotels	X	X
Promote/encourage conversion of cooling towers and other industrial water using processes	X	
Require buildings with water cooled air conditioning to raise the temperature modestly		X

Adaptive capacities employed by water providers were explored in the CWCB 2013 drought survey, the statewide results of which are presented in Figure 9.7 through Figure 9.10. Figure 9.7 shows the percentage of survey respondents who implemented water restrictions, which could be considered either a mitigating action or a response action depending on when the restrictions were implemented, during the drought of 2002/2003, again during the drought of 2012, and are anticipating implementing restrictions during 2013. These results show that mandatory water restrictions were implemented by 59% of the survey respondents during 2002/2003 but were implemented by only 8% of survey respondents in 2012. This significantly lower implementation rate is largely attributed to the fact that during 2012, many providers relied upon normal to above-normal reservoir storage to meet customer demands while implementing voluntary restrictions in response to the drought. The percentage of respondents planning to implement mandatory restrictions in 2013 is much higher than 2012, which is attributed to below-average reservoir storage and the anticipated severe to exceptional drought conditions across a large portion of Colorado. This result highlights the importance of reservoir storage for planning purposes during drought.

Figure 9.7 also indicates that a larger percentage of the respondents consider water restrictions to be standard operating procedure in 2012 when compared to the drought in 2002/2003, highlighting how attitudes around water restrictions have changed with time. Twenty-six percent of the respondents did not implement water restrictions in 2002/2003 or 2012 and did not plan to do so in 2013.

Figure 9.7 Water Restrictions

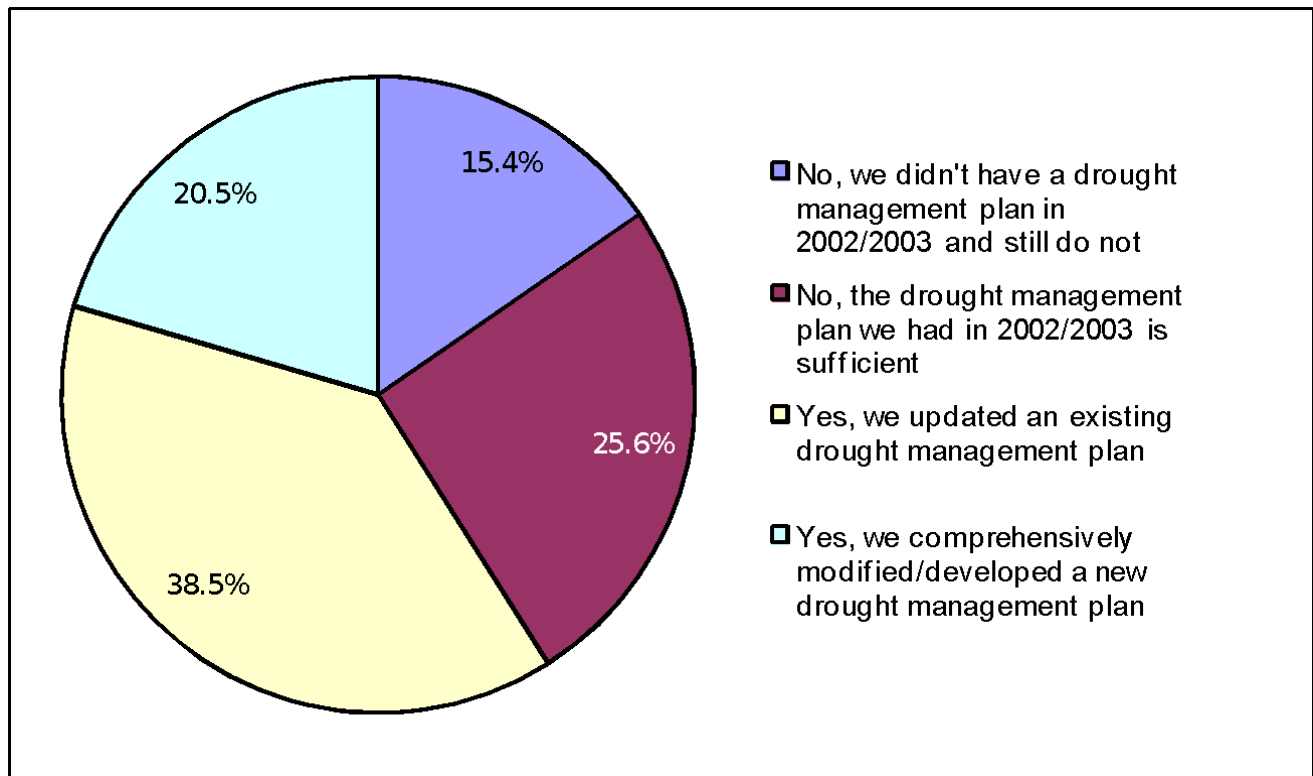


Source: CWCB 2013 drought survey data

Note: These results are based on 39 survey responses

Drought management plans are an adaptive capacity mitigation strategy. In 2013, 15% of survey respondents did not have a drought management plan, while 59% of survey respondents both had a drought management plan and had updated it in the years since 2002 (Figure 9.8). When asked if they would work to improve their system's level of drought preparedness following the 2012/2013 drought, 51% of respondents indicated that they would (Figure 9.9). Two-thirds of respondents expressed that there is sufficient funding either in-basin or through State and Federal sources to fund water supply reliability, conservation and drought planning efforts (Figure 9.10).

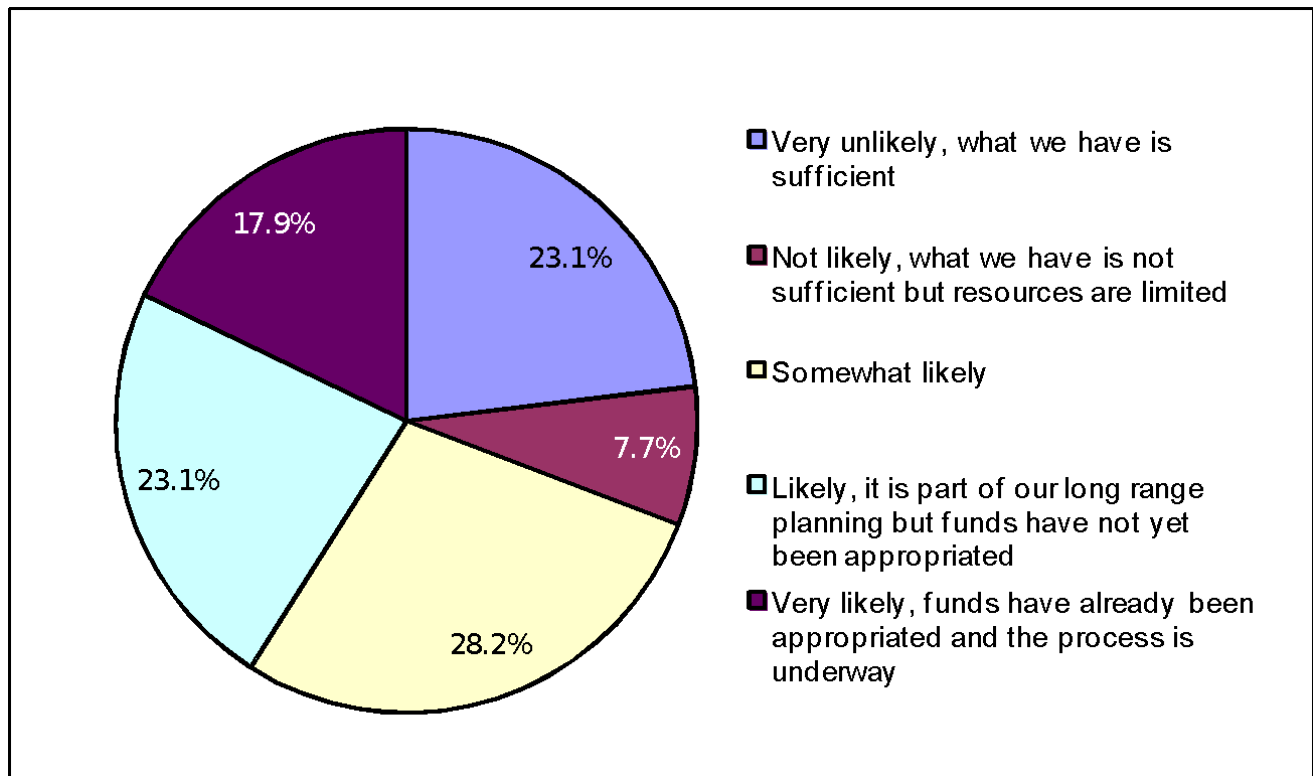
Figure 9.8 Drought Management Plan Update Since 2002



Source: CWCB 2013 drought survey data

Note: These results are based on 39 survey responses

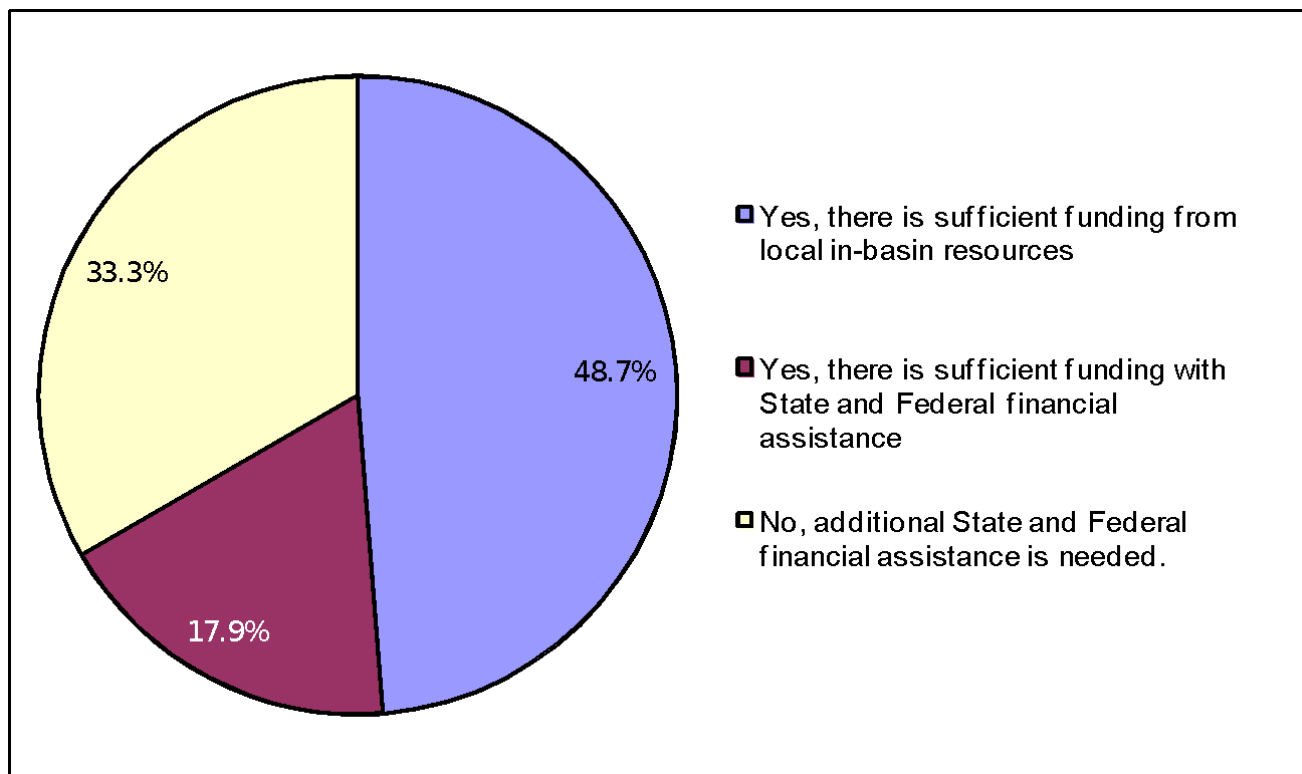
Figure 9.9 Likelihood to Improve Drought Preparedness Following 2012/2013



Source: CWCB 2013 drought survey data

Note: These results are based on 39 survey responses

Figure 9.10 Sufficient Funding to Support M&I Water Supply Reliability, Conservation and Drought Planning



Source: CWCB 2013 drought survey data

Note: These results are based on 39 survey responses

Table 9.4 highlights the basin-level results of the 2013 CWCB drought survey showing the percentage of survey respondents within each basin that updated/developed drought plans following the 2002 drought, are anticipating improving drought preparedness following 2012/2013 and perceive that there is sufficient funding for water supply reliability, conservation and drought planning. These results indicate that over half of the respondents in the South Platte, Arkansas, Gunnison and Colorado basins developed/updated their drought plans after the drought in 2002. A smaller percentage of respondents in the majority of basins plan to improve their drought preparedness following 2012/2013. Over 60% of the respondents in the South Platte, Arkansas, Colorado, Yampa and San Juan/Dolores basins perceive there is sufficient funding for water supply reliability, conservation and drought planning. This percentage could be increased through stakeholder outreach that addresses the availability of funding sources for water resources planning. Relating drought planning to the larger M&I water supply planning efforts underway across the State may also be of benefit to reducing drought vulnerability.

Table 9.4 Basin M&I Drought Planning

Basin	Updated / comprehensive revision to drought plan since 2002	Likely improve drought preparedness following 2012/2013	Perceives there is sufficient funding for planning available (in-basin, state or federal)
South Platte Basin	53% 19 respondents	42% 19 respondents	68% 19 respondents
Arkansas Basin	56% 7 respondents	0% 7 respondents	72% 7 respondents
Rio Grande Basin	0% Zero respondents	0% Zero respondents	0% Zero respondents
Gunnison Basin	100% 3 respondents	100% 3 respondents	0% Zero respondents
Colorado Basin	67% 6 respondents	50% 6 respondents	64% 6 respondents
Yampa Basin	0% 1 respondent	0% 1 respondent	100% 1 respondent
San Juan/Dolores Basin	67% 3 respondents	33% 3 respondents	67% 3 respondents

Source: CWCB 2013 drought survey data

The SWSI 2010 developed, and the Colorado Water Plan summarized, the projected 2050 M&I water supply gaps (the difference between supply and demand) for each basin. Basin Roundtables identified projects and conservation/reuse strategies that seek to close these gaps in their BIPs. These basin-specific strategies are important for drought planning, and are discussed in more detail in the Regional Assessments (Section 9.4.1).

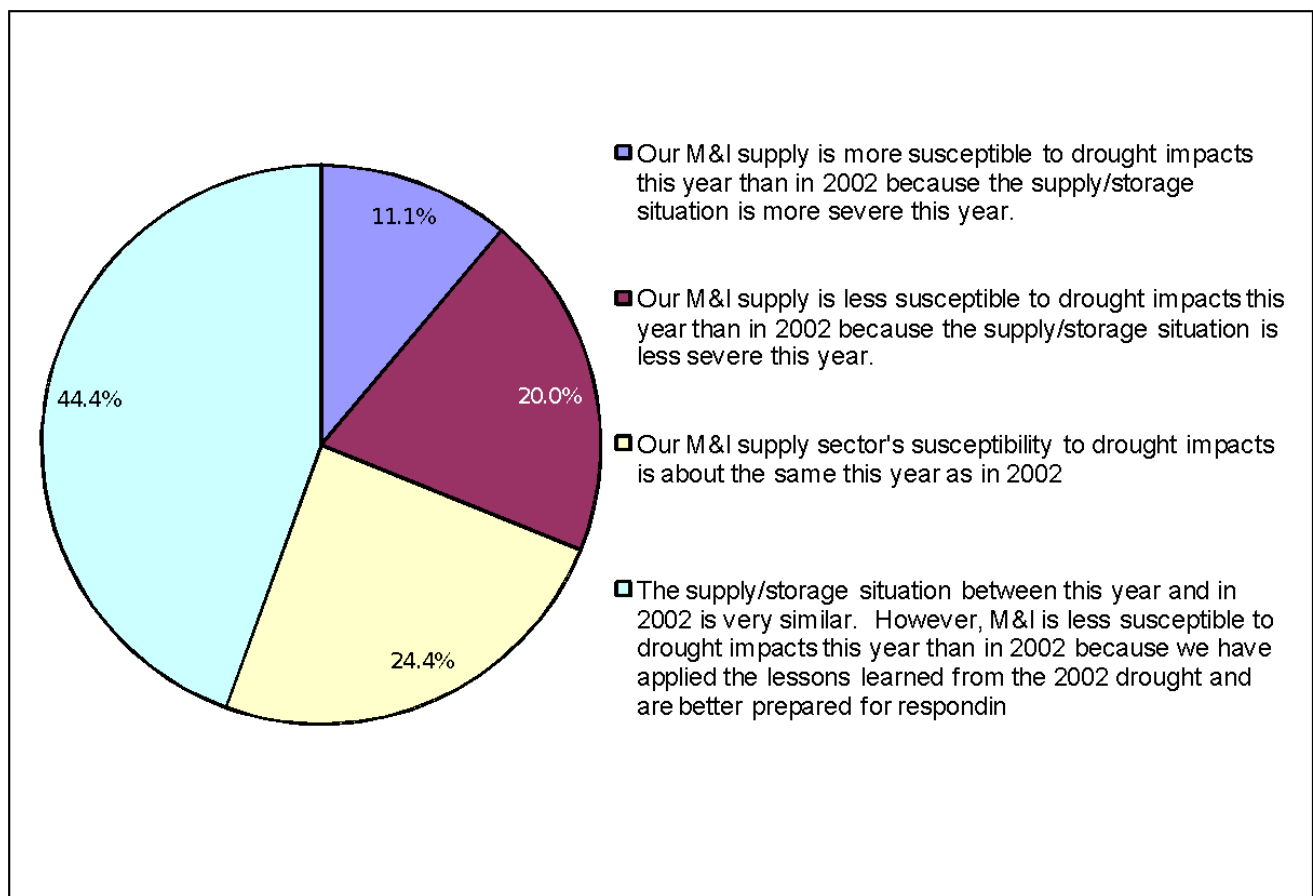
9.4 Measurement of Vulnerability

Drought vulnerability can significantly vary among M&I providers. Section 9.3 introduced the many water supply, distribution system, demand, and adaptive capacity factors that influence M&I drought vulnerability. Each of these factors is unique to individual M&I providers and can affect providers in many different ways and magnitudes during a drought.

Evaluation of M&I drought vulnerability would require extensive characterization of water right portfolios, storage capabilities, distribution system efficiencies, demands, adaptive capacities, etc., and is best left to individual M&I providers to do as part of their drought management planning processes. A thorough statewide evaluation of M&I drought vulnerability would require a means to account for and incorporate the uniqueness of each M&I provider, which is beyond the scope of this study. For this assessment, a qualitative assessment of M&I vulnerability was conducted at regional basin-wide level in addition to the CWCB 2013 drought survey which included three questions specific on drought vulnerability.

Figure 9.11 through Figure 9.14 summarize the statewide results of the CWCB 2013 drought survey on vulnerability. Figure 9.11 shows that 44% of the survey respondents indicated that while conditions between 2002 and 2013 are similar, they are less susceptible to drought impacts in 2013 than in 2002 because they are better prepared. Eleven percent of the respondents indicated that they are more susceptible to drought in 2013 because the supply/storage situation is more severe than in 2002.⁹ Table 9.5 summarizes the basin results, indicating that over 40% of respondents in the South Platte, Arkansas, Gunnison, Colorado and San Juan/Dolores basins feel that they are less susceptible to drought impacts in 2013 than in 2002 although conditions in 2002 and 2013 are similar. This suggests that the drought vulnerability of the M&I sector in many regions throughout the State may be lessening as a result of lessons learned from the 2002 and 2012 droughts in addition to improved M&I mitigation and drought response.

Figure 9.11 State-wide Drought Vulnerability in 2002 and 2013



Source: CWCB 2013 drought survey data

Note: These results are based on 45 survey responses

⁹ The survey period began in early May 2013 before a series of snowstorms occurred in central and northern Colorado and concluded after the snow events. Anticipated water supply shortages were reduced or eliminated for certain M&I providers following the snow events. Consequently, results of the survey may be somewhat skewed depending on when the respondents completed the survey.

Table 9.5 Basin Drought Vulnerability in 2002 and 2013

Basin	More susceptible to drought impacts in 2013 than in 2002 because the supply/storage situation is more severe in 2013	Less susceptible to drought impacts in 2013 than in 2002 because the supply/storage situation is less severe in 2013	Susceptibility to drought impacts is about the same in 2013 as in 2002	The supply/storage situation between 2013 and in 2002 is very similar. However, M&I is less susceptible to drought impacts in 2013 than in 2002 because of the lessons learned from the 2002 drought and are better prepared
South Platte Basin	13% 23 respondents	22% 23 respondents	17% 23 respondents	48% 23 respondents
Arkansas Basin	14% 7 respondents	14% 7 respondents	29% 7 respondents	43% 7 respondents
Rio Grande Basin	0% 1 respondent	0% 1 respondent	100% 1 respondent	0 respondents
Gunnison Basin	0% 3 respondents	0% 3 respondents	33% 3 respondents	67% 3 respondents
Colorado Basin	0% 6 respondents	34% 6 respondents	17% 6 respondents	50% 6 respondents
Yampa Basin	0% 2 respondents	50% 2 respondents	50% 2 respondents	0% 2 respondents
San Juan/Dolores Basin	33% 3 respondents	33% 3 respondents	33% 3 respondents	67% 3 respondents

Source: CWCB 2013 drought survey data

The survey results in Figure 9.12 and Table 9.6 indicate that half or more of respondents have applied lessons learned from 2002 and better prepared for drought in 2013 than they were the decade prior. Preparation is expected to continue to increase as drought and climate change planning becomes more prevalent among water providers.

The need for mandatory water restrictions can be an indicator of drought vulnerability. The vast majority (93%) of 2013 survey respondents statewide replied that they can meet their indoor and outdoor water needs during a 1-in-20 year drought with or without mandatory water restrictions. In a 1-in-50 year drought most (67%) water providers would implement mandatory water restrictions but would still be able to meet demands. Seven percent of respondents indicated that they cannot meet their indoor or outdoor needs even with mandatory water restrictions during a 1-in-20 year drought, and 12% cannot meet these needs during a 1-in-50 year drought (Figure 9.13).

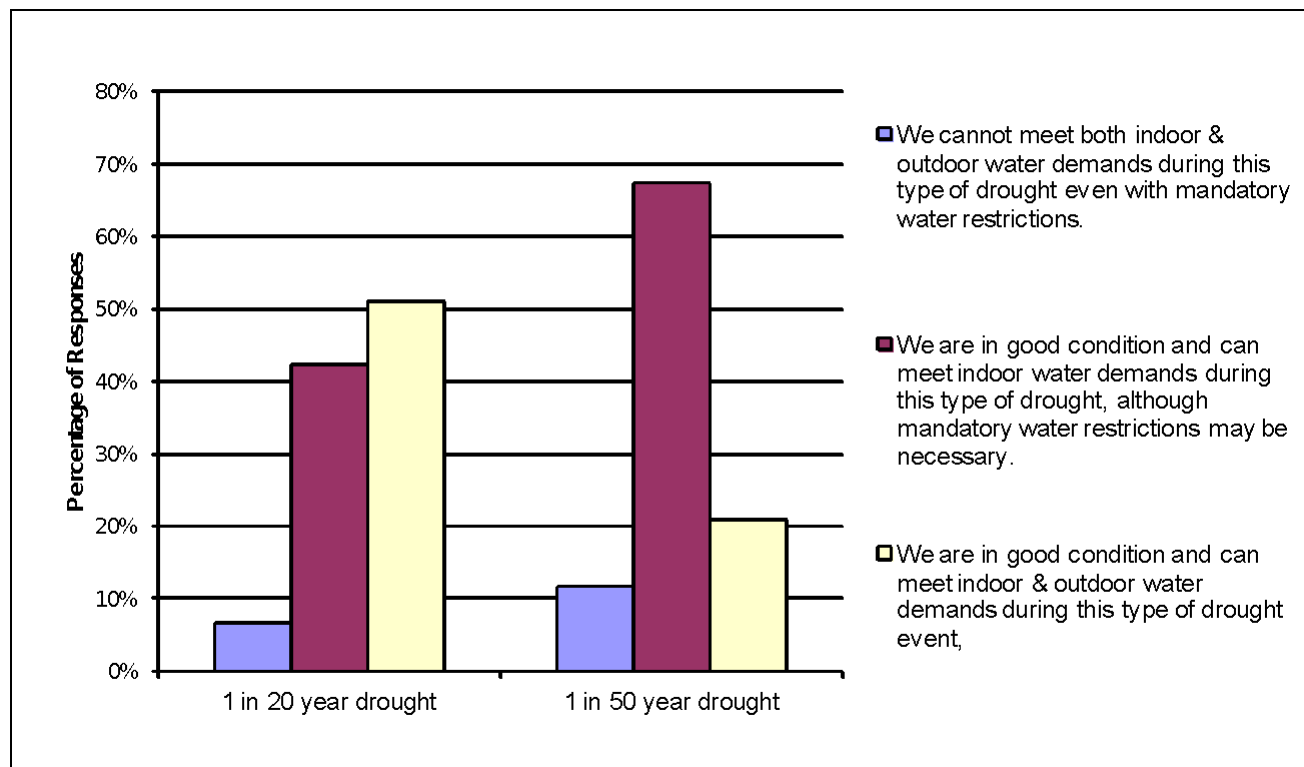
Table 9.8 shows the basin results. Although the sample size is small, the responses indicate the following important points:

- There are M&I providers in the South Platte and San Juan/Dolores basins that would struggle to meet demands in a 1-in-20-year drought, even with the implementation of mandatory water restrictions.

- In the event of a 1-in-50-year drought, there are M&I providers in the Arkansas, Gunnison, South Platte, and San Juan/Dolores basins that would not be able to meet demands, even with the implementation of mandatory water restrictions (the one survey from the Rio Grande basin did not respond to this question).

These survey results highlight the importance of cooperative agreements between water providers to allocate resources as efficiently as possible in times of shortage.

Figure 9.12 Water Restrictions for a 1-in-20 and 1-in-50 Year Drought



Source: CWCB 2013 drought survey data

Note: These results are based on 45 survey responses

Table 9.6 Basin Water Restrictions for a 1-in-20 and 1-in-50 Year Drought

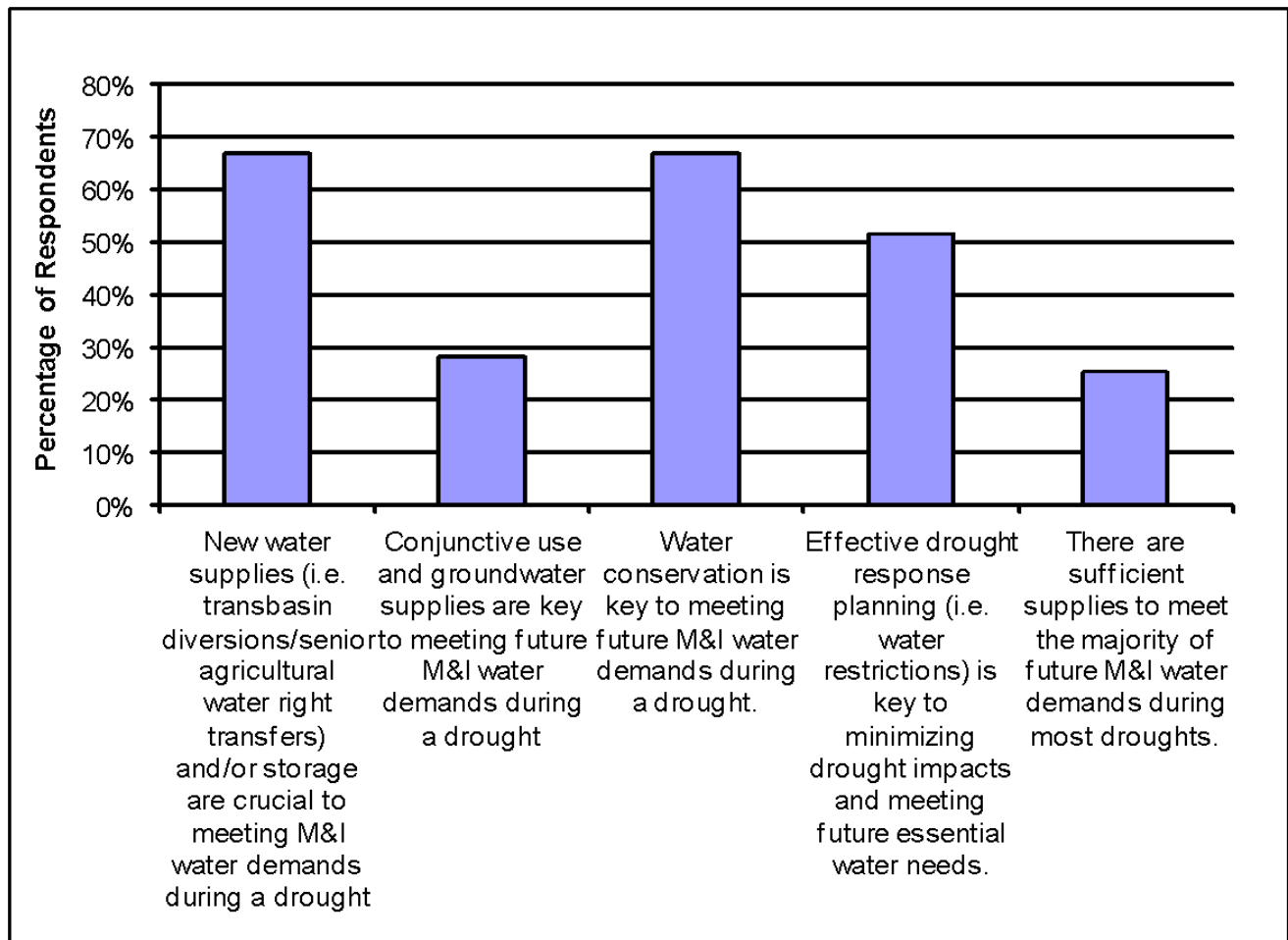
Basin	1-in-20 year drought			1-in-50 year drought			Number of Respondents
	Can meet indoor & outdoor water demands	Can meet indoor water demands, although mandatory water restrictions may be necessary	Cannot meet indoor & outdoor water demands even with mandatory water restrictions	Can meet indoor & outdoor water demands	Can meet indoor water demands, although mandatory water restrictions may be necessary	Cannot meet indoor & outdoor water demands even with mandatory water restrictions	
South Platte Basin	66%	30%	4%	22%	74%	4%	23
Arkansas Basin	57%	43%	0%	43%	43%	14%	7
Rio Grande Basin	0%	100%	0%	0%	0%	0%	1
Gunnison Basin	0%	100%	0%	0%	67%	33%	3
Colorado Basin	20%	80%	0%	0%	100%	0%	6
Yampa Basin	100%	0%	0%	50%	0%	0%	2
San Juan/Dolores Basin	33%	0%	67%	0%	33%	67%	3

Source: CWCB 2013 drought survey data

As of 2013, municipalities planned to implement a variety of water supply and demand management options to meet their future long-term needs. Figure 9.13 indicates that over 60% of the 2013 CWCB drought survey respondents statewide plan to develop new water supplies and also rely on water conservation in meeting their future water needs. Planning for future water supplies is different than securing these water supplies. The Colorado Water Plan noted that competition for additional M&I water supplies is substantial, and that in some cases multiple M&I suppliers have identified the same water supplies as future water sources. Twenty-six percent of the respondents stated that they have sufficient supplies to meet their needs during most droughts.

Table 9.7 highlights the basin results, also indicating that obtaining new water supplies and promoting water conservation tend to be the highest-ranking long-term water supply options; however, M&I providers' ability to meet future demand varies among the basins. For instance, 57% percent of the survey respondents in the Arkansas Basin indicated that they have sufficient long-term supplies to meet their future needs, whereas zero percent of the respondents in the Gunnison Basin believes they have sufficient supplies. The BIPs, which came out of the Basin Roundtable process, identified ways to address future shortages and facilitated collaboration among basin stakeholders on how long-term water supply needs may be met in the future.

Figure 9.13 Long-term Water Supply Planning



Source: CWCB 2013 drought survey data

Note: These results are based on 39 survey responses

Table 9.7 Basin Long-term Water Supply Planning

Basin	Highest two ranking long-term supplies	Percentage with sufficient long-term supplies
South Platte Basin	1) New water supplies 2) Water conservation	21%
Arkansas Basin	1) New water supplies 2) Water conservation	57%
Rio Grande Basin	No respondents	No respondents
Gunnison Basin	1) Water Conservation 2) New water supplies	0%
Colorado Basin	1) Drought response 2) New water supplies 3) Water Conservation	67%
Yampa Basin	1) New water supplies 2) Sufficient supplies	100%

Basin	Highest two ranking long-term supplies	Percentage with sufficient long-term supplies
San Juan/Dolores Basin	1) New Water Supplies 2) Sufficient supplies	0%

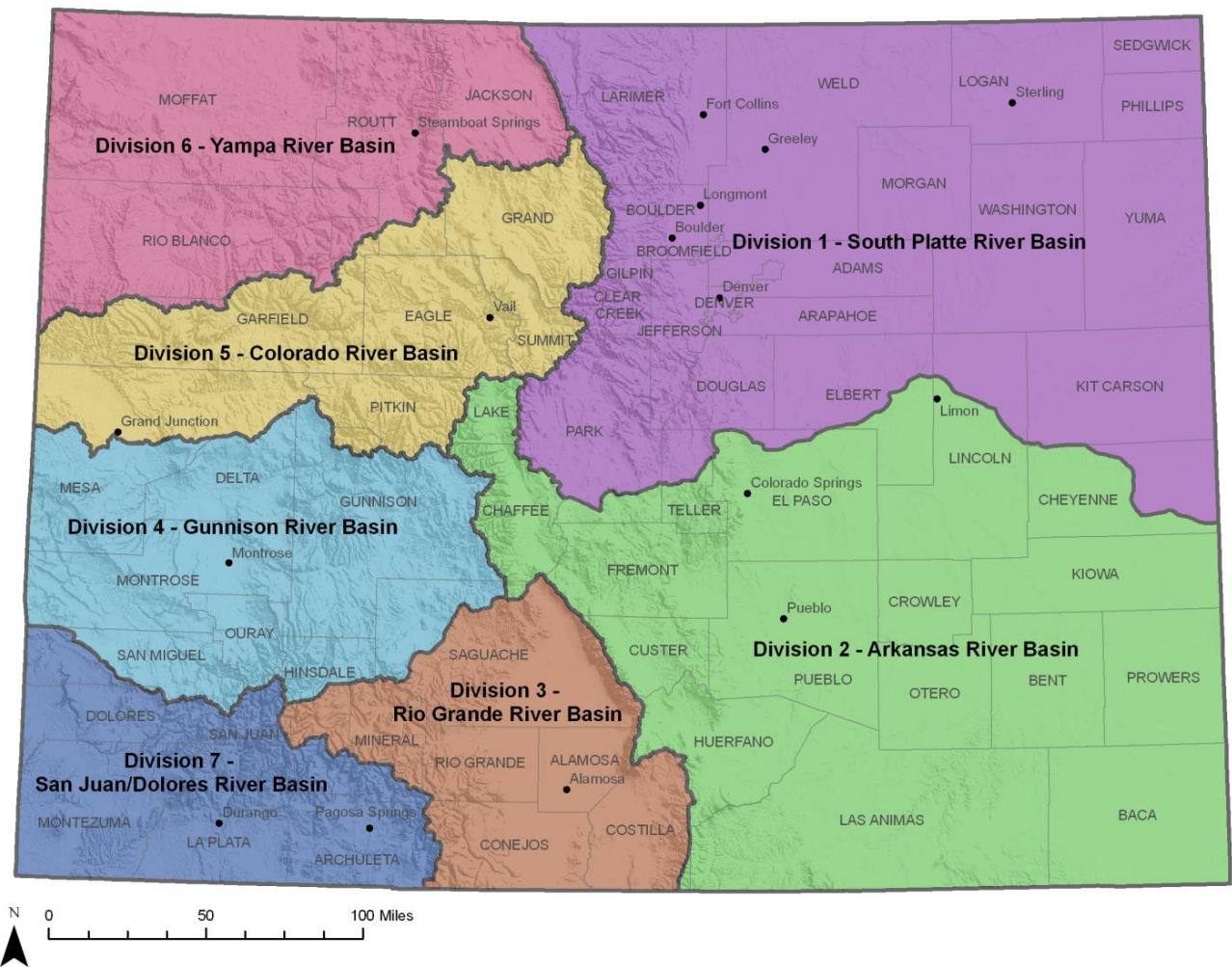
Source: CWCB 2013 drought survey data

As a component of the State drought planning process, the CWCB has developed a Municipal Drought Management Plan Guidance Document for water providers and local governments to use when developing local Drought Mitigation and Response Plans. This Guidance Document informs providers on how they may evaluate drought vulnerability and incorporate this information into their plans. Municipal providers are encouraged to submit their local plans to the CWCB. These individual local drought mitigation and response plans will serve as a vehicle to inform the State of local M&I drought vulnerability in the future. Ongoing work with the BIPs, the update to SWSI, and the water use data collected from water providers under House Bill (HB) 1051 will also contribute to more detailed assessments of vulnerability in the future. Recommendations for conducting a more detailed statewide M&I drought vulnerability assessment are made in Section 9.5.

9.4.1 Regional Assessment

For purposes of this regional assessment, the State was divided into Colorado Division of Water Resources' seven division basins (Figure 9.14). Drought vulnerability was evaluated by assessing historical drought impact information from the 2002 and 2012 droughts coupled with information on future population growth and adaptive capacities M&I providers have pursued to address drought and water supply reliability.

Figure 9.14 Colorado Water Division Basins



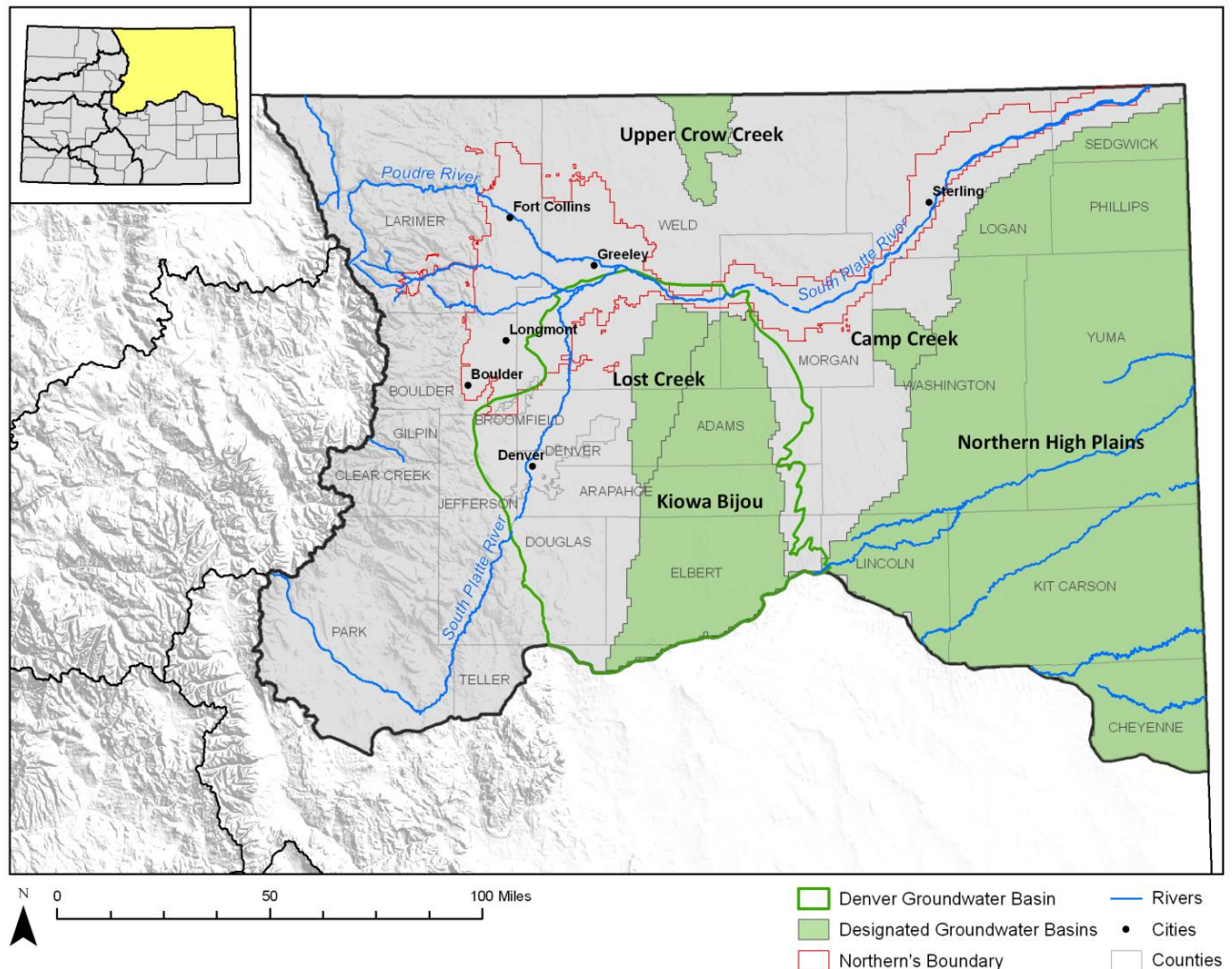
While historical drought information is not a direct reflection of future drought vulnerability, historical 2002 and 2012 drought impact data do provide a relatively recent snapshot of M&I drought vulnerability in a specific drought situation. The majority of historical drought-related impact information was obtained from CWCB’s 2004 DWSA and CWCB 2013 surveys, information on which is provided in Section 9.1. Projected future municipal water demands were obtained from CWCB’s *State of Colorado 2050 Municipal and Industrial Water Use Projections* developed for the Statewide Water Supply Initiative (SWSI 2010) process and used in the Basin Roundtables’ BIPs and the Colorado Water Plan. Case study information was also used for the assessment of the Front Range metropolitan area in the South Platte River Basin.

Division 1 - South Platte River Basin

The majority of the State’s population is located in the South Platte Basin with the densest population centers in the Denver Metropolitan Area and urban development along the northern Front Range. M&I water needs are met through a combination of surface water supplies delivered

via the South Platte River and tributaries, transbasin diversions, tributary groundwater supplies, and non-tributary/designated groundwater (Figure 9.15). Many of the municipalities in the northern half of the Basin specifically rely on Colorado - Big Thompson (C-BT) transbasin water, which is delivered via a Bureau of Reclamation project operated by the Northern Colorado Water Conservancy District (Northern).

Figure 9.15 South Platte River Basin



Historical Drought Impacts

During the 2002 drought, which was one of the worst drought years on record in terms of streamflow for many areas of the State, South Platte Basin M&I providers generally had sufficient supplies to meet demands but imposed mandatory water restrictions along the majority of the Front Range area. Many of the M&I providers that enforced water restrictions used them as a precautionary response given that the duration of the drought was unknown, and water savings achieved through restrictions would be essential to meeting future demands. M&I providers were concerned their storage reserves would not last through another year or two of similar 2002 drought conditions.

The 2004 DWSA survey results shown in Figure 9.16 indicates that over 40% of the 97 surveyed M&I providers in the South Platte River Basin experienced the following impacts during the 1999-2003 drought period:

- Loss of system flexibility
- Loss of operations revenue
- Loss of reliable water supply
- Loss of landscaped property
- Increased expenses for public education

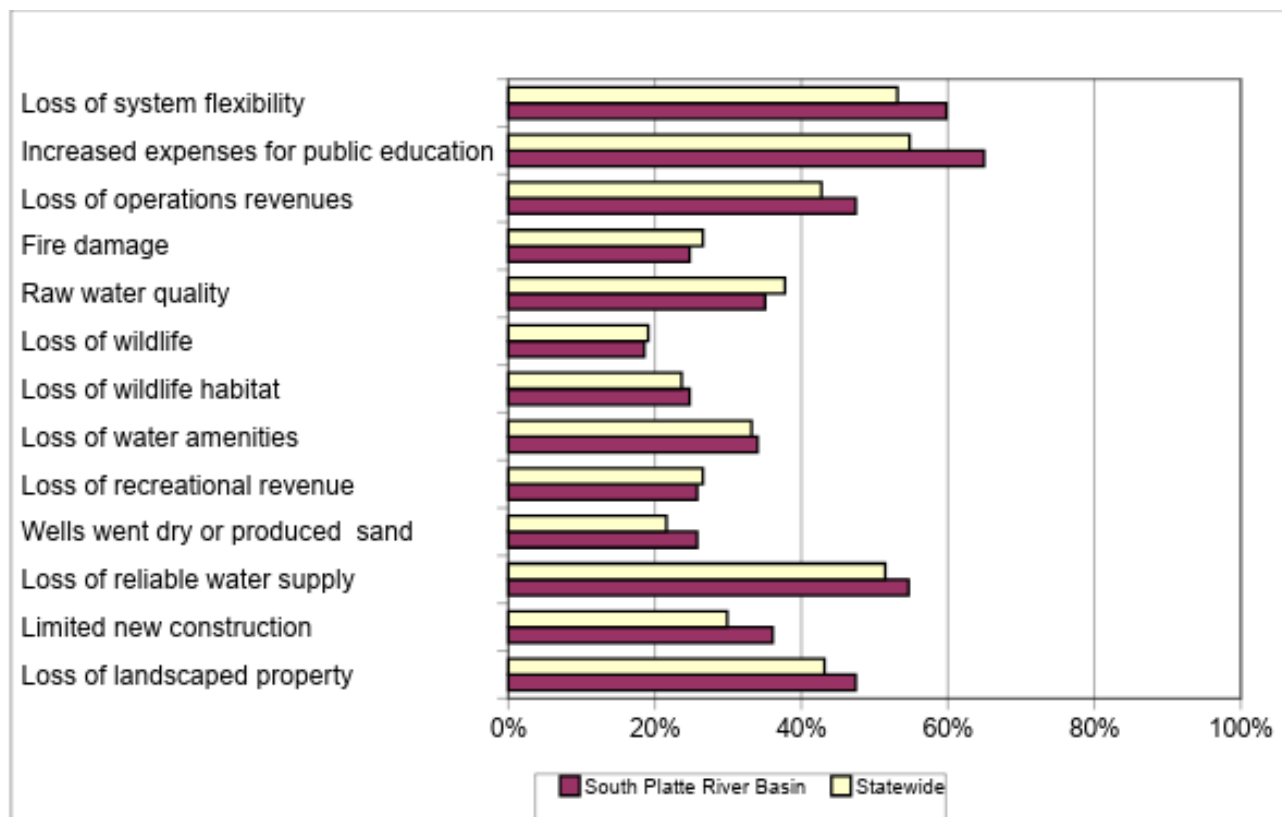
The increased expense for public education was the most frequently experienced impact, exceeding the statewide level percentage and suggesting that South Platte Basin M&I providers on average placed more financial investment into responding to the drought through public education than other basins in the State. Most of the basin-specific impacts shown in Figure 9.16 are consistent with the percentage of impacts recorded on a statewide level.

The 2013 CWCBC drought survey impacts ranked as having the highest frequency/level of concern in 2012, anticipated for 2013 and experienced for the longest duration from 2002 to 2006 were the following:

- Loss of system flexibility
- Significant loss in storage that carried over to the following year
- Increased staff time to address drought
- Increased expenses for public education and outreach
- Voluntary water restrictions

Losses in system flexibility, reliability of water storage, and increased expenses for public education as well as staff time to manage drought are common high-ranking impacts among both surveys.

Figure 9.16 South Platte River Basin 1999-2003 Drought Impacts¹⁰



Source: DWSA 2004 survey data.

Adaptive Capacities

In 2002, most M&I providers focused on implementing drought response measures to reduce demands as well as to increase supplies. The City of Louisville appears to have been the first major water provider along the Front Range of the South Platte River Basin to implement mandatory water restrictions. Most other M&I providers adopted mandatory restrictions, but generally not until mid-July or early August. Only Aurora, Berthoud, and Denver adopted pricing surcharges. Very few water M&I providers placed any restrictions on the issuance of new taps (Luecke et al., 2003).

Some M&I providers also implemented measures to increase their supplies. Examples included canceling or not renewing M&I leases of water to farmers, leasing irrigation rights from farmers, reducing minimum streamflow bypasses, increased utilization of ditch water or treated effluent for irrigating park lands, drilling supplemental wells, and in the case of some small water systems, trucking in emergency water supplies. Lafayette traded C-BT project water to Boulder for

¹⁰ Note: A comprehensive review and internal testing process of the survey tool was conducted, yet it is important to recognize that these DWSA 2004 surveyed impact results are subjective. The impacts in the figure above are, in many cases, a reflection of those surveyed interpretation of the listed impacts.

Boulder’s Baseline Reservoir water. This trade allowed each city to give up water that it controlled but could not easily use in exchange for water that was more directly deliverable. In a similar fashion, Eldora ski area acquired a lease on C-BT water and traded that water to Louisville in an exchange, whereby water from Louisville’s Marshall Reservoir was supplied to facilitate increased snowmaking diversions from South Boulder Creek for the 2002-2003 season (Luecke et al., 2003).

A few utilities began building facilities to allow them to make better use of their existing water rights. Lafayette began building a new diversion from Boulder Creek upstream of Boulder’s wastewater discharge in order to maximize use of its Boulder Creek water rights. Broomfield continued developing facilities to increase its reuse of treated wastewater effluent for irrigation (Luecke et al., 2003).

M&I providers also invoked a variety of drought reservations that allowed them to reduce bypass requirements and to interrupt agricultural leases. Denver Water invoked drought reservations that allowed it to reduce its minimum flow bypasses at its Fraser Basin points of diversion and at Strontia Springs Reservoir, and to stop other irrigation diversions temporarily above Williams Fork Reservoir. Boulder invoked its drought reservation with the CWCB in order to use senior water rights for M&I purposes, even though Boulder had previously conveyed these rights to the CWCB for instream flow purposes. In spite of this action, Boulder Creek streamflows remained at nominal levels. This is because the low water levels caused senior water rights at the bottom of Boulder Creek to place call for water forcing many users upstream from them to stop diverting. As a result water that normally would have been diverted at upstream locations was left in the creek until it got to the downstream call (Luecke et al., 2003).

The severe 2002 drought condition was a wake-up call for many M&I providers. Since this drought, municipalities and special districts have improved public education on the importance of water conservation as well as drought response and management. Some M&I providers have also developed or refined drought mitigation and response plans, while several M&I providers have been successful in regulating outdoor water use and implementing alternative water pricing programs.

Table 9.8 indicates that 72% of the 2007 DWSU surveyed municipalities in the South Platte River Basin incorporate drought recurrence in long-term water supply planning. One-third of the surveyed municipalities have drought management plans and over half have conservation and raw or treated master plans, however, the comprehensiveness of these plans varies widely. In the ten years since this survey, more municipalities have developed their own drought plans, often funded by grants.

Table 9.8 South Platte Provider Planning Efforts 2007 DWSU Survey Results¹¹

Drought-Related Planning Efforts	South Platte River Basin		Statewide Average	
	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002
Have a drought management plan	33%	27%	25%	19%
Have a raw and/or treated master plan	60%	44%	61%	37%
Have a conservation plan	51%	38%	44%	30%
Drought recurrence is considered in long-term water supply and conservation planning	72%	n/a	66%	n/a

Source: DWSU 2007 Survey

The 2013 CWCB drought survey indicated that 53% of the survey respondents either updated or developed a new comprehensive plan following the 2002 drought and 42% anticipate improving their drought preparedness following the 2012/2013 dry period. Sixty-eight percent perceive that there is sufficient funding either in-basin or through state/federal resources to support water supply reliability, conservation and drought planning.

Drought Vulnerability

The largest urban growth in the South Platte River Basin is anticipated to occur along the Front Range corridor. M&I drought vulnerability will largely depend on planning efforts and how effectively drought is incorporated into long-term water supply reliability planning as the region continues to develop.

The South Platte BIP (SP BRT, 2015) identifies the possible combined M&I and self-supplied industrial water supply gap at 428,000 acre-feet per year under a medium-level demand scenario, and notes that there is no more unappropriated water in the basin (the only remaining water is available during spring runoff in wetter-than-average years). In addition, the South Platte Basin has reduced its water use by approximately 20% since 2000 and has one of the lowest per capita uses in the state. Nearly all the growing South Platte Basin municipalities plan to fully utilize the water that they are legally entitled to reuse. This efficiency of water use under normal operating conditions makes M&I providers in the South Platte vulnerable to drought because they have a limited buffer in which to meet demands under a reduced supply scenario. Table 9.9 lists the identified projects and processes (IPPs) in the South Platte BIP. These IPPs are strategies to meet the M&I water supply gap, and either directly or indirectly help meet demands during drought periods.

¹¹ Note: A relationship between drought vulnerability and the adaptive capacities provided in this table cannot be deciphered solely using these data. While these results provide a general indication of the number of drought, conservation and raw/treated master plans, they do not provide information on the content and “overall effectiveness” of the plans. However, they do provide a general indication of M&I drought awareness on a basin-wide level.

Table 9.9 Major IPPs in the South Platte River Basin¹²

IPP Type	Project	Estimated Yield (acre-feet per year)
Passive conservation	Retrofitting homes and businesses with higher efficiency fixtures; implementing regulations and ordinances for conservation in new and existing construction.	158,000 (Passive + active conservation)
Active conservation	Education programs, incentives and rebates, fixture replacement programs, audits, and conservation rates and surcharges	
Reuse	Numerous reuse IPPs identified; see South Platte BIP for full list	58,135
Agricultural	Eight agricultural transfer IPPs identified; see South Platte BIP for full list	19,900
In-basin	Numerous in-basin IPPs identified; see South Platte BIP for full list	116,280
Transbasin	Five transbasin IPPs identified; see South Platte BIP for full list	58,000
Total Estimated Yield		410,315

The IPPs identified in the South Platte BIP and summarized in the above table are intended to close the projected gap between 2050 supply and demand. Many of these projects will also increase planning and collaboration between water providers, two strategies which have been previously identified as reducing vulnerability to drought.

To build on the discussion of drought vulnerability in the South Platte Basin, non-tributary` the populous Front Range area is divided into the Northern Front Range, Denver Metropolitan Area, and South Metro.

Northern Front Range – M&I water demands in Boulder, Larimer, and Weld Counties are anticipated to increase from the 2008 demand of 171,000 acre-feet per year to between 294,000 and 367,000 acre-feet per year by 2050 (the range reflects two scenarios: low demand with passive

¹² IPPs as identified in the South Platte BIP (SP BRT, 2015).

conservation vs. high demand with no passive conservation).¹³ These counties include municipalities of moderate size such as Boulder, Fort Collins, Greeley, Longmont, and Loveland and smaller communities and rural domestic water districts in the region that are experiencing rapid growth. Many of these entities are purchasing C-BT units and transferring the units from agricultural to M&I use. This trend is expected to continue as the area develops further. The C-BT project has a relatively reliable water supply and can provide a certain level of drought reliability, as was demonstrated during 2002 conditions. However, supplies were affected and took several years to fully recover.¹⁴ C-BT water can also be physically delivered to many northern Front Range communities. Delivery can be achieved by various exchanges and trades municipalities may be willing to develop during periods of drought. While many smaller fast-growing communities may not be sufficiently prepared for a drought, on a regional scale, emergency water needs may be provided by C-BT water and also by agricultural transfers. The northern Front Range is adjacent to the largest agricultural producing area of the State, where foregoing agricultural production by temporary transfers can be used to meet M&I needs during periods of drought. The opportunities for coordination among C-BT shareholders, holders of senior agricultural water rights, and municipalities in need of water can greatly reduce the overall drought vulnerability of the northern Front Range. Despite these opportunities, it is important to emphasize that the exchange potential along the South Platte River and tributaries, and the overall ability to meet demands through augmentation and substitute water supply plans, will generally decrease during periods of drought as streamflows, the availability of some replacement supplies (specified in augmentation and substitute water supply plans), system flexibility and overall water availability decline. Growing communities that have not incorporated drought into their long-term water supply planning efforts will thus be more vulnerable to future droughts.

Denver Metropolitan Area – M&I water demands in Adams, Denver, and Jefferson Counties are anticipated to increase from the 2008 demand of 273,000 acre-feet to between 370,000 and 470,000 acre-feet per year by 2050¹⁵ (the range reflects two scenarios: low demand with passive conservation vs. high demand with no passive conservation). The majority of the Denver Metropolitan Area is serviced by Denver Water and Aurora Water. Denver Water customers alone amount to almost one-fourth of the State’s population with a total treated water consumption in 2016 of 21,200 acre-feet (Denver Water, 2016). This water is supplied to the City and County of Denver in addition to the surrounding suburban population (Denver Water, 2013). The majority of Denver Water’s supplies come from the South Platte, Blue, Williams Fork, and Fraser River

¹³ These data are based on the 2050 projections done for SWSI 2010 (CWCB, 2010. Appendix H: *Final State of Colorado 2050 Municipal and Industrial Water Use Projections*).

¹⁴ C-BT storage was affected by below-average supplies in 2000 and 2001. In 2002, NCWCD only set a 70% quota and C-BT storage was significantly depleted by the end of 2002. This resulted in low (50% to 60%) quotas in 2003 and 2004 that reflected limited C-BT supplies.

¹⁵ These data are based on the 2050 projections done for SWSI 2010 (CWCB, 2010. Appendix H: *Final State of Colorado 2050 Municipal and Industrial Water Use Projections*).

watersheds, but supplies are also provided from the South Boulder Creek, Ralston Creek, and Bear Creek watersheds.

During the 2002 drought, Denver Water experienced a variety of drought-related impacts including the reduction in storage reserves, disruption of water supplies, loss of revenue from reduction in water sales, increased costs to respond to the drought and degraded water quality. An indirect impact was the Hayman wildfire that caused significant erosion and disrupted South Platte River supplies. Denver Water primarily responded to the drought through mandatory water restrictions and an effective drought public education campaign encouraging wise water use and conservation. Despite the 2002 drought impacts mentioned above, Denver Water was able to meet the essential needs of its service area during 2002.

Drought vulnerability within the Denver Metropolitan Area is relatively low when compared to other regions within the State. This is primarily attributed to the fact that Denver Water owns one of the most senior urban water rights portfolios along the Front Range. Denver Water has also taken additional drought mitigation actions since 2002 to further improve water supply reliability. As of 2018, the permitting process for enlarging Gross Reservoir is complete and the preliminary design phase has started. The objective of this project is to help resolve three major water supply challenges: a future water shortfall, the risk of running out of water in a future drought, and an imbalance in the collection system. Denver Water has also partnered with the Colorado State Forest Service, US Forest Service, local counties, and other M&I providers to develop watershed management plans, which will develop specific forest management practices for reducing wildfire risks with the intention of reducing water supply impact during future wildfires. Denver Water's board of directors has also adopted a policy to review and consider any proposed "cooperative action" that regions outside its service area may bring during periods of drought. Denver Water staff has subsequently discussed future possibilities for cooperative actions with suburban water suppliers in the south, northwest and northeast regions, Summit County, Grand County, Eagle County, and the City of Aurora.

Aurora Water has a diverse water rights portfolio both in the South Platte and Arkansas River Basins with a substantial portion of senior water rights. Additionally, Aurora Water has also undergone a significant effort to develop additional supplies and improve overall water supply reliability during drought periods. During the 2002 drought, Aurora Water's storage was reduced to 25% of total capacity. Aurora Water learned that they were not sufficiently prepared for a drought of this magnitude. In response, Aurora Water developed a variety of tools to enhance water supply forecasting and planning guidance during drought periods. This includes a Drought Contingency Plan, a water supply forecasting model based on reservoir levels and an annual water management plan that sets the water restrictions and level of enforcement for the upcoming year. The 2002 drought also initiated the development of the Prairie Waters Project which when operating in full capacity will increase Aurora's water supply by more than 20% by reusing return flows that remain reliable during a drought.

These efforts further reduce drought vulnerability within the Denver Metropolitan Area, although it is important to note that drought will impact individual M&I providers within the region quite differently. M&I providers with a more junior portfolio of water rights that have not effectively incorporated drought planning into their long-term supply efforts will be more vulnerable to drought than those who have more senior water right and/or effective drought plans.

South Metro - The South Metro region primarily consists of Douglas and portions of Arapahoe County south of the Denver Metropolitan Area. This area has been one of the country's fastest growing areas over the past decade. M&I providers in this region primarily rely on non-renewable Denver Basin groundwater as their principal source of supply, although some also use some relatively junior surface water flows from Cherry Creek, Plum Creek, and the South Platte River as well. While there is still a large amount of groundwater in the Denver Groundwater Basin, well pumping in response to population growth exceeds the aquifers' natural recharge and well water levels are declining. It will eventually become prohibitively expensive to pump at existing and projected withdrawal levels without significant increases in artificial recharge, or deployment of more advanced well technology; both of which are likely to be relatively costly. M&I providers and local government are proactively addressing the long-term implications of continued reliance on finite groundwater, and have formed the Douglas County Water Resource Authority and South Metro Water Supply Authority to explore strategies for a sustainable water supply future including the development of additional renewable water supplies, maximize reuse, aquifer storage and recovery (ASR), and continued water conservation (South Metro Water, 2013; Douglas County Water, 2013).

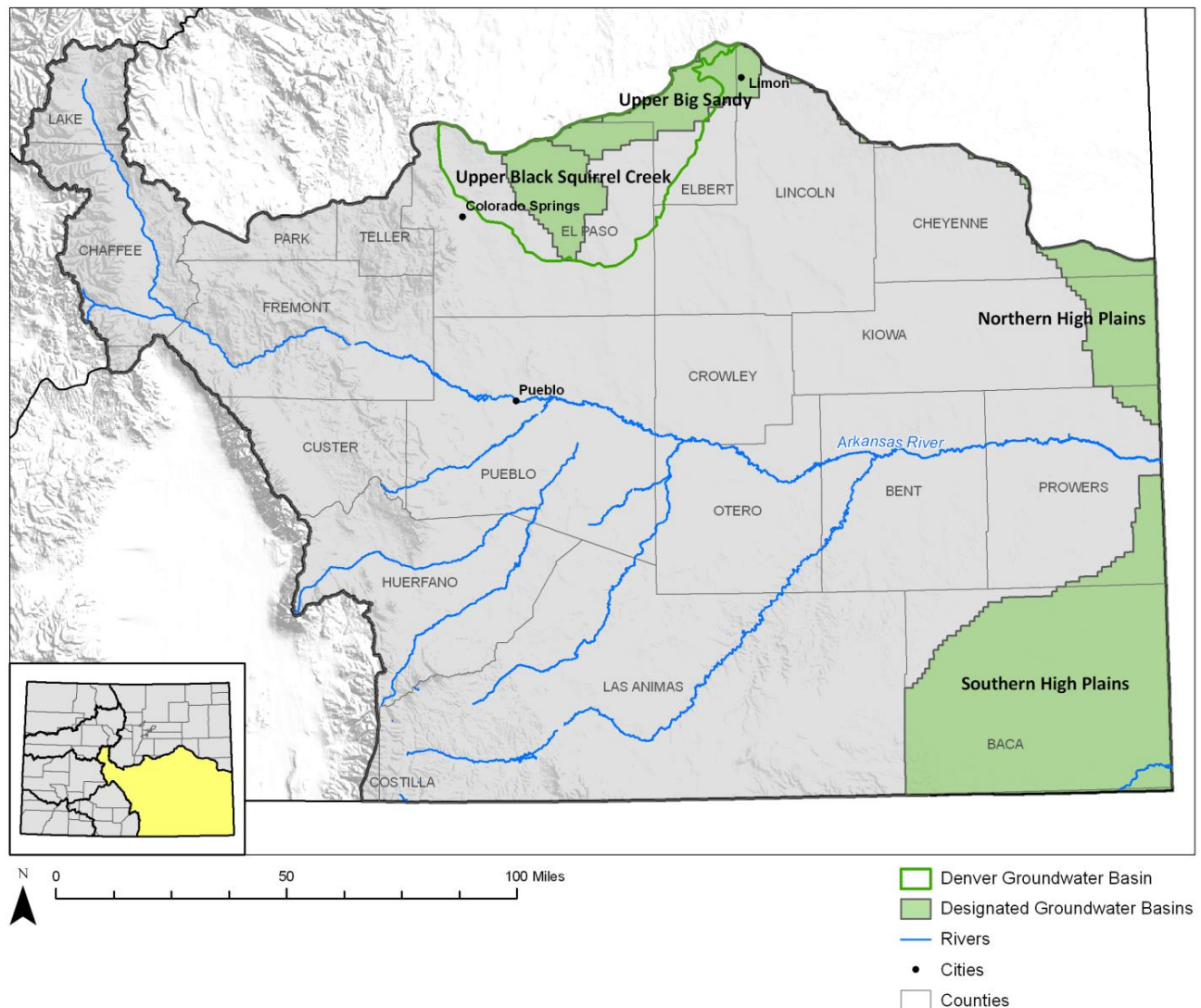
Despite long-term water supply concerns, the South Metro Area was not severely affected by the 2002 drought. Relatively few water providers enforced mandatory watering restrictions. Loss of well production was observed in some areas as a result of increased demands. However, despite these well production declines, the Denver Groundwater Basin is not affected by drought to the extent as surface water and consequently provides a more "stable" supply during drought. Consequently, the South Metro Area is not as vulnerable to drought as other municipalities along the Front Range that rely on surface water and tributary groundwater supplies. However, if alternative renewable supplies are not developed in a timely manner to address water supply reliability, the water supply reliability within the region will be at risk and long-term drought vulnerability could increase. The future vulnerability of the region to drought will depend on how reliable the new renewable water supplies actually are during periods of drought and how successfully drought planning is incorporated into long-term planning efforts.

Division 2 - Arkansas River Basin

The Division 2 - Arkansas River Basin supports the second largest population in the State and includes municipalities of moderate size such as Colorado Springs and Pueblo, and numerous smaller communities and rural domestic water districts. M&I water needs are met through a combination of surface water supplies primarily delivered via the Arkansas River and tributaries, transbasin diversions, tributary groundwater supplies, and non-tributary/designated groundwater

(Figure 9.17). M&I providers in the Southeastern Colorado Water Conservancy District (SCWCD) are heavily reliant on Fryingpan-Arkansas (Fry-Ark) transbasin diversion allocations. Other large transbasin diversions that provide M&I supplies include Homestake, Blue River, and Twin Lakes. El Paso County and communities on the Eastern Plains rely on non-tributary groundwater, while Custer, Huerfano, and Las Animas Counties primarily rely on tributary groundwater and surface water supplies.

Figure 9.17 Arkansas River Basin



Historical Drought Impacts

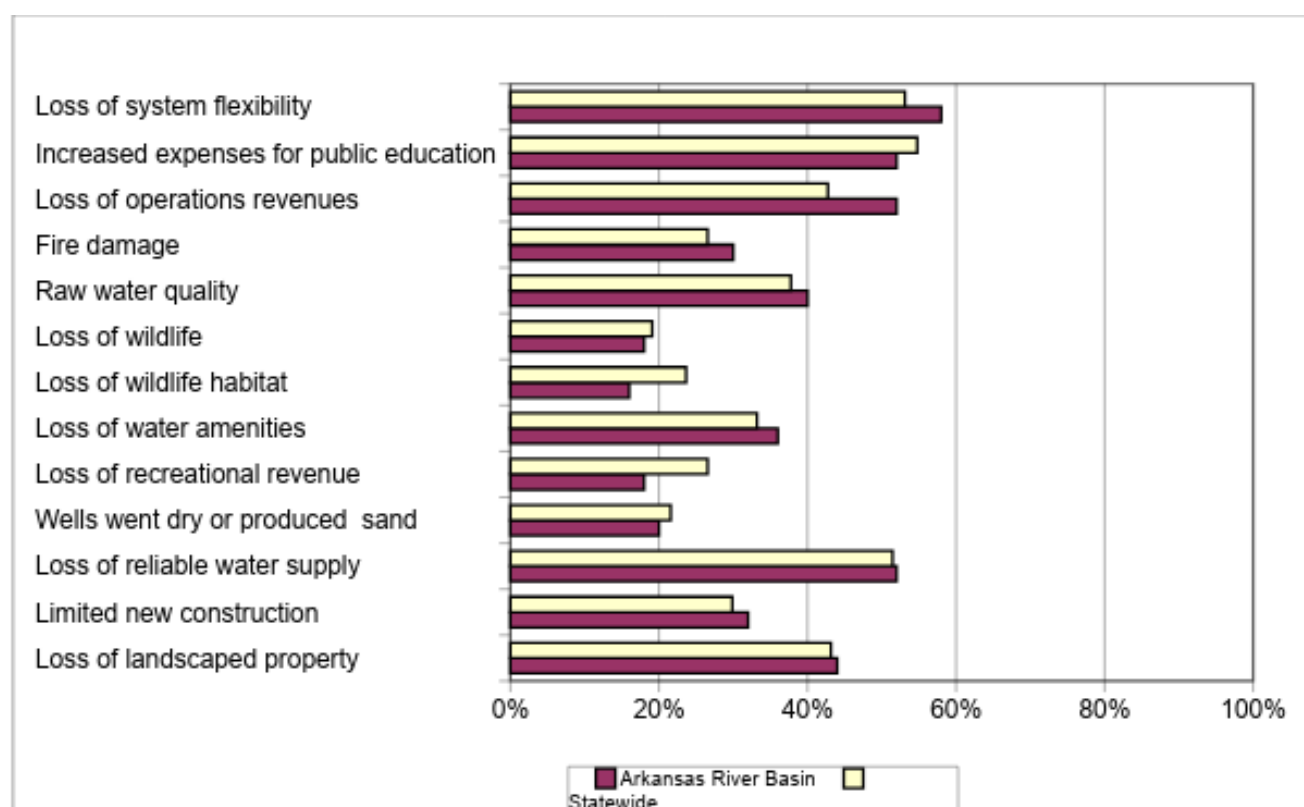
The 2004 DWSA survey results shown in Figure 9.18 indicates that over 40% of the 50 surveyed M&I providers in the Arkansas River Basin experienced the following impacts during the 1999-2003 drought period:

- Loss of system flexibility

- Increased expenses for public education
- Loss of operations revenues
- Loss of reliable water supply
- Loss of landscaped property

The loss of system flexibility appeared to be the most frequently experienced impact. All of these impacts listed above, with exception of increased expenses for public education, exceeded the frequency of impact on a statewide level. However, Figure 9.18 shows that the percentage of M&I providers that experienced impacts in the Arkansas River Basin was relatively similar to statewide surveyed impacts. The percentage of impacts at the basin level and statewide is relatively similar.

Figure 9.18 Arkansas River Basin 1999-2003 Drought Impacts¹⁶



Source: DWSA 2004 survey data.

The 2013 CWCB drought survey impacts ranked as having the highest frequency/level of concern in 2012, anticipated for 2013 and experienced for the longest duration from 2002 to 2006 were the following:

- Loss of water amenities

¹⁶ Note: A comprehensive review and internal testing process of the survey tool was conducted, yet it is important to recognize that these DWSA 2004 surveyed impact results are subjective. The impacts in the figure above are, in many cases, a reflection of those surveyed interpretation of the listed impacts.

- Loss of system flexibility
- Significant loss in storage that carried over to the following year
- Increased staff time necessary to address drought
- Loss of irrigated vegetation within urban areas
- Loss of recreational revenue
- Increased expenses for public education and outreach
- Mandatory restrictions

Of the survey impacts listed above, 1) loss of system flexibility, 2) increased expenses for public education and 3) loss of landscaped property were high ranking impacts recorded for both the 2013 CWCB survey and 2004 DWSA.

Adaptive Capacities

Table 9.10 indicates that 70% of the 2007 DWSU surveyed municipalities in the Arkansas River Basin incorporate drought recurrence in long-term water supply and conservation planning. Twenty-seven percent of the surveyed municipalities have drought management plans and 53% and 64% have water conservation plans and raw or treated water master plans, respectively. These values are expected to be higher, as many municipalities have developed formal plans to address drought in the ten years since the 2007 DWSU survey.

Table 9.10 Arkansas River Provider Planning Efforts 2007 DWSU Survey Results¹⁷

Drought-Related Planning Efforts	Arkansas River Basin		Statewide Average	
	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002
Have a drought management plan	27%	20%	25%	19%
Have a raw and/or treated master plan	64%	43%	61%	37%
Have a conservation plan	53%	39%	44%	30%
Drought recurrence is considered in long-term water supply and conservation planning	70%	n/a	66%	n/a

Source: DWSU, 2007 Survey.

The 2013 CWCB drought survey indicated that 56% of the survey respondents either updated or developed a new comprehensive drought plan following the 2002 drought and 72% perceive that there is sufficient funding either in-basin or through state/federal resources to support water supply

¹⁷ Note: A direct relationship between drought vulnerability and adaptive capacity cannot be deciphered solely using these data. While these results provide a general indication of the number of drought, conservation and raw/treated master plans, they do not provide information on the content and “overall effectiveness” of the plans. However, they do provide a general indication of M&I drought awareness on a basin-wide level.

reliability, conservation and drought planning. None of the respondents anticipate improving their drought preparedness following the 2012/2013 dry period.

Drought Vulnerability

M&I drought vulnerability will largely depend on drought planning efforts and how effectively drought is incorporated into long-term water supply reliability planning as the region continues to develop. The Arkansas BIP (Ark BRT, 2015) identifies the possible M&I gap at 20,000 acre-feet by 2020 and continue increasing through 2050, and notes that continued dependence on nonrenewable groundwater is exacerbating the gap in water supply and demand. In addition, the South Platte Basin has reduced its water use by approximately 20% since 2000 and has one of the lowest per capita uses in the state. Municipal goals in the Arkansas Basin include new regional infrastructure, including storage, and continued pursuit of Alternative Transfer Methods (ATMs) for the temporary transfer of agricultural water to municipalities. Over 200 planned future projects (IPPs) were formalized in the Arkansas. Table 9.11 lists the major projects and processes identified in 2013 to address long-term water supply needs. Many of these projects will be instrumental in maintaining water supply reliability and either directly or indirectly meeting demands during drought periods.

Table 9.11 Major IPPs in the Arkansas River Basin¹⁸

M&I Providers	Project	IPP Type
Colorado Springs Utilities, Fountain, Security WSD, Pueblo West MD	Southern Delivery System Phase I (with Local System Improvements) Southern Delivery System Phase II (with Local System Improvements)	
Colorado Springs Utilities, Aurora, Vail Consortium (Eagle River W&SD, Upper Eagle W&SD, Vail Associates), the Colorado River Water Conservation District, Cyprus Climax Metals Company	Eagle River Joint-Use Project (Eagle River MOU)	New Transbasin Project Firming Transbasin Rights
El Paso County Water Authority	Groundwater	Regional In-Basin Project
	Reuse	Reuse
Upper Arkansas Water Conservancy District	Augmentation Plan	Firming In-Basin Rights
East Twin Lakes Ditches & Waterworks Economic Development	Cache Creek Reservoir	
Southeastern Colorado Water Conservancy District	Arkansas Valley Conduit	Firming Transbasin Rights
	Preferred Storage Option Plan - Fry-Ark	
	Preferred Storage Option Plan - Pueblo Reservoir	

¹⁸ Note: The draft list of IPPs in this table is based on the 2013 information and does not include conservation.

M&I Providers	Project	IPP Type
	Preferred Storage Option Plan - Turquoise Reservoir	
Pueblo Board of Water Works	Water Rights Acquisition – Bessemer Ditch	Agricultural Transfers
	Reuse Plan	Reuse

The largest urban growth in the Arkansas Basin is anticipated in the Colorado Springs and Pueblo metropolitan areas. These municipalities have a relatively diverse portfolio of water supplies and undergo relatively comprehensive raw water master planning efforts. Consequently, they are not as vulnerable to drought as other smaller communities in the Basin. Additionally, the Southern Delivery System, which started operating in 2016 (Phase I), will provide additional drought protection to Colorado Springs, Fountain, Security, and Pueblo West.

Communities in the headwaters of the Basin are also projected to experience high growth rates, and this area will find it challenging to develop augmentation water necessary to augment well requirements (CWCB, 2004). Communities in the eastern plains are not anticipated to experience as much growth (CWCB, 2004); however, many of these communities rely on more junior surface and tributary groundwater rights in addition to non-tributary groundwater. Water quality is also a concern in part of the lower portions of the Basin. The Colorado Department of Public Health and Environment (in a February 2002 report) stated: “The Lower Arkansas River in Colorado is the most saline stream of its size in the United States. The average salinity levels increased from 300 ppm TDS east of Pueblo to over 4,000 ppm near the Kansas state line. The shallow alluvial groundwater along the river has a similar salinity.” The Arkansas Valley Conduit will help relieve some of the water quality concerns for M&I water providers and reduce drought vulnerability. In 2017, the Bureau of Reclamation completed a Feasibility Design Report for the Arkansas Valley Conduit (Southeastern Colorado Water Conservancy District, 2018). This pipeline will convey water from Pueblo Reservoir to M&I water providers along the Arkansas River east to Lamar, Colorado.

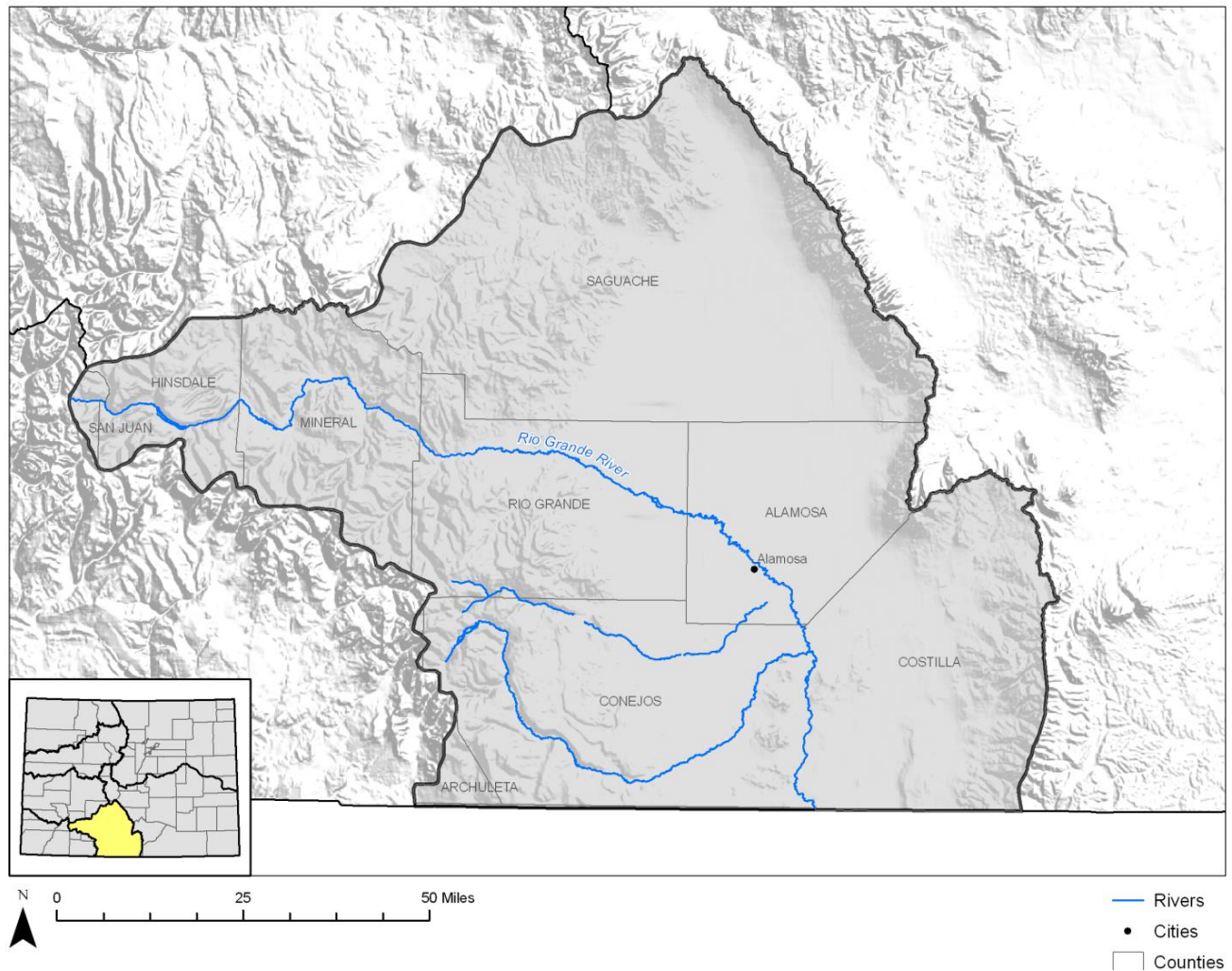
There is interest and economic incentive to sell agricultural rights to municipalities outside of the Basin (Arkansas Valley Irrigator Incorporated, 2013). The Super Ditch Company was developed with the Lower Arkansas Valley Water Conservancy District to preserve irrigated agriculture in the Lower Arkansas Basin with temporary water transfers and other methods that can benefit both the municipal interests and those of local agriculture. The primary mechanism for temporary water transfer is rotational fallowing of fields under ditches that participate in the Super Ditch Company. The first leasing arrangement was a pilot project that transferred certain shares of agricultural water from farmland irrigated by the Catlin Canal, in Otero County, to temporary municipal use by the Town of Fowler, City of Fountain, and the Security Water District. This occurred toward the end of 2009. As of 2015, there are irrigation companies and municipalities willing to participate in the program, but the project is moving forward slowly. This program could facilitate mutually beneficial reductions in M&I drought vulnerability while also reducing agricultural impacts within the lower Arkansas River Basin.

As the Arkansas River Basin continues to develop, Arkansas River compact obligations will still need to be met. The drought vulnerability of smaller communities, relying on surface and tributary supplies, can be reduced if these communities are prepared for how changes in river administration can affect overall water supply reliability during times of drought. Generally, communities with senior water right portfolios and diverse supplies or using relatively stable non-tributary groundwater supplies have relatively high water supply reliability. These communities are less vulnerable to drought than communities relying on less reliable junior surface rights to meet their needs. However, it is important to note that unsustainable use of non-tributary groundwater can result in long-term water supply concerns.

Division 3 - Rio Grande River Basin

The Division 3 - Rio Grande River Basin contains some of the State's oldest and most productive agricultural lands, with relatively little urban development compared to other basins. M&I water needs in the Basin are largely met through groundwater pumping and make up a very small amount of the overall water demands in the Basin (CWCB, 2004). The State and existing groundwater users in the Basin are engaged in rulemaking and management activities to ensure that groundwater pumping is maintained at sustainable levels.

Figure 9.19 Rio Grande River Basin

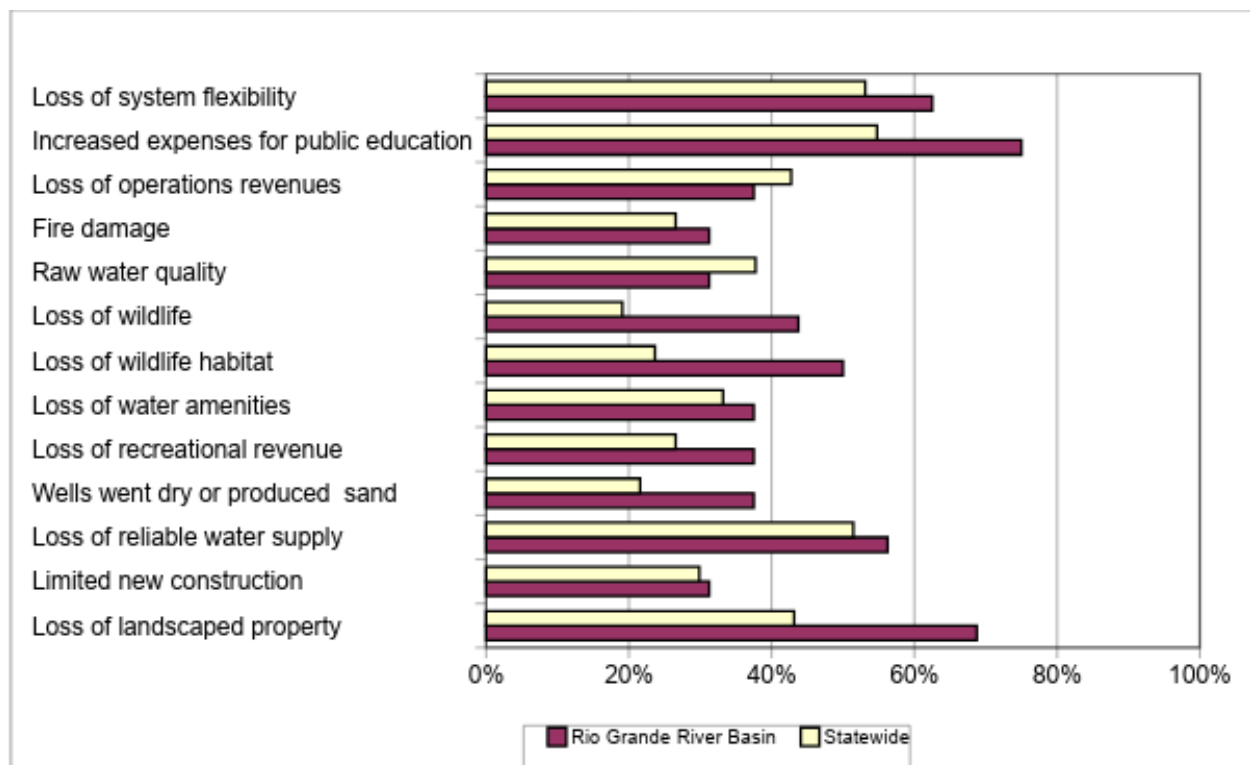


Historical Drought Impacts

The 2004 DWSA survey results shown in Figure 9.20 indicates that over 40% of the 16 surveyed M&I providers in the Rio Grande River Basin experienced the following impacts during the 1999-2003 drought period:

- Loss of system flexibility
- Increased expenses for public education
- Loss of wildlife
- Loss of wildlife habitat
- Loss of reliable water supply
- Loss of landscaped property

Figure 9.20 Rio Grande River Basin 1999-2003 Drought Impacts¹⁹



Source: DWSA 2004 survey data.

Increased expenses for public education followed by loss of landscaped property were the most frequently experienced impacts. All of the impacts with exception to raw water quality and loss of operations revenues exceeded statewide levels suggesting that M&I drought-related impacts were generally greater than experienced at a statewide level.

The 2013 CWCB drought survey impacts ranked as having the highest frequency/level of concern in 2012, anticipated for 2013 and experienced for the longest duration from 2002 to 2006 were the following:

- Decreased groundwater availability
- Significant loss in storage that carried over to the following year
- Loss of system flexibility
- Decrease in operations revenue
- Increased expenses for public education and outreach
- Loss of recreational revenue
- Increased staff time necessary to address conditions

¹⁹ Note: A comprehensive review and internal testing process of the survey tool was conducted, yet it is important to recognize that these DWSA 2004 surveyed impact results are subjective. The impacts in the figure above are, in many cases, a reflection of the DWSA author's interpretation of the listed impacts.

Of the survey impacts listed above, loss of system flexibility and increased expenses for public education were high ranking impacts recorded for both the 2013 CWCB survey and 2004 DWSA.

The Basin has experienced an extended drought that began in 2002 and is currently (as of 2018) ongoing; this has rendered the Rio Grande Compact with downstream states New Mexico and Texas increasingly difficult to administer (RG BRT, 2015). The average river flow since 2000 has been 15% lower than the long-term historical average, and some climate change scenarios show that flows could decrease by 30% from the long-term average.

Adaptive Capacities

Table 9.12 presents 2007 DWSU survey results. This shows that 56% of the surveyed municipalities in the Rio Grande River Basin incorporate drought recurrence in long-term water supply planning. Eleven percent of the surveyed municipalities have drought management plans while 22% and 33% have water conservation and raw or treated water master plans, respectively. These planning efforts are below the statewide average.

Table 9.12 Rio Grande River Basin Provider Planning Efforts 2007 DWSU Survey Results²⁰

Drought-Related Planning Efforts	Rio Grande River Basin		Statewide Average	
	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002
Have a drought management plan	11%	0%	25%	19%
Have a raw and/or treated master plan	33%	11%	61%	37%
Have a conservation plan	22%	11%	44%	30%
Drought recurrence is considered in long-term water supply and conservation planning	56%	n/a	66%	n/a

Source: DWSU 2007 Survey.

Drought Vulnerability

Population in the Rio Grande River Basin is not anticipated to increase substantially relative to the remainder of the State,²¹ and consequently future M&I demand growth is expected to be relatively small.²² However, the drought that started in 2002 and continued through 2015 resulted in higher demand on the aquifer, and the unconfined aquifer is facing an average annual over-draft of 85,000

²⁰ Note: A direct relationship between drought vulnerability and adaptive capacity cannot be deciphered solely using these data. While these results provide a general indication of the number of drought, conservation and raw/treated master plans, they do not provide information on the content and “overall effectiveness” of the plans. However, they do provide a general indication of M&I drought awareness on a basin-wide level.

²¹ This is based on the Baseline M&I forecast for the medium 2050 growth scenario presented in CWCB. 2010. *Final State of Colorado 2050 Municipal and Industrial Water Use Projections*

²² These data are based on the Baseline M&I forecast for the medium 2050 growth scenario presented in CWCB. 2010. *Final State of Colorado 2050 Municipal and Industrial Water Use Projections*.

acre-feet. While most of the reductions in consumptive use will come from agriculture (as this sector makes up 99% of the water use in the Basin), M&I well users will be subject to the same rules and will need to find replacement water to continue pumping into the future (RG BRT, 2015).

The Rio Grande BIP notes that M&I use, which is primarily met with confined aquifer pumping, represents a very small part of water use in the Basin. M&I use is projected to increase from a 2008 demand of 18,000 acre-feet per year to between 25,000 and 30,000 acre-feet per year, depending on growth scenario (SWSI 2010). Many of the Basin's water providers have a service area population of less than 1,000. These smaller water providers likely lack staff and resources to develop drought management plans and respond to capital improvement requirements in the event of reduced water quality. For the majority of towns, the existing treated water infrastructure is believed to be adequate, but the towns of Sanford, Romeo, and Baca Grande may require development of additional water resources in the future.

The Rio Grande BIP identified IPPs that meet needs and goals for M&I water supply, and either directly or indirectly help meet demands during drought periods. These are:

- Doppler Radar Weather Forecasting Project
- Groundwater Management Subdistricts
- Rio Grande Basin Hydrology Study (Long-Term)
- Rio Grande Cooperative Project
- Rio Grande Headwaters Restoration Project
- Rio Grande Initiative Conservation Easements
- Rio Grande National Forest Plan Revision
- Rio Grande Water Quality Study, Post-Wildfire Impacts
- Trujillo Meadows Reservoir Storage
- Upper Rio Grande Assessment

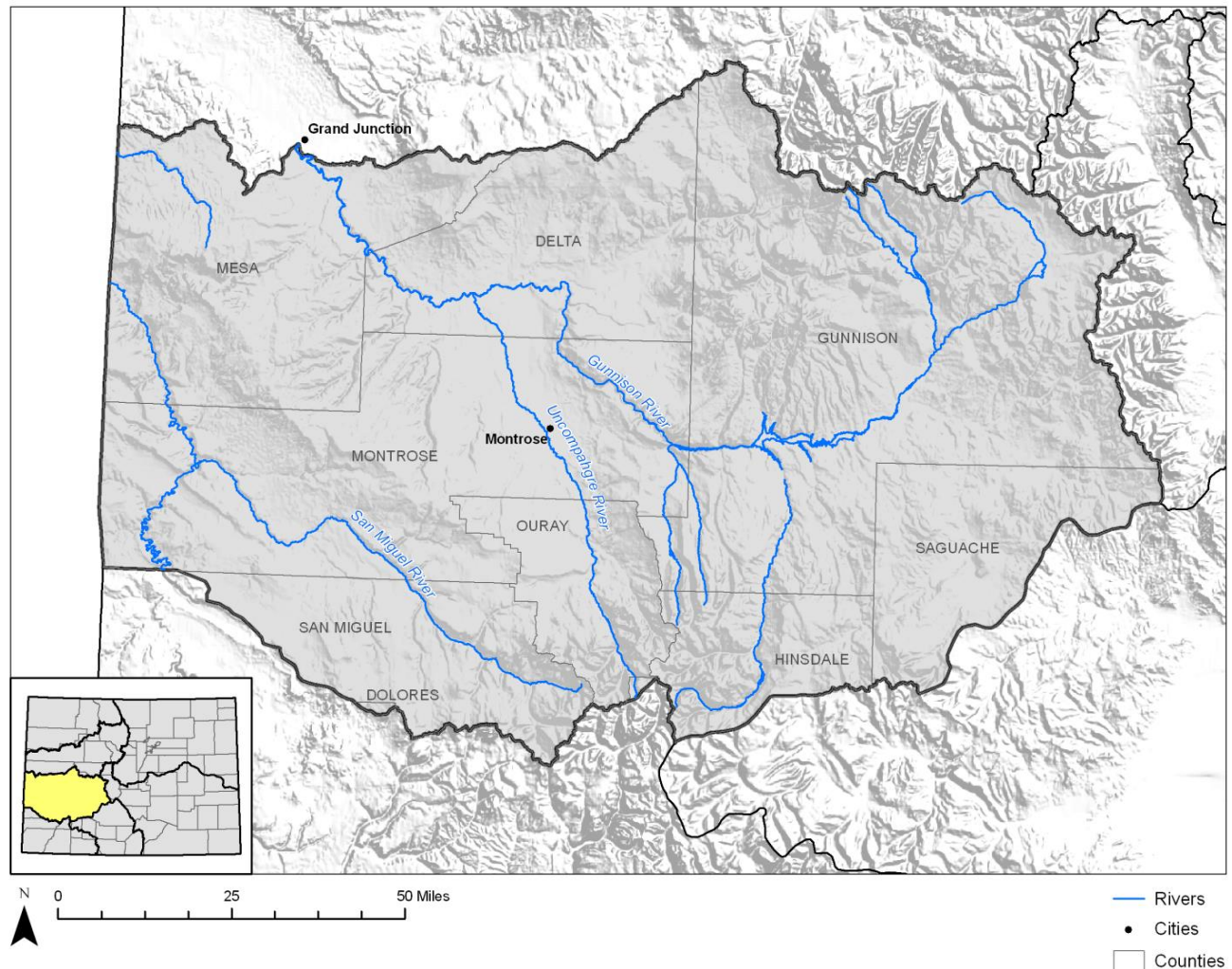
In addition to collaborating during the process of writing the Rio Grande BIP, water users in the Basin are working together to develop a means to maintain groundwater levels and augment stream depletions while also meeting the Rio Grande Compact out-of-state delivery requirements. The Rio Grande Compact's delivery requirements coupled with the recently new rules limits the development of new water in the Basin. Consequently, augmentation of M&I well pumping will likely be provided through existing transbasin water rights diverted from the San Juan/Dolores River Basin and existing and future agricultural transfers. Future M&I drought vulnerability will largely depend on the seniority and reliability of M&I augmentation supplies during periods of drought.

Division 4 - Gunnison River Basin

The Division 4 - Gunnison River Basin is sparsely populated and the M&I water demands are relatively minor compared to other basins in the State. Water uses are balanced between irrigated agriculture, gold medal fisheries, and growing communities. Populated urban areas include the

towns of Gunnison, Crested Butte, Montrose, and Delta. One major transbasin diversion, the Redlands Power Canal, exports water from the Gunnison Basin to the Colorado mainstem basin. M&I water needs are primarily met through a combination of surface water supplies delivered via the Gunnison River and its tributaries and tributary groundwater supplies (CWCB, 2004).

Figure 9.21 Gunnison River Basin



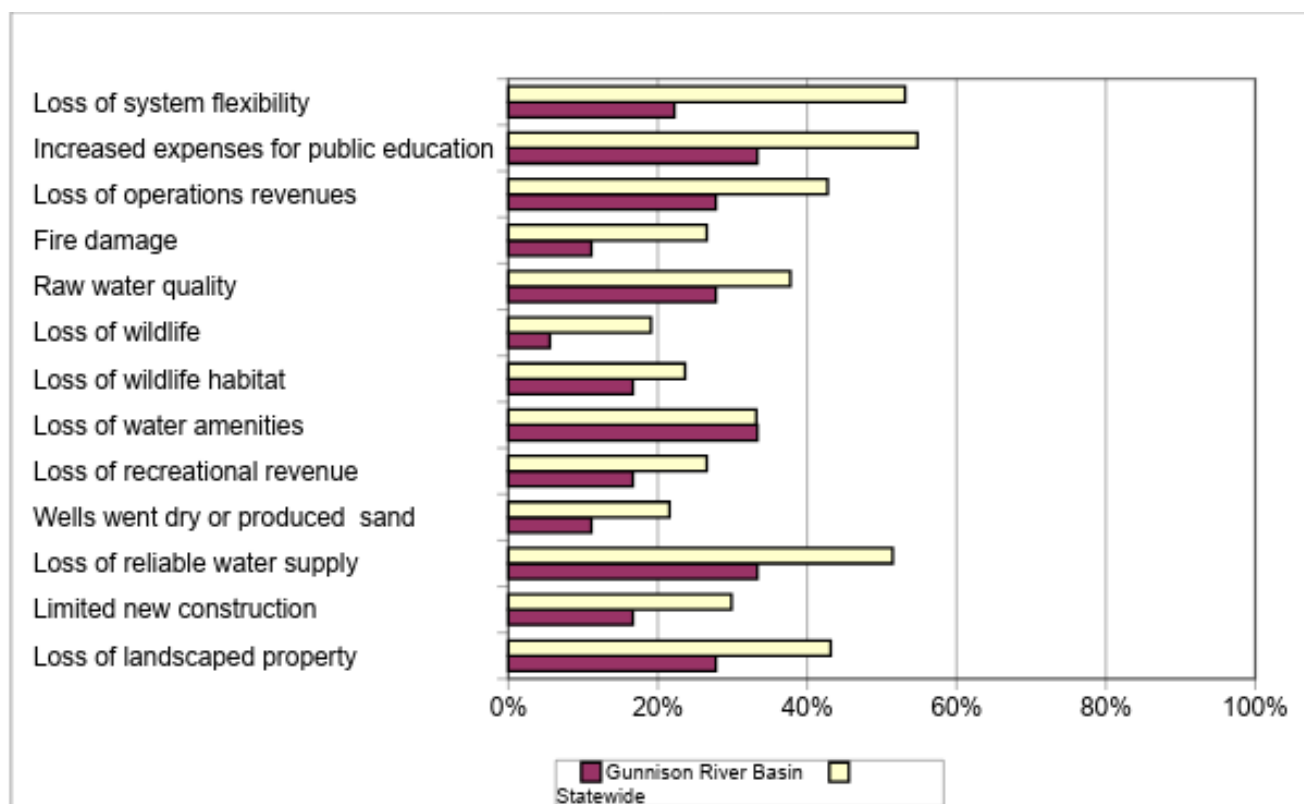
Historical Drought Impacts

The Gunnison River Basin, along with the Yampa River Basin, had the lowest number of impacts during the 1999-2003 drought period based on the 2004 DWSA survey results. The 2004 DWSA survey impacts for the Gunnison River Basin are shown in Figure 9.23. Impacts with the highest percentage of occurrence among the 18 surveyed M&I providers were the following:

- Increased expenses for public education
- Loss of water amenities
- Loss of reliable water supply

All impacts with exception to loss of water amenities were less than statewide levels.

Figure 9.22 Gunnison River Basin 1999-2003 Drought Impacts²³



Source: DWSA 2004 survey data.

The 2013 CWCB survey impacts ranked as having the highest frequency/level of concern in 2012, anticipated for 2013 and experienced for the longest duration from 2002 to 2006 were the following:

- Loss of system flexibility
- Significant loss in storage that carried over to the following year
- Increased staff time necessary to address drought
- Decrease raw water quality

None of the high ranking impacts in the CWCB 2013 drought survey were the same impacts identified during the 2004 DWSA. However, each of the surveys capture impacts related to water supply reliability which include loss of system flexibility, loss in carryover storage and loss in overall system reliability.

²³ Note: A comprehensive review and internal testing process of the survey tool was conducted, yet it is important to recognize that these DWSA 2004 surveyed impact results are subjective. The impacts in the figure above are, in many cases, a reflection of those surveyed interpretation of the listed impacts.

Adaptive Capacities

Table 9.13 indicates that 40% of the 2007 DWSU surveyed municipalities in the Gunnison River Basin incorporate drought recurrence in long-term water supply and conservation planning, which is lower than the statewide average. Thirty percent of the surveyed municipalities have drought management plans while 50% have conservation and raw or treated master plans, respectively. Drought and conservation planning is above the State average while conversely, treated/raw master planning is below the State average.

All three of the 2013 CWCB drought survey respondents indicated that they have either updated or developed a new comprehensive plan following the 2002 drought and anticipate improving their drought preparedness following the 2012/2013 dry period. None of the respondents feel that there is sufficient funding to support water supply reliability, conservation and drought planning.

Table 9.13 Gunnison River Basin Provider Planning Efforts 2007 DWSU Survey Results ²⁴

Drought-Related Planning Efforts	Gunnison River Basin		Statewide Average	
	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002
Have a drought management plan	30%	10%	25%	19%
Have a raw and/or treated master plan	50%	30%	61%	37%
Have a conservation plan	50%	30%	44%	30%
Drought recurrence is considered in long-term water supply and conservation planning	40%	n/a	66%	n/a

Source: DWSU 2007 Survey.

Drought Vulnerability

Many of the municipalities in the Gunnison River Basin, particularly the headwaters communities (e.g., Crested Butte) are anticipated to grow by 2050. Urban development will mainly be concentrated in Delta, Montrose, and Mesa Counties. Many of these M&I providers have identified plans for meeting future water needs that include local storage projects and agricultural transfers. Much of the M&I needs will be addressed through existing rights and new regional in-basin projects (SWSI 2010, GBRT 2014). Table 9.14 lists major projects and processes identified in 2013 to address long-term water supply needs. These projects will be instrumental in maintaining water supply reliability and either directly or indirectly meeting demands during drought periods.

²⁴ Note: A direct relationship between drought vulnerability and adaptive capacity cannot be deciphered solely using these data. While these results provide a general indication of the number of drought, conservation and raw/treated master plans, they do not provide information on the content and “overall effectiveness” of the plans. However, they do provide a general indication of M&I drought awareness on a basin-wide level.

Table 9.14 Major Identified Projects and Processes in the Gunnison River Basin²⁵

M&I Providers	Project	IPP Type
Upper Gunnison River Water Conservancy District	Plan for augmentation for non-agricultural purposes using Aspinall Unit	Firming In-Basin Rights
	Reservoirs on Cochetopa Creek	
Mt. Crested Butte and the Upper Gunnison River Water Conservancy District	Augmentation Storage for Mt. Crested Butte	Firming In-Basin Rights
Upper Gunnison River Water Conservancy District and Hinsdale County Commissioners	Lake San Cristobal water development	Regional In-Basin Project

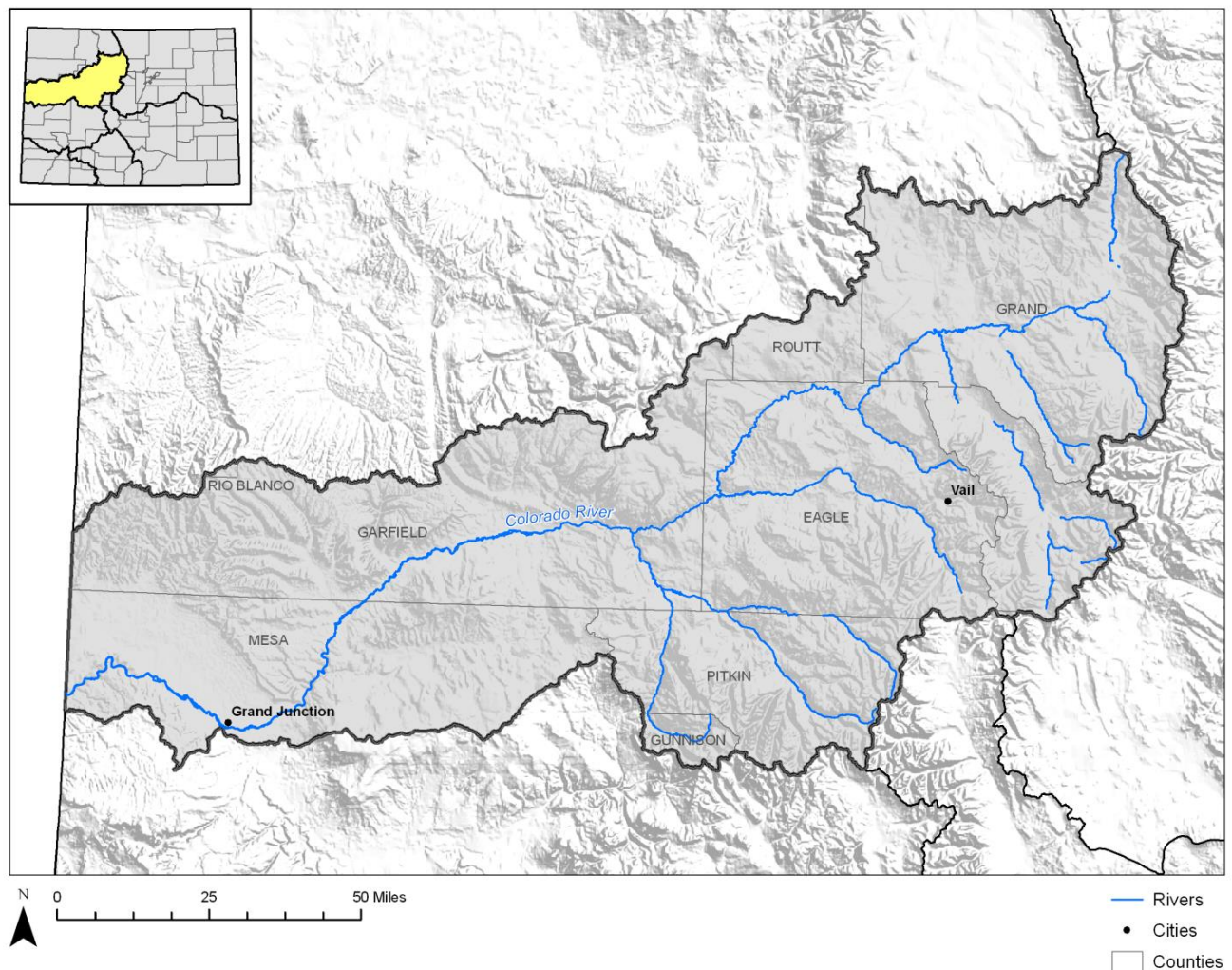
Well augmentation water is necessary to meet many of the M&I demands in the upper Gunnison and Uncompahgre sub-basins; the Upper Gunnison River Water Conservancy District provides augmentation for wells in a portion of the upper basin. The drought impacts recorded in Figure 9.23 are generally well below the statewide average. However, future M&I growth may stress water supplies, especially during times of drought. M&I drought vulnerability could increase for some M&I providers if drought is not effectively incorporated into long-term water supply reliability planning.

Division 5 - Colorado River Basin

The Division 5 - Colorado River Basin supports growing mountain resort communities in Eagle, Summit, Pitkin, and Grand Counties as well as Grand Junction, the largest city in the basin, and the agricultural community of Palisade. M&I water needs are met through a combination of surface water supplies primarily delivered via the Colorado River and its tributaries and tributary groundwater supplies.

²⁵ Note: The draft list of IPPs in this table is based on the 2013 information and does not include conservation. A full list of IPPs for the Rio Grande Basin can be found in their BIP.

Figure 9.23 Colorado River Basin



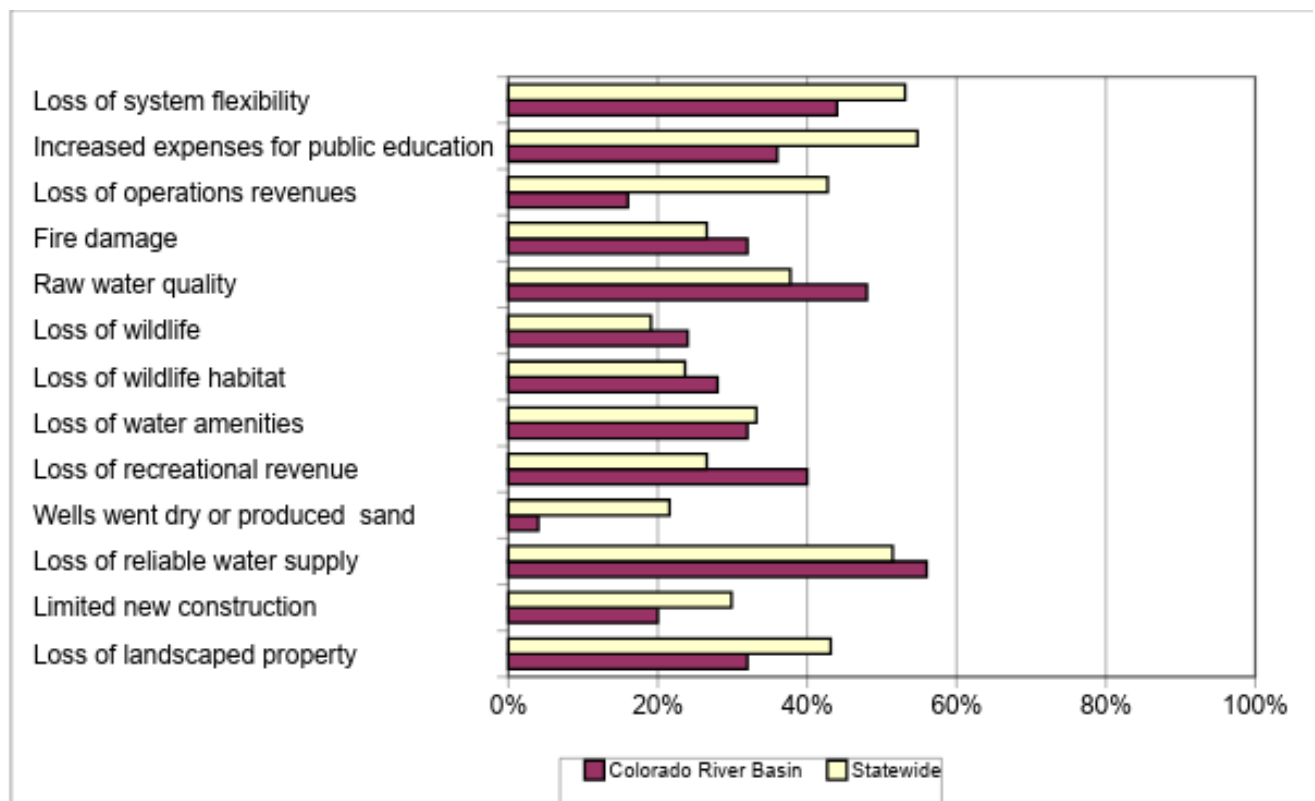
Historical Drought Impacts

The 2004 DWSA survey results shown in Figure 9.24 indicate that over 40% of the 25 surveyed M&I providers in the Colorado River Basin experienced the following impacts during the 1999-2003 drought period:

- Loss of system flexibility
- Raw water quality
- Loss of reliable water supply

The loss of reliable water supply was the most frequently experienced impact, exceeding the statewide level percentage. Raw water quality and the impacts related to recreation, wildlife, and fire damage also exceeded statewide levels. However, many of the impact percentages were significantly lower than statewide levels with the greatest differences observed for the loss of operations revenues, wells went dry and increased expenses for public education impacts.

Figure 9.24 Colorado River Basin 1999-2003 Drought Impacts²⁶



Source: DWSA 2004 survey data.

The 2013 CWCB drought survey impacts ranked as having the highest frequency/level of concern in 2012, anticipated for 2013 and experienced for the longest duration from 2002 to 2006 were the following:

- Loss of system flexibility
- Decreased raw water quality
- Increased expenses for public education and outreach
- Voluntary water restrictions
- Mandatory water restrictions
- Decreased storage levels

Losses in system flexibility and decreased raw water quality were high ranking impacts among both the 2004 DWSA and 2013 CWCB drought surveys.

²⁶ Note: A comprehensive review and internal testing process of the survey tool was conducted, yet it is important to recognize that these DWSA 2004 surveyed impact results are subjective. The impacts in the figure above are, in many cases, a reflection of those surveyed interpretation of the listed impacts.

The 2003 Upper Colorado River Basin Study (UPCO) identified the following major impacts during the 2002 drought that resulted in local M&I water shortages (Hydrosphere, 2003):

- Problems occurred with Green Mountain Reservoir including exhausting the historic users pool and the impact of the Heeney slide, which prevented full use of the reservoir’s available storage;
- Denver Water reduced its bypass flows past their Moffat Collection System, significantly reducing streamflows in the Fraser River Basin;
- Due to agreements between water users and Xcel Energy, there were changes in the administration of the Shoshone call;
- Clinton Reservoir failed to fill for the majority of the 1999-2003 dry period, causing shortages in the planned 3-year supply for certain shareholders; and
- Denver Water nearly exhausted its Williams Fork Reservoir supply and resorted to use of Dillon Reservoir to augment its Fraser River diversions.

The Colorado River BIP notes that climate change, like drought, can have serious impacts on water supplies. These impacts include shifts in timing and intensity of precipitation, reductions in late-summer flows, decreases in runoff, increases in drought, and modest declines for Colorado’s high-elevation snowpack (CBRT, 2015).

Adaptive Capacities

Table 9.15 indicates that 74% of the 2007 DWSU surveyed municipalities in the Colorado River Basin incorporate drought recurrence in long-term water supply and conservation planning. This is higher than the statewide average. Twenty-six percent of the surveyed municipalities have drought management plans, while 40% and 63% have conservation and raw or treated master plans, respectively. The percentage of surveyed providers with conservation plans in the Basin is below the State average while conversely, treated/raw master planning is above the State average.

Table 9.15 Colorado River Basin Provider Planning Efforts 2007 DWSU Survey Results²⁷

Drought-Related Planning Efforts	Colorado River Basin		Statewide Average	
	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002
Have a drought management plan	26%	22%	25%	19%
Have a raw and/or treated master plan	63%	48%	61%	37%
Have a conservation plan	40%	26%	44%	30%

²⁷ Note: A direct relationship between drought vulnerability and adaptive capacity cannot be deciphered solely using these data. While these results provide a general indication of the number of drought, conservation and raw/treated master plans, they do not provide information on the content and “overall effectiveness” of the plans. However, they do provide a general indication of M&I drought awareness on a basin-wide level.

Drought recurrence is considered in long-term water supply and conservation planning	74%	n/a	66%	n/a
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Source: DWSU 2007 Survey.

Sixty-seven percent of the 2013 CWCB drought survey respondents (6 respondents) indicated that they have either updated or developed a new comprehensive plan following the 2002 drought and 50% anticipate improving their drought preparedness following the 2012 – 2013 dry period. Sixty-four percent of the respondents feel that there is sufficient funding to support water supply reliability, conservation and drought planning.

Drought Vulnerability

Figure 9.2 indicates that by 2050, M&I providers in Garfield, Eagle, and Summit Counties are anticipated to experience the greatest increase in M&I demands within the Colorado River Basin.²⁸ The projected Colorado River Basin Gap ranges from 22,000 to 48,000 acre-feet per year, depending upon low to high population projections (SWSI 2010), although the CBRT considers this number an irrelevant statistic for the Colorado River Basin, and plans to quantify the gap following completion of the basinwide Stream Management Plan (CBRT, 2015). Table 9.16 lists some of the basin-wide top projects identified by the CBRT to address long-term water supply needs. The complete list of regional projects and detailed project information sheets are in the Colorado River BIP. Many of these projects will be instrumental in maintaining water supply reliability and either directly or indirectly meeting demands during drought periods.

Table 9.16 Major Identified Projects and Processes in the Colorado River Basin

Project	Sponsor
Protect existing and future west slope uses	CBRT, West Slope entities, Colorado River District, The Nature Conservancy
Colorado River Cooperative Agreement	17 West Slope signatories and Denver Water
Grand Valley Roller Dam Rehabilitation	Grand Valley Water Users Association, Orchard Mesa, Palisade and Mesa County Irrigation Districts, Colorado Basin Roundtable
Colorado Basin Stream Management Plan	Conservancy District, Watershed Groups, Local Governments, Environmental Groups, CPW, CWCB, CBRT, USFS, BLM
Protect the Shoshone Hydroelectric Plant Call	CRCA Signatories, Xcel Energy, other diverters, Reclamation, and the State of Colorado

It is anticipated that augmentation contracts available out of Ruedi, Green Mountain, and Wolford reservoirs will be an important part of meeting existing and projected 2030 demands in the Basin, especially in the upper headwater counties. As indicated above, problems occurred with Green Mountain Reservoir during the 2002 drought exhausting the historic users pool, and the impact of the Heeney slide ultimately prevented full use of the reservoir's available storage. Low

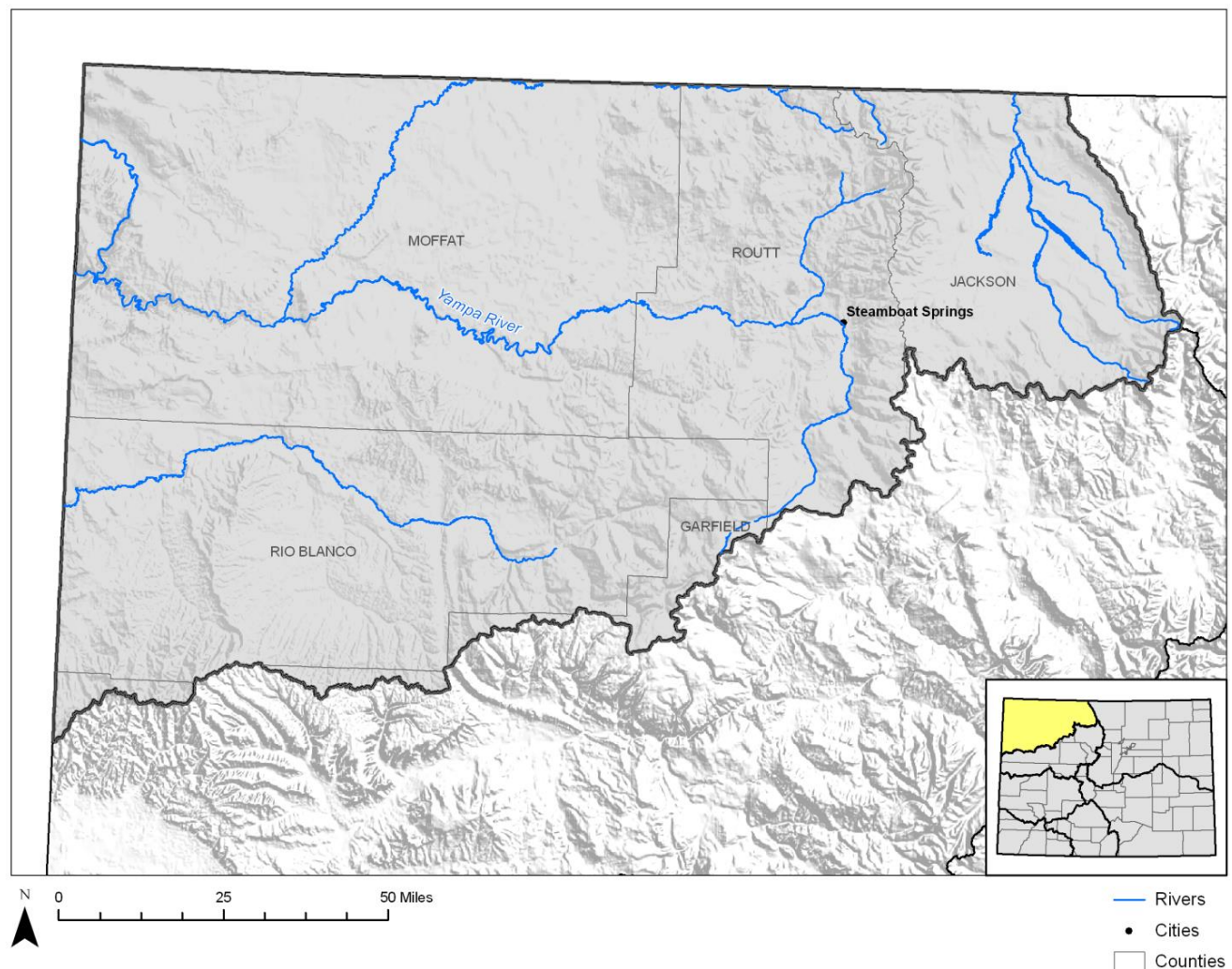
²⁸ The data presented in the table is based on the Baseline M&I forecast for the medium 2050 growth scenario presented in *Final State of Colorado 2050 Municipal and Industrial Water Use Projections*

streamflows also reduced the amount of water physically available for diversions, impacting several upper basin M&I providers. These areas may continue to be more vulnerable to drought unless supply alternatives and effective response measures can be developed for drought periods. The Colorado BIP calls for water providers to update their master plans to account for extreme droughts, a Compact call, and climate change scenarios, as reliance on historical hydrology will not prepare for a future with extended droughts and climate change (CBRT, 2015).

Division 6 - Yampa River Basin

The Division 6 - Yampa River Basin includes Routt, Rio Blanco, Moffat, and part of Eagle and Garfield Counties. The Basin is sparsely populated with Steamboat Springs and Craig being the largest towns. M&I water needs are mainly met through surface water supplies delivered via the Yampa River and tributaries and secondarily by tributary wells.

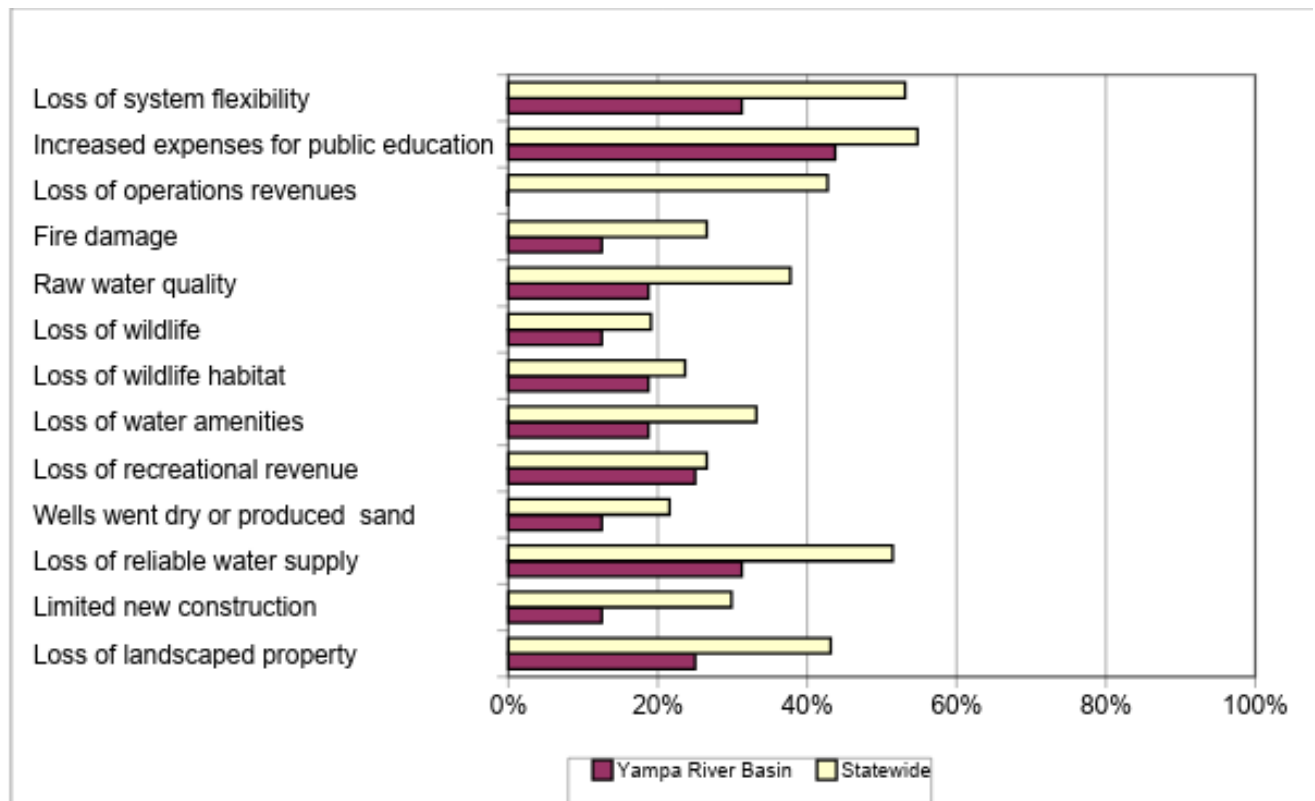
Figure 9.25 Yampa River Basin



Historical Drought Impacts

The Yampa River Basin, along with the Gunnison River Basin, had the lowest number of impacts during the 1999-2003 drought period based on the 2004 DWSA survey results. The 2004 DWSA survey impacts for the Yampa River Basin are shown in Figure 9.26. The greatest impact was increased supplies for public education (40% of the 16 surveyed M&I providers reported this). Loss of system flexibility and loss of reliable water supply were the next most frequent impacts. All impacts, with the exception of loss of crop yields, were lower than statewide levels.

Figure 9.26 Yampa River Basin 1999-2003 Drought Impacts²⁹



Source: DWSA 2004 survey data.

The 2013 CWCB drought survey impacts ranked as having the highest frequency/level of concern in 2012, anticipated for 2013 and experienced for the longest duration from 2002 to 2006 were the following:

- Loss of irrigated vegetation within urban service area
- Significant loss in storage that carried over to the following year

²⁹ Note: A comprehensive review and internal testing process of the survey tool was conducted, yet it is important to recognize that these DWSA 2004 surveyed impact results are subjective. The impacts in the figure above are, in many cases, a reflection of those surveyed interpretation of the listed impacts.

- Decrease in groundwater availability or drop of groundwater levels

Losses in system flexibility and loss of irrigated vegetation/landscaped property were high ranking impacts recorded among both the 2004 DWSA and 2013 CWCB drought surveys.

Adaptive Capacities

Table 9.17 indicates that 60% of the 2007 DWSU surveyed municipalities in the Yampa River Basin incorporate drought recurrence in long-term water supply. None of the surveyed M&I providers had drought management plans and while 20% and 60% have conservation and raw or treated master plans, respectively. These planning efforts are below the statewide averages.

Table 9.17 Yampa River Basin Provider Planning Efforts 2007 DWSU Survey Results³⁰

Drought-Related Planning Efforts	Yampa River Basin		Statewide Average	
	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002
Have a drought management plan	0%	0%	25%	19%
Have a raw and/or treated master plan	60%	10%	61%	37%
Have a conservation plan	20%	10%	44%	30%
Drought recurrence is considered in long-term water supply and conservation planning	60%	n/a	66%	n/a

Source: DWSU 2007 Survey.

The 2013 CWCB drought survey results are limited to one respondent in the Yampa Basin. This respondent indicated that they have not updated or developed a new comprehensive plan following the 2002 drought nor anticipate improving their drought preparedness following the 2012/2013 dry period. The respondent feels that there is sufficient funding to support water supply reliability, conservation and drought planning. The Yampa/White/Green Basin Roundtable seeks to ensure that existing and anticipated future needs can be met, even during drought periods (YWG BRT, 2015).

Drought Vulnerability

The population of the Yampa River Basin is expected to triple by 2050 (SWSI 2010) and M&I water usage is anticipated to more than double, from 12,000 acre-feet per year currently to 31,000 acre-feet per year in 2050. Future M&I needs are anticipated to be met through existing water rights and storage in Stagecoach, Elkhead, and Yamcolo reservoirs. However, the role of the Basin's streamflows in meeting the state's compact obligations is a central issue in the Roundtable planning efforts. If river administration is based upon a statewide application of the prior

³⁰ Note: A direct relationship between drought vulnerability and adaptive capacity cannot be deciphered solely using these data. While these results provide a general indication of the number of drought, conservation and raw/treated master plans, they do not provide information on the content and "overall effectiveness" of the plans. However, they do provide a general indication of M&I drought awareness on a basin-wide level.

appropriation system on the Colorado mainstem and tributary basins, the burden to curtail would likely fall disproportionately on the Yampa Basin, as its water rights are relatively junior to those of other Colorado River basins.

During the 2002 drought, high transit losses were observed in certain areas in delivering downstream supplies (CWCB, 2004). As a result, projected M&I firm yields could be lower than anticipated during future drought, requiring the development of additional M&I water. Table 9.18 lists the ten IPPs that were modeled in the Yampa/White/Green Projects and Methods Study (YWG BRT, 2014). major projects and processes identified to address long-term water supply needs. These projects will be instrumental in maintaining water supply reliability and either directly or indirectly meeting demands during drought periods.

Table 9.18 Major Identified Projects and Processes in the Yampa River Basin

Project	Project Location	Primary Purpose of Project
Lake Avery Enlargement	Expansion to Big Beaver Reservoir (Avery Lake)	The only operation for the Lake Avery Enlargement is making direct releases to meet oil shale demands.
Little Bear 1 Reservoir	Fortification Creek Basin	Agricultural needs
Milk Creek Reservoir	Upstream of the confluence with Yampa River	Agriculture and Industrial
Lower White River Storage Project	Possible off-channel storage sites near the White River: Wolf Creek, Spring Creek, and Gilliam	Water storage, M&I, recreation, supplemental flows, energy, augmentation
Monument Butte Reservoir	Morapos Creek Basin	Agriculture
Morrison Creek Project	Morrison Creek	Firming Stagecoach Reservoir
Oil Shale Production Pipelines/Diversions (new diversions)	White	Industrial
Peabody-Trout Creek Reservoir	Trout Creek upstream of the confluence with the Yampa River	Meet 6,000 acre-feet per year of energy development demands that are part of the Peabody-Trout Creek Project
Rampart Reservoir	Lower Fortification Creek upstream of Wisconsin Ditch	Agriculture
South Fork II Reservoir	Fortification Creek Basin	Agriculture
Upper Morrison Reservoir	Section 14, Township 3N, Range 84W	M&I
Wolf Creek Reservoir	White River downstream of the confluence with Piceance Creek	Industrial (oil shale production demands)
Yellow Jacket Water Conservancy District Reservoir Feasibility Study	White River and drainages	M&I, agriculture, recreation, environmental, other beneficial uses

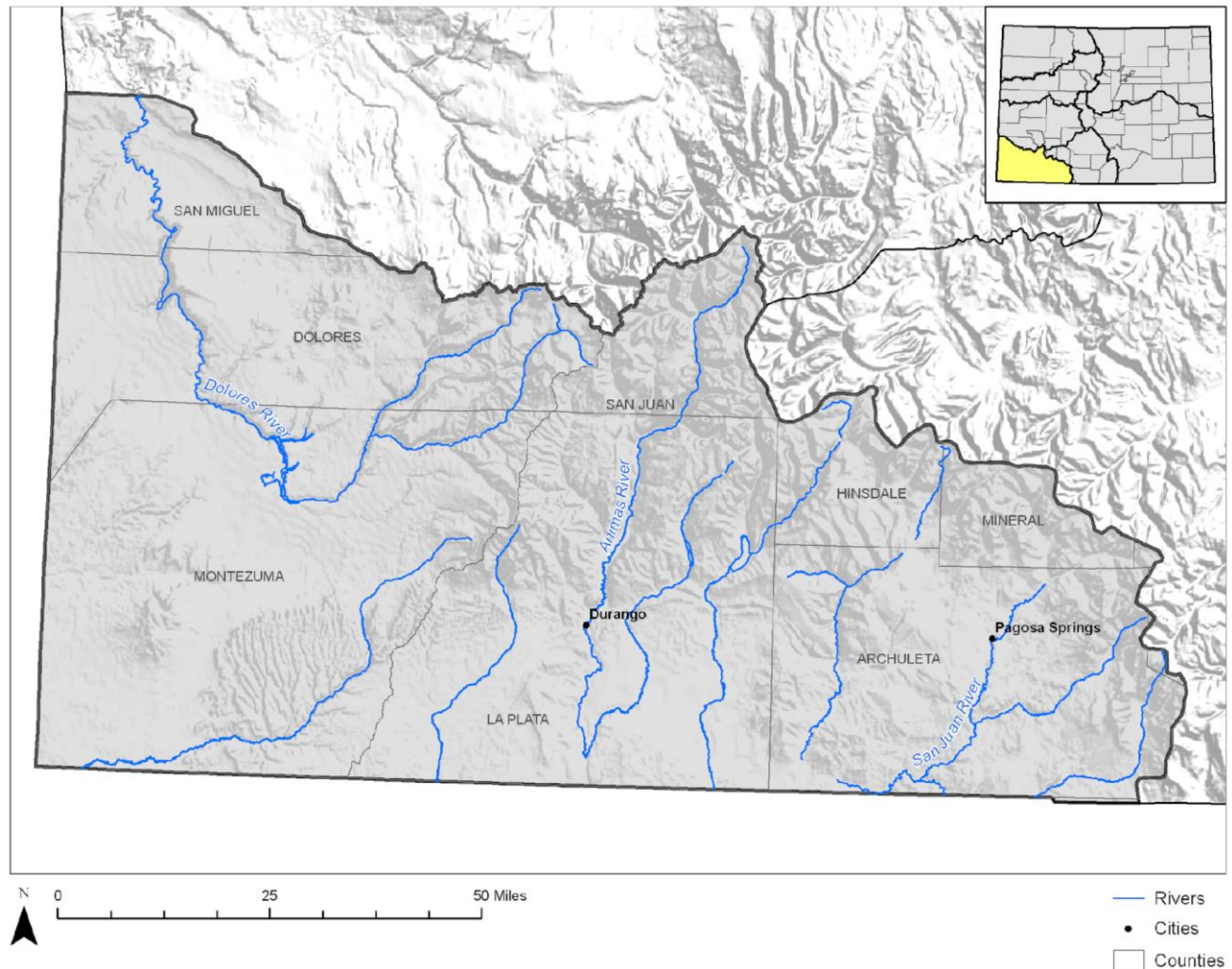
Historically, the mainstem of the Yampa River has not been administered and the 1999-2003 drought impacts recorded in Figure 9.28 are generally well below the statewide average. However, future M&I growth coupled with significant growth in the Energy Sector within the Basin (estimated to require between 22,000 and 67,000 acre-feet per year [YWG BRT, 2015]) could

further stress water supplies during dry periods and will likely necessitate tighter administration of the river. Additionally, new storage projects or enlargements of existing reservoirs may be necessary to meet future demands in the Basin. Several proposed transbasin diversions including the Yampa Pumpback and Flaming Gorge Reservoir Pipeline could alter river administration which could impact future operations of some M&I providers. Background information on these transbasin projects is provided in Section 9.3.

Division 7 - San Juan/Dolores River Basin

The Division 7 - San Juan/Dolores River Basin encompasses the counties of Archuleta, La Plata, San Juan, Montezuma, Dolores, San Miguel, and portions of Mineral, Hinsdale, Montrose, and Mesa. It has a relatively low population density with Durango and Cortez being the largest population centers. M&I water needs are met through a combination of surface water supplies and tributary groundwater supplies (CWCB, 2004). This area of Colorado may be particularly impacted as the climate warms (CWCB, 2012; WRF, 2012), as projections of future flows tend to be drier in the more southerly portions of the State. Current drought conditions (as of 2018) are likely to lead to a number of lessons learned. The Southwest Basin Roundtable represents this basin, which has a complexity of hydrography, political entities, water compacts and treaties, and distinct communities.

Figure 9.27 San Juan/Dolores River Basin



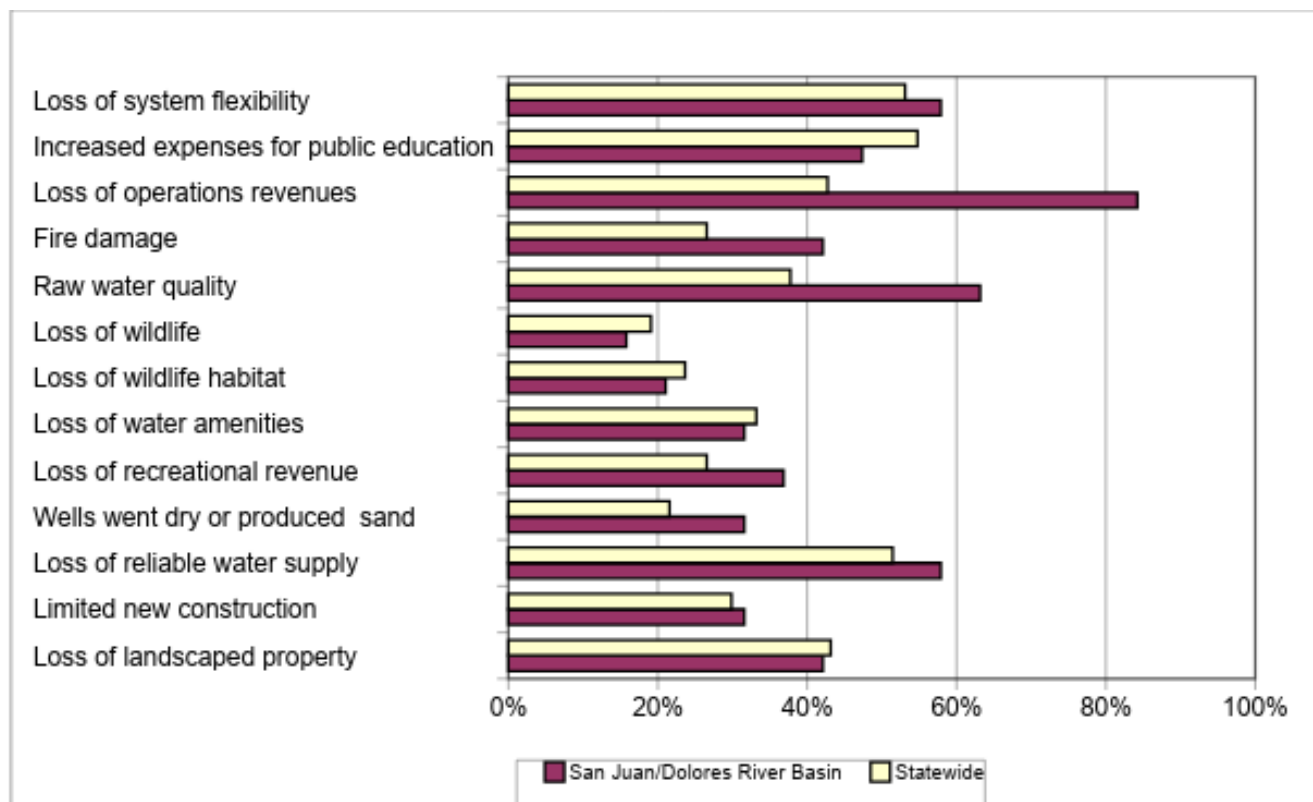
Historical Drought Impacts

The 2004 DWSA survey results shown in Figure 9.28 indicates that over 40% of the 19 surveyed M&I providers in the San Juan/Dolores River Basin experienced the following impacts during the 1999-2003 drought period:

- Loss of system flexibility
- Increased expenses for public education
- Loss of operations revenues
- Fire damage
- Raw water quality
- Loss of water supply
- Loss of landscaped property

The increased expenses of public education were the most frequently experienced impact, closely followed by losses of system flexibility and water supply reliability. Almost all of the impacts listed above exceeded the frequency of impact on a statewide level, and loss of operations revenues and raw water quality were significantly higher than statewide levels. Impacts with lower percentages of occurrence (less than 30 percent) were generally lower than statewide levels.

Figure 9.28 San Juan/Dolores River Basin 1999-2003 Drought Impacts³¹



Source: DWSA 2004 survey data.

The 2013 CWCB drought survey impacts ranked as having the highest frequency/level of concern in 2012, anticipated for 2013 and experienced for the longest duration from 2002 to 2006 were the following:

- Increase staff time necessary to address conditions
- Limits in new construction permits
- Loss or irrigated vegetation within urban service areas
- Loss of recreational revenue
- Increase staff time necessary to address conditions

³¹ Note: A comprehensive review and internal testing process of the survey tool was conducted, yet it is important to recognize that these DWSA 2004 surveyed impact results are subjective. The impacts in the figure above are, in many cases, a reflection of those surveyed interpretation of the listed impacts.

- Voluntary restriction
- Decreased revenue
- Increased expenses for public education and outreach
- Decreased storage levels

Increased expenses for public education, loss of revenue and water supply/storage in addition to the loss of landscape property were high ranking impacts recorded among both the 2004 DWSA and 2013 CWCB drought surveys.

Adaptive Capacities

Table 9.19 indicates that 82% of the 2007 DWSU surveyed municipalities in the San Juan/Dolores River Basin incorporate drought recurrence in long-term water supply and conservation planning. This is higher than the statewide average. Twenty-four percent of the surveyed municipalities have drought management plans, which is close to the State average. 53% and 65%, have conservation and raw or treated master plans, respectively, which is above the State average.

Table 9.19 San Juan/Dolores River Basin Provider Planning Efforts 2007 DWSU Survey Results³²

Drought-Related Planning Efforts	San Juan/Dolores River Basin		Statewide Average	
	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002	Percentage of Surveyed M&I providers	Percentage of Plans Updated Since 2002
Have a drought management plan	24%	18%	25%	19%
Have a raw and/or treated master plan	65%	35%	61%	37%
Have a conservation plan	53%	24%	44%	30%
Drought recurrence is considered in long-term water supply and conservation planning	82%	n/a	66%	n/a

Source: DWSU 2007 Survey

The 2013 CWCB drought survey indicated that two of the three survey respondents either updated or developed a new comprehensive drought plan following the 2002 drought and 2 out of the 3 respondents perceive that there is sufficient funding either in-basin or through state/federal resources to support water supply reliability, conservation and drought planning. One of the three respondents anticipate improving their drought preparedness following the 2012/2013 dry period.

³² Note: A direct relationship between drought vulnerability and adaptive capacity cannot be deciphered solely using these data. While these results provide a general indication of the number of drought, conservation and raw/treated master plans, they do not provide information on the content and “overall effectiveness” of the plans. However, they do provide a general indication of M&I drought awareness on a basin-wide level.

Drought Vulnerability

Future population growth is projected to mainly occur in Montezuma and La Plata Counties along the San Juan Skyway including Cortez and Durango as well as in the Telluride Canyon. Future M&I water needs are anticipated to be met through the Dolores and Animas-La Plata projects. The SW BRT identified approximately 40 M&I IPPs as part of the process of developing the BIP (SW BRT, 2015). Types of IPPs are water diversion structures construction, improvements to infrastructure, construction of new infrastructure, and storage facilities. Table 9.20 lists some major projects and processes identified in 2013 to address long-term water supply needs. These projects, if constructed, could be instrumental in maintaining water supply reliability and, either directly or indirectly, meeting demands during drought periods.

Table 9.20 Major Identified Projects and Processes in the San Juan/Dolores River Basin³³

M&I Providers	Project	IPP Type
City of Cortez	Purchase of Additional McPhee Water	Growth into Existing Supplies
Montezuma Water Company	Water from McPhee Reservoir and other sources	Growth into Existing Supplies
Rico Alluvial Pipeline Water Supply Project	Rights to water from Dolores Water Conservancy District; Potable supplies from Montezuma Water Company	Growth into Existing Supplies
City of Durango	Animas-LaPlata Contract Purchase	Regional In-Basin Project. Growth into existing supplies
	Horse Gulch Reservoir	
	Excess supply from water right on Animas and Florida River, plus minimal storage in terminal reservoir	
	La Posta Pumping Station	
	Recreation Complex	
	Water for Wetland Replacement	
La Plata Archuleta Water District	Water System	Regional In-Basin Project
La Plata West Water Authority	Western La Plata County Domestic Water System	Regional In-Basin Project
Pagosa Area Water and Sanitation District, San Juan Water Conservancy District	Dry Gulch Reservoir & Inlet Pump Station Project	Regional In-Basin Project
	Stevens Reservoir Enlargement	Regional In-Basin Project
Dolores Water Conservancy District	WETPACK Lawn and Garden M&I Water	
	Totten Reservoir	

³³ Note: The draft list of IPPs in this table is based on 2013 information and does not include conservation. A full list of IPPs for the San Juan/Dolores River Basin can be found in the SW BIP.

M&I Providers	Project	IPP Type
Ute Mountain Ute Tribe	Unspecified M&I Project	Regional In-Basin Project
Florida Water Conservancy District (FWCD)	Multipurpose Project (M&I and Ag) - New Bureau Contract, Augmentation Rights, Ditch Improvements	Regional In-Basin Project

Many of the drought impacts recorded in Figure 9.28 are above the statewide average. Future M&I growth could stress water supplies especially during times of drought. M&I drought vulnerability could increase for some M&I providers if drought is not effectively incorporated into long-term water supply reliability planning.

9.4.2 Aspects of Vulnerability

An M&I provider's drought vulnerability depends on the reliability of a provider's water supply system and their ability to effectively respond to drought. However, there are many complex factors that influence the overall reliability of M&I water supply systems and effectiveness of adaptive capacities. Below are many of the factors that can influence overall system reliability, for discussion purposes these factors are grouped into water supply, water distribution, water demand, and adaptive capacity factors.

Water Supply Factors

Source of water supplies – M&I water supplies are generally surface water, tributary groundwater hydraulically connected to the stream, or deep groundwater. Deep groundwater may be divided into non-tributary, designated groundwater, or Denver Basin groundwater. Designated and Denver Basin groundwater lie within a designated groundwater basin that is managed by the Colorado Groundwater Commission. Non-tributary groundwater may be defined as water that is outside of a designated basin whose pumping will not affect surface water levels within 100 years. In contrast to tributary and surface water, designated groundwater and non-tributary groundwater is not subject to the prior appropriation system and consequently the availability of supplies is not legally limited in times of drought. Consequently, municipalities strictly using designated groundwater and non-tributary groundwater are not directly impacted by a drought due to surface water declines. However, the increase of pumping to meet greater outdoor demands during drought periods can lower groundwater levels below “normal” levels and impact municipalities that depend on aquifers already stressed during non-drought periods.

Seniority of water rights – Surface water and tributary groundwater are administered by the prior appropriations system, as discussed in the Chapter 1 Introduction. Municipalities with a more senior water rights portfolio will likely be less impacted by drought than municipalities more reliant on junior water rights. Lower stream flows during periods of drought can also lower exchange potential³⁴ and replacement supplies for augmentation and substitute water supply plans.

³⁴ An exchange allows an upstream water user to divert water that a downstream water user would normally receive as long as the water is replaced at the time, place, quantity, and suitable water quality that the downstream user would

This can reduce the availability of water supplies for many M&I providers relying upon exchanges, substitute water supply plans and augmentation plans. Reduced streamflows can also physically limit the amount of water a municipality may divert from a stream and limit a municipalities' ability to fill its reservoir(s) within priority.

Storage Capacity – Storage can improve the reliability of an M&I water supply system and can lesson drought vulnerability. However, droughts can physically and legally limit the amount of water available to fill reservoirs. Droughts of multi-year duration further stress water supply systems and can significantly deplete storage reserves by reducing the ability for reservoirs to fill in sequential years.

Diversity of supplies – The severity of a drought can vary across different watersheds. M&I water supply systems with sources in different watersheds may be impacted less during a drought if the drought does not extend over a large geographic area. M&I providers that have a diversity of supplies may also have greater flexibility to adjust the management of their water supplies to better meet water needs during drought periods. For instance, conjunctive use is often an effective drought management tool for providers that have surface and non-tributary groundwater supplies. Conjunctive use involves the management of surface water and groundwater supplies to maximize the yield of total water supplies. During periods of drought providers can draw from their non-tributary groundwater to compensate for less available surface water supplies.

Water Distribution System Factors

Distribution system efficiency – M&I providers that have inefficient water distribution systems can lose significant amounts of water as system losses (i.e. leaky pipes or ditches with high seepage rates) before reaching the end user. This can reduce a provider's ability to meet demands during normal conditions as well as periods of drought.

Distribution system redundancy – System redundancy can enhance a provider's ability to meet demands in specific parts of its service area during drought by providing multiple means in distributing water throughout the service area. If a particular water source is depleted during a drought, distribution systems with adequate redundancy can deliver replacement supplies to the locations by utilizing other sources.

Water quality implications – Drought can degrade water quality by lowering stream and reservoir levels resulting in higher temperatures and increased concentration of pollutants. Drought can also cause M&I providers to pull water from intakes situated lower in the reservoir which may have

have used if the exchange had not taken place. Exchange potential refers to the ability to implement exchanges along a particular stream reach without causing legal injury to senior downstream users. Exchange potential is generally higher when streamflows are relatively high and there are "surplus" flows to exchange as opposed to low flow conditions when all of the water in the stream is owed to senior users downstream.

higher sediment concentrations and decreased quality. Degraded water quality can increase water treatment costs and have implications for taste and odor.

Wildfire – Wildfires are a natural phenomenon. The occurrence and severity of wildfires can increase under dry conditions. When wildfires occur debris and sediment runoff as can severely degrade water quality within a watershed and drastically increase sediment loading to reservoirs as well as affect the overall health of the watershed. M&I providers can help reduce impacts associated with wildfires through the support of proper forest management.

Water Demand Factors

Customer drought response and total demands – Customer water demands can either increase or decrease during a drought depending on how effectively customers alter water use behavior. Generally, soil moisture and evapotranspiration rates increase during drought periods, in turn increasing irrigation requirements. However, an effective drought response program can encourage customers to conserve water and significantly reduce total demands relative to normal conditions.

Outdoor water demand – M&I providers often require mandatory watering restriction during periods of severe drought thus reducing demands and conserving water for more essential needs. Outdoor water demand generally offers a significant source for potential for M&I water savings during drought periods.

Adaptive Capacity Factors

Drought mitigation and response efforts and planning – Drought mitigation refers to actions taken in advance of a drought that reduce potential drought-related impacts when the event occurs. For purposes of this study, drought mitigation is considered a component of a municipality's capacity to adapt to drought. Drought response planning addresses the conditions under which a drought induced water supply shortage occurs and specifies the actions that should be taken in response.

Water supply reliability planning – Many M&I providers throughout the State have found it necessary to assess the reliability of their supplies under stressed drought conditions in order to ensure that they have sufficient supplies to meet anticipated existing and future plans. This is often referred to as water supply reliability planning. Water supply reliability planning plays a crucial role in mitigating the drought vulnerability of communities experiencing rapid growth. M&I providers that account for future growth and plan for additional demands considering stressed water supplies during times of drought will be less vulnerable to drought when compared to M&I providers that do not effectively incorporate drought into their planning efforts.

Conservation efforts and planning – Water conservation planning involves a combination of strategies for reducing water demand while also maintaining or improving water use efficiency and increasing reuse of water. The main objective of a water conservation plan is to achieve lasting, long-term improvements in water use efficiency, reducing overall water demands. However, some

conservation measures can serve the dual purpose of providing long-term water saving benefits during normal and drought periods. For example, a xeriscape landscape requires less overall water, and is also more likely to survive during drought periods when strict outdoor watering restrictions are enforced. Large areas of xeriscape landscape can reduce drought-related landscaping impacts in a community while also conserving water during normal periods.

There is a common notion that conservation can result in demand hardening which may be defined as follows: “By saving water, long-term conservation can also reduce the water saving potential for short-term demand management strategies during water shortages” (Flory, J.E., and T. Panella 1994). For instance, during times of drought, savings achieved via outdoor watering restrictions may be used for more essential indoor uses. If the amount of irrigated turf is reduced in advance of a drought through conservation measures, less of a “water savings potential or buffer” through outdoor irrigation savings is available during times of drought. Whether this “water saving potential” is actually smaller prior to conservation than with conservation largely depends on how the saved water is used during normal and wet years. Water saved through conservation can be stored in drought reserves and improve a provider’s drought adaptive capacity. Conversely, providers that sell all their conserved water to meet increasing demands from population growth could reduce their ability to respond to drought.

9.5 Recommendations

9.5.1 Adaptation to Drought

A variety of mechanisms can be used to further reduce M&I drought vulnerability by encouraging local water supply reliability and drought management planning. These include the following:

- HB 08-1141 was passed in 2008 preventing all local governments from approving new development permits until they determine, at their discretion, that the proposed water supply for the development will be adequate. Information must be submitted to local governments on the development’s water supply requirements at buildout, physical source of supply, projected water supply yield under various hydrologic conditions, planned conservation efforts, etc. Continued implementation of this policy helps to ensure that growing communities have a reliable water supply during dry periods reducing drought vulnerability.
- Continued incentives for M&I providers to develop drought management plans that specify essential elements for effective drought management planning through CWCB financial and technical assistance. Among these elements includes a stakeholder drought management plan development process, a formal drought declaration protocol, and specific drought mitigation and response actions.
- Continuation of CWCB financial assistance to covered M&I providers that have retail water deliveries of over 2,000 acre-feet annually. This program provides incentive and valuable financial resources especially for smaller providers that are in need of assistance for drought management planning.

-
- The CWCB offers technical assistance to municipalities developing drought management plans. This includes an M&I Drought Management Guidance Document, sample M&I drought plan, a web-based drought toolbox, and CWCB staff consultation. Broader utilization of these tools at the local level will decrease drought vulnerability. For municipalities unsure of where to begin, a phone call to CWCB staff to get oriented to the online resources may be the best starting point.

9.5.2 Improving Vulnerability Assessment

There are a variety of factors that influence the drought vulnerability of M&I providers. Each of these factors is unique to individual M&I providers and can affect providers in many different ways and in varying magnitudes during a drought. The basin-wide vulnerability assessment presented in this study addressed drought vulnerability from a qualitative perspective. Although beyond the scope of this study, future quantitative analyses that also incorporate river administration and the prior appropriation system in more detail would provide a more detailed characterization of M&I vulnerability. Continued incorporation of population growth and basin-specific studies is recommended for future updates. Recommendations for further studies are itemized below.

Prior appropriation system and river administration - As indicated above, the prior appropriation system and river administration play a significant role in M&I water supply reliability, and ultimately drought vulnerability. To better understand how these systems function during drought, future studies should, to the extent possible, incorporate a review of river administration and call data during the 2002 drought at a minimum by water division and where appropriate at the district level. Potential future changes to the river administration as a result of planned water development projects could also be incorporated into the analysis.

Water supply reliability - There are several significant water supply factors that influence M&I water supply reliability and drought vulnerability. These include the type of water supplies, water rights, storage, and diversity of supplies. The characterization of these factors on a local scale coupled with implementation of HB 1051, which creates a mechanism to collect water efficiency data, could further enhance the ability to access M&I drought vulnerability. The incorporation of information from the Colorado Water Plan and the BIPs into this 2018 update enhanced the characterization of factors influencing water supply reliability on a local scale.

Collection of historical drought impact data – Historical drought impact data provides a snapshot of an M&I provider's drought vulnerability. Although these impacts are not a direct reflection of drought vulnerability, historical impact information coupled with a provider's drought preparedness efforts provide valuable insight into characterizing overall M&I drought preparedness. It is recommended that CWCB coordinate efforts with NDMC on recording local drought impacts within the State through NDMC's Drought Impact Reporter.

10 RECREATION SECTOR

Key Findings

- Climate change has the potential to make future droughts more frequent and more severe (IPCC, 2007), and this would exacerbate impacts already experienced by the Recreation Sector.
- Key drought impacts for skiing include reduced snowpack and a shortened ski season, resulting in higher operating costs due to increased snowmaking, loss of revenue due to decreased visitation, and seasonal layoffs.
- Wildlife viewing and hunting have been impacted by lower production and recruitment numbers and by animals moving away from traditional viewing/hunting areas due to lack of water, loss of vegetative cover, and/or heat.
- Fishing areas have been impacted by lower reservoir and lake levels, decreased streamflows, sedimentation, and fish decline.
- Impacts to camping include forced closure of campsites and surrounding forest due to wildfires and risk of wildfires and/or hazard trees; both conditions exacerbated by drought.
- Golf courses are impacted if municipalities impose watering restrictions or if water rights become out of priority due to low streamflows.
- Lower reservoir and lake levels have placed restrictions upon and made boating impossible by rendering boat ramps unusable and can act as a deterrent to potential boaters.
- Swim beach closures due to either water quality concerns or low water.
- Rafting companies have been impacted by low flows, resulting in loss of revenue.
- Diversification and communication with the public, media, and local governments was found to be the most widely-repeated strategy for adapting to drought conditions.
- As a result of both the diversity in the sector and a lack of understanding regarding drought, data appropriate for measuring the impacts of drought on the sector is difficult to come by. Therefore, specific measures of drought impacts on the sector are difficult to determine.

Key Recommendations

- The recreation sector in Colorado has been a leader in responding to climate change (POW, 2018). Statewide support for drought mitigation programs could be expanded to address or mitigate climate change impacts as well, thus garnering participation and support from more entities within the recreation sector.
- Public perception of recreational offerings during a drought is a primary concern among all recreation sub-sectors. Public relations plans and strategies can help mitigate or prevent negative public perception during drought.
- Diversifying the recreational activity and/or tourist area is an adaptive capacity cited in numerous sources and interviews. Adjusting the seasonality and variety of offerings can mitigate against a severe one-season drought by allowing for income in the other half of the year.
- The methods and model of stakeholder engagement laid out in the Drought Assessment for Recreation and Tourism (DART) Report should be used as a guideline for determining how best to incorporate stakeholders into the process of developing meaningful drought metrics. Incorporating stakeholders will help facilitate data collection, create awareness about the

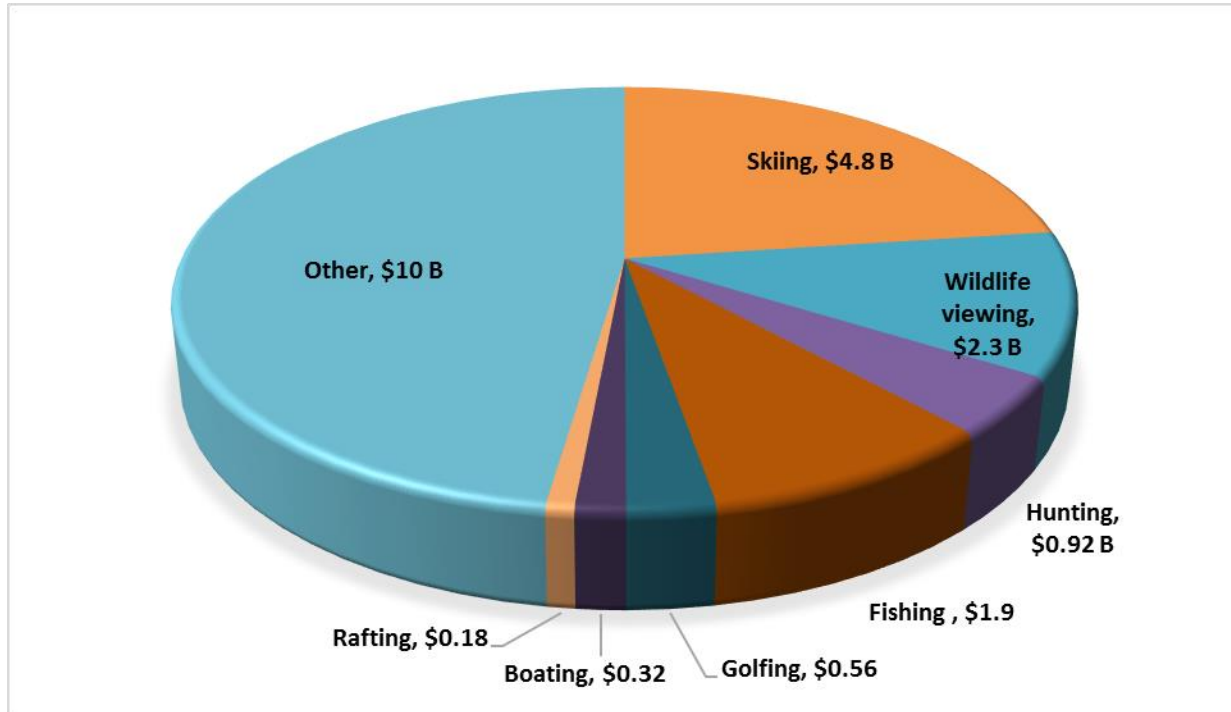
linkages between drought and recreation/tourism, and identify successes from which best practices can be identified.

10.1 Introduction to Sector

Recreation and tourism is an important industry in Colorado, attracting tourists and residents with its outdoor recreation opportunities, physical beauty, and high quality of life. Outdoor recreation in Colorado is estimated to directly contribute \$21 billion annually into the State's economy (CPW, 2014). This includes lodging, food, and gas. In 2014, the industry directly supported 201,442 jobs in Colorado, and in 2010, the industry contributed \$750 million in local and state tax revenue, which was approximately equivalent to 19% of Colorado's economy (Thomas & Wilhelmi, 2012).

Recreation and tourism is a broad category that encompasses numerous activities. As such, only key, representative sub-sectors were chosen for analysis. The following sub-sectors were chosen based on their significance to the Colorado economy and their dependence on water resources: downhill skiing, wildlife viewing, hunting/fishing/camping, golfing, boating, and rafting. Other recreation and tourism activities not specifically analyzed in this assessment are listed at the end of this section (Section 10.1), and include bicycling, hiking, and other trail-based activities; touring the State; tourism based around agriculture; and water- and snow-based activities other than downhill skiing, boating, and rafting. Figure 10.1, which assumes an overall \$21 billion impact, presents a general picture of the relative economic importance of sub-sectors within the Recreation Sector.

Figure 10.1 Recreation and Tourism Economic Impact in Billions¹



The statewide impact is not the whole picture, because the spatial distribution of these industries and the timing of their activities have an impact at a county level. For example, the rafting sub-sector is not as big a statewide economic driver as skiing, but for the handful of counties where rafting is concentrated, the localized economic impact can be quite significant. Another consideration is the season in which the activity occurs; for example, golfing is primarily a warm month activity while skiing occurs primarily in the cold months. The temporal nature of the recreation activity will have a seasonal effect on the counties in which these activities are prominent. The timing of drought can influence which sectors are impacted or not. Table 10.1, below, shows the sub-sectors, their seasonality, and the way they use water.

Table 10.1 Seasonality and Water Use of Sub-sectors

Seasonality and Water Use of Sub-sectors		
Sub-sector	Season	Water Use
Skiing	October through April, handful of resorts open past April	Ski areas depend on natural snowfall for most of terrain coverage and use surface water for snowmaking. Primarily impacted by lack of winter precipitation; however, below-normal summer precipitation can result in lower streamflows leading into the fall, which could cause water rights to be out of priority when resorts start making snow in the late fall and early winter.
Wildlife viewing	Year-round	Animals depend on plant and water availability and will migrate to different geographic areas to find food/water. Depending on migration

¹ Source of estimates: 1) skiing, CSCUSA 2015; 2) wildlife viewing, CPW, 2014; 3) hunting & fishing, CPW, 2014; 4) golf, Davies et al 2004; 5) boating, RMRC at MSU, 2008; 6) rafting, Blevins, 2017.

Seasonality and Water Use of Sub-sectors		
Sub-sector	Season	Water Use
		patterns, this could increase or decrease the wildlife viewing opportunities in a given area.
Hunting, fishing, and camping	Year-round, but more participants in the summer months	Game animals can be impacted by water and food shortages. Fishing requires adequate water in reservoirs, rivers, and streams. Campsites generally require little water for consumptive use but are often dependent on water-based recreation for visitors.
Golfing	April through October, with May through September being the peak time	Golf courses depend on water to irrigate course. Water source can be surface rights, groundwater, purchased from municipalities, or reused (purchased) from wastewater treatment plants.
Boating	April through October	Reservoir, river, and stream levels can be impacted by less snowmelt to initially fill reservoirs/lakes and/or lack of spring/summer precipitation. Higher-than-normal temperatures and lower precipitation in a spring-fall drought will cause higher evaporation rates.
Rafting	April through September, with late June through mid-August being the peak time	Ability to run a stretch of river depends on the streamflow, which can be decreased early in the season by below-normal or too-early snowmelt, and later in the season by a lack of summer precipitation.

Skiing

Downhill skiing has been a large part of Colorado tourism for several decades, and is growing more visible as resorts expand and advertise to new consumers across the country (Colorado Ski Country USA, 2015). However, the skiing sub-sector includes more than just downhill, as there is also a large market for cross-country/Nordic skiing and backcountry skiing. Apart from skiing, other snow-based activities that are popular include snowmobiling and snowshoeing. A secondary beneficiary of snow-based activities is hut and yurt camping, which are structures with basic amenities generally located in remote areas that are rented by various agencies and accessible by snowshoe, snowmobile, or cross-country skiing. These activities are mentioned here to point out their existence/importance in the snow-based recreation arena, but they will not be covered in further detail within the skiing sub-sector. For the purpose of this assessment, “skiing” refers to downhill skiing or snowboarding at an established ski area with motorized lifts and lift pass sales.

There are 28 downhill resorts in Colorado. Table 10.2 gives the name of the resort and the county in which it is located.

Table 10.2 Ski Area Names and Location

Ski Area Names and Location (County)	
Name	County
Arapahoe Basin	Summit
Aspen Buttermilk	Pitkin
Aspen Highlands	Pitkin
Aspen Mountain	Pitkin
Beaver Creek	Eagle

Ski Area Names and Location (County)	
Name	County
Breckenridge	Summit
Cooper	Eagle
Copper Mountain	Summit
Crested Butte	Gunnison
Echo Mountain Park	Clear Creek
Eldora	Boulder
Granby Ranch	Grand
Hesperus	La Plata
Howelsen Hill	Routt
Kendall Mountain	San Juan
Keystone	Summit
Loveland	Clear Creek
Monarch	Chaffee
Powderhorn	Mesa
Purgatory (Durango)	La Plata
Silverton	San Juan
Snowmass	Pitkin
Steamboat	Routt
Sunlight	Garfield
Telluride	San Miguel
Vail	Eagle
Winter Park	Grand
Wolf Creek	Mineral

A review of ski area websites shows that most (>80%) of these areas have snowmaking machines. Snowmaking capabilities are relevant to a drought vulnerability discussion because they allow ski resorts to determine their opening date (i.e., ensure ski-able terrain) even in a dry winter. Water rights are typically obtained by the resort from nearby streams. The water use is considered non-consumptive because when the snow melts in the spring the water returns to the streams as runoff. In general ski areas are not in competition with agriculture or other recreation because they are high in the watershed and are diverting water in an “off” season.

In Colorado, the total acreage of the ski areas ranges from 50 acres (Howelson Hill) to 5,289 acres (Vail), and the base elevation ranges from Howelson Hill at 6,696 feet above sea level (asl) to

10,800 feet asl at Loveland. As shown in Figure 10.5,² the ski areas are all located in mountainous regions of the State and are primarily west of the continental divide (with the exception of Echo Mountain and Eldora).

Wildlife Viewing

Wildlife can be viewed anywhere in the State, from the mountains to the eastern plains. Because there are no geographic requirements for this activity, it is difficult to present the total distribution of areas where wildlife viewing is possible. However, Colorado Parks and Wildlife (CPW), formerly the Division of Wildlife, has a viewing guide on their website with about 350 suggested parks, natural areas, and fish hatcheries (collectively referred to as State Wildlife Areas). Figure 10.6 shows these areas as they are located around the State; note there is no real concentration of suggested wildlife viewing areas. There are only a handful of counties (Cheyenne, Crowley, Costilla, and Custer) without a specific site, but this does not mean wildlife is absent from those counties. Important waterfowl hunting and viewing areas were identified in the South Platte Basin in the 2010 Non-consumptive Needs Assessment (NCNA) Focus Mapping Report (CWCB 2010). The results are presented in Figure 10.7. Wildlife viewing sites tend to be concentrated in the mountains and the southwest portion of the State. Overlapping recreational activities often accompany wildlife viewing in a given county. For example, if a visitor was already planning to visit El Paso County to see Pikes Peak, they could be further enticed to drive up the mountain to see big-horned sheep.

Hunting, Fishing, and Camping

Similar to wildlife viewing, hunting, fishing, and camping activities occur throughout the State. The only stipulation for each of these activities is a designated camping spot or allowable dispersed camping, a body of water for fishing, and/or the presence of wildlife for hunting. Maps for this sub-sector show: 1) the number of acres of CPW land in Colorado, which generally corresponds to lands open to hunting and fishing; and 2) the location of campgrounds, state parks, fish hatcheries, and CPW State Wildlife Areas (see Figure 10.6 and Figure 10.8).

Like wildlife viewing, there are hunting, fishing, and camping areas throughout the State with a higher concentration of all in the western half and southwest corner. There is a notable absence of large tracts of parks, wilderness areas, and state and federal owned lands in the central eastern plains region.

Golf

There are approximately 250 golf courses throughout Colorado (Ivahnenko, 2009). (Other sources³ confirm that number as of 2018. The USGS report discussed below and Ivanhenko, 2009 are

² All figures referenced in this section are located at the end of Section 10.1, before the start of the Vulnerability discussion.

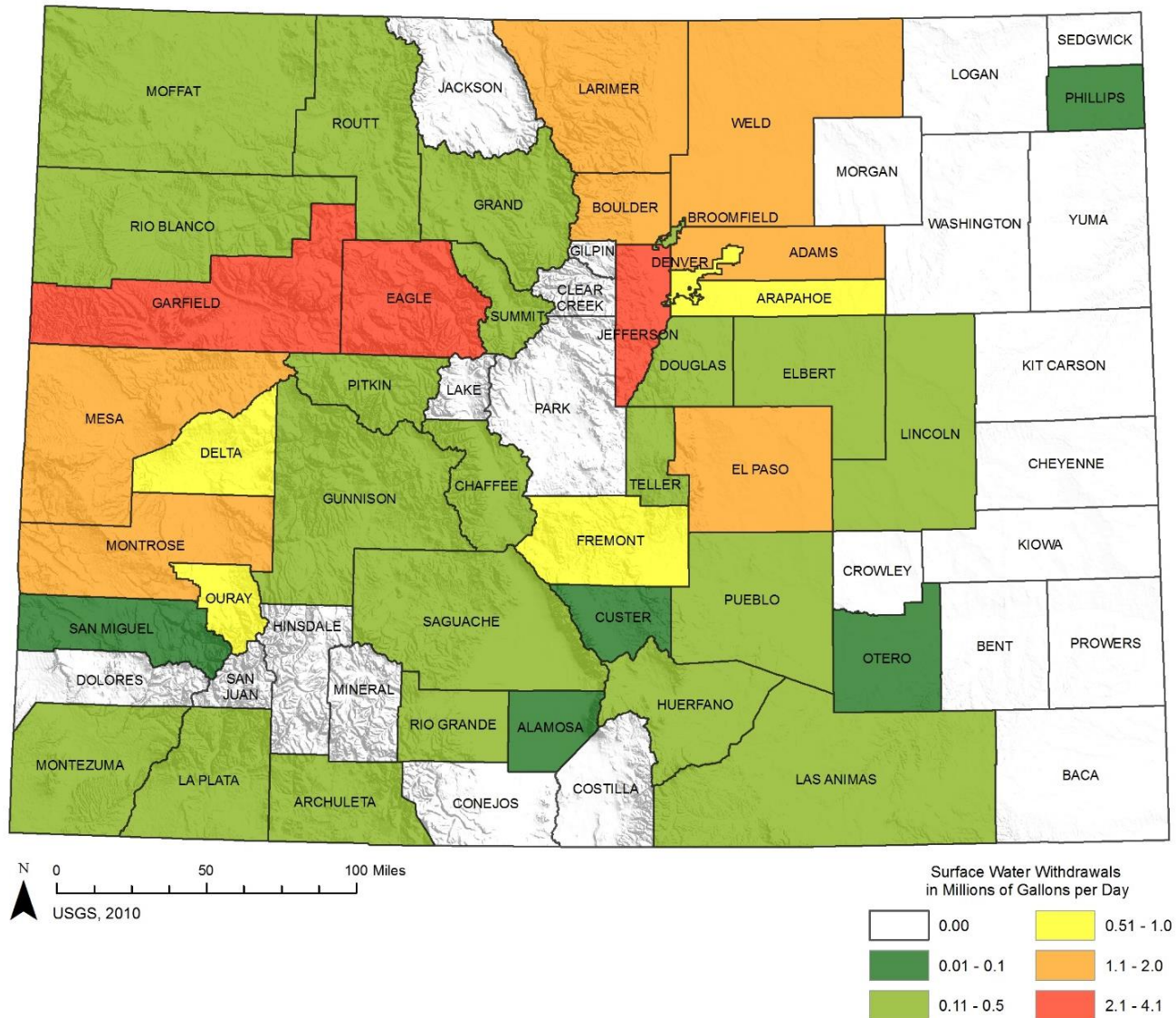
³ <https://www.coloradoavidgolfer.com/courses/>

believed to be the best available data sources.) Figure 10.9 shows the number of courses per county. Jefferson, Arapahoe, and El Paso Counties have the highest number of golf courses (23, 22, and 20 respectively) as of 2005. As of 2005, eleven counties had no golf courses. There are two sand courses in Colorado, one in Baca County and one in Lincoln County. Sand courses require little to no irrigation and are considered in this assessment as alternatives to typical grass courses.

Data for golf courses in Colorado is available from a 2005 study conducted by the United State Geological Survey (USGS) that examined water use by golf courses in Colorado. A survey was distributed to the members of the Rocky Mountain Golf Course Superintendents Association, and additional information was collected through telephone. For the courses that responded (43% returned the survey and an additional 225 phone calls were made for follow-up information), the survey found that about 64% use surface water as part of their irrigation supply, 23% use groundwater as part of the supply, 14% use purchased potable water for part of their supply, and 14% use reclaimed wastewater for a portion of the supply (Ivahnenko 2009).

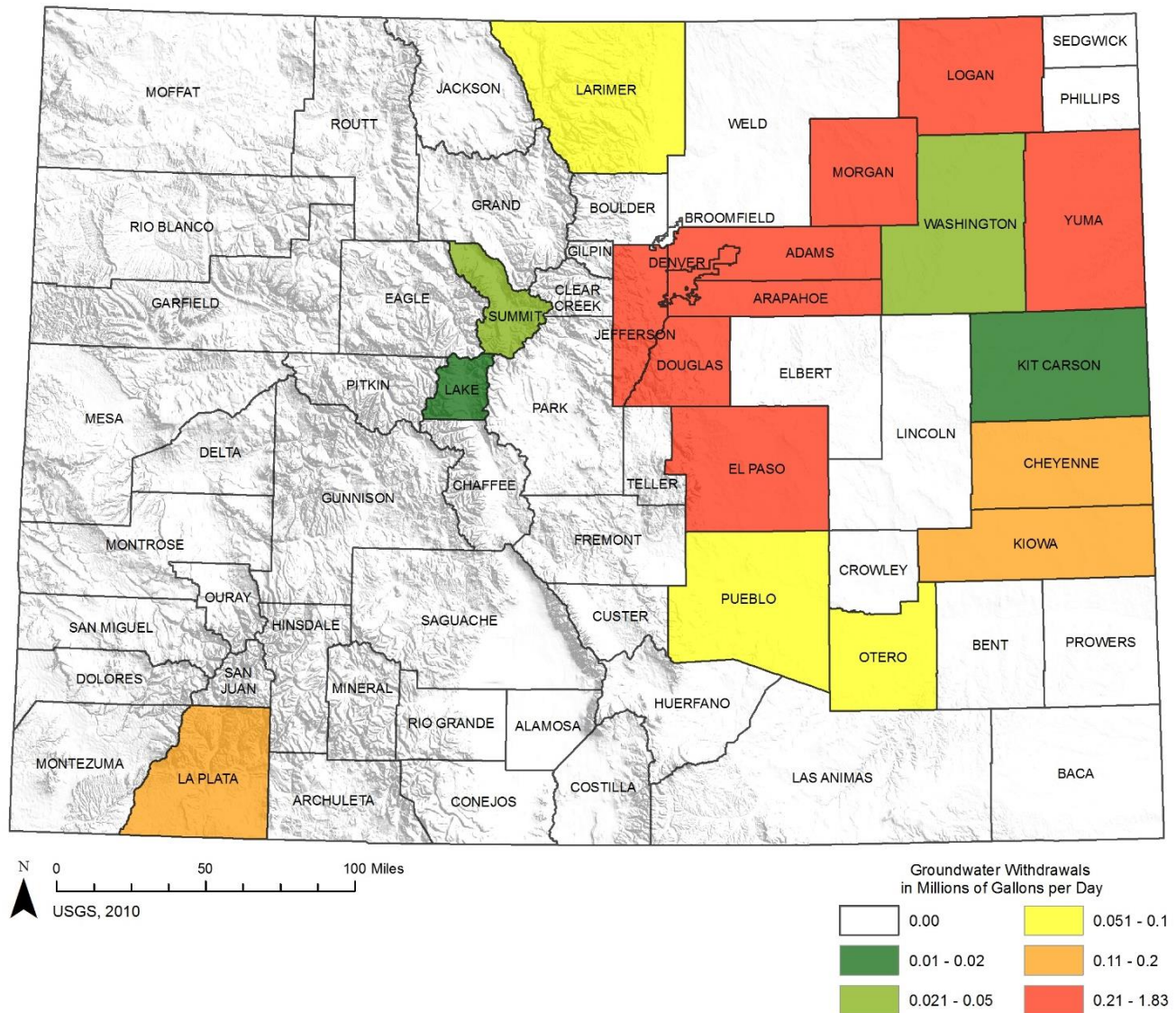
The USGS report included a table showing the estimated golf course irrigation water use by source water (i.e., surface, groundwater, potable water, or reclaimed wastewater). Although the data are available, it is not possible to make a general statement about what type of irrigation water is more vulnerable to drought. There are complicating factors to this, primarily the water rights priority system and municipal attitudes towards golf courses and other visible users of water. The two figures below (Figure 10.2 and Figure 10.3), extracted from the USGS report, highlight the spatial variability in surface water use compared to groundwater use.

Figure 10.2 Surface Water Golf Course Irrigation Water Use, by Colorado County, 2010



Source: USGS, water use study published in 2010

Figure 10.3 Groundwater Golf Course Irrigation Water Use, by Colorado County, 2010



Source: USGS water use study, published in 2010

As these maps show, surface water is the primary source for golf course irrigation water. Groundwater use is more common on the eastern half of the state. Potable water and reclaimed water (maps not shown) are seen mainly, but not exclusively, along the Front Range.

Boating

Boating takes place at reservoirs, lakes, and rivers around the state. CPW manages boating registrations and maintains a list of “boat-able” waters on their website. Although it is listed here as a sub-sector of recreation and tourism, boating contributes to a portion of State Parks revenue from licensing and visitation fees and thus influences state assets as well.

Boating is a general designation for water-based activities involving a boat and can include sailing, motorized watercraft, towed water sports, and scuba diving and swimming off the side of a boat. Boating also involves rafting, kayaking, and canoeing, but these activities are discussed within the “rafting” sub-sector of this chapter.

Table 10.3 provides a snapshot of boating registrations in Colorado from 2000 to 2012.

Table 10.3 Annual Boat Registrations, 2000-2012

Annual Boat Registration	
Year	Number of Boats
2000	104,946
2001	104,500
2002	101,948
2003	100,580
2004	98,076
2005	98,572
2006	98,063
2007	98,976
2008	96,222
2009	96,719
2010	-
2011	90,090
2012	88,007

Source: Colorado State Parks 2010, CPW 2013

Table 10.3 shows the general magnitude of personal watercraft in the state (data was not available for 2010). There is a significant drop in registrations from 2009 to 2011 and 2012. However, it is difficult to separate the impacts of drought from the economy. Assuming each registered boat represents 2-10 boaters, the number of boaters would be closer to half a million. With an estimated population of five-and-a-half million people (Colorado State Demographer, 2016), the boating registrations shown above indicate that close to 10% of the population takes part in boating activities. Figure 10.10 shows the state parks and other recreation areas within Colorado.

CPW operate many of the reservoirs and boating facilities; a great deal of boating within the state occurs at state parks. Table 10.4 lists the state parks where water-based activities are offered and the county or counties in which the parks are located.

Table 10.4 State Parks with Boating Activities

Water-based State Parks		
State Park Name	Activities	County
Arkansas Headwaters	Rafting	Chaffee (also in Fremont, Lake, and Pueblo)
Barr Lake	Fishing, boating, bicycling, horseback riding, hiking	Adams
Boyd Lake	Boating, fishing, swimming, hiking, biking, hunting	Larimer
Chatfield	Boating, biking, hiking, camping	Douglas (also in Jefferson and Arapahoe)
Cherry Creek	Boating, horseback riding, shooting range, biking, camping, fishing	Arapahoe
Crawford	Fishing, boating, hiking, water sports	Delta
Eleven Mile	Boating, fishing	Park
Elkhead Reservoir	Boating, fishing	Moffat (also in Routt)
Harvey Gap	Fishing, small boats, ice fishing	Garfield
Highline Lake	Fishing, boating, birding	Mesa
Jackson Lake	Swimming, boating, fishing, waterskiing	Morgan
James M. Robb-Colorado River	Fishing, hiking, swimming	Mesa
John Martin Reservoir	Boating, fishing	Bent
Lake Pueblo	Boating, fishing	Pueblo
Lathrop	Boating, fishing, swimming	Huerfano
Mancos	Canoe, kayak, fishing, camping	Montezuma
Navajo	Boating, camping, fishing	Archuleta (also in La Plata)
North Sterling	Boating, fishing, hunting, camping	Logan
Paonia	Fishing, boating, camping	Gunnison
Pearl Lake	Camping, fishing, canoeing	Routt
Ridgway	Camping, biking, boating, winter sports, birding	Ouray
Rifle Falls	Camping, fishing, hiking	Garfield
Rifle Gap	Boating, fishing, swimming, water-skiing, windsurfing, camping	Garfield
Spinney Mountain	Fishing, bird watching, boating	Park
St. Vrain	Biking, boating, camping, fishing, hiking	Weld
Stagecoach	Biking, bird watching, boating, camping, fishing, ice fishing	Routt
Steamboat Lake	Backcountry camping, biking, birding, boating, camping, cross-country skiing, fishing, hiking, horseback riding, hunting, ice fishing, jet skiing, sailboarding, snowmobiling, snowshoeing, swimming, water skiing	Routt
Sweitzer Lake	Biking, boating, cross-country skiing, fishing, hiking, hunting, jet skiing, sailboarding, swimming, water skiing	Delta
Sylvan Lake	Biking, boating, camping, cross-country skiing, fishing, hiking, hunting, ice fishing, snowmobiling, snowshoeing	Eagle

Water-based State Parks		
State Park Name	Activities	County
Trinidad Lake	Biking, boating, camping, fishing, hiking, horseback riding, ice fishing, jet skiing, snowshoeing, water skiing	Las Animas
Vega	Fishing, boating, water skiing, hiking, ice fishing, cross-country skiing	Mesa
Yampa River	Birding, boating, camping, fishing, hiking, hunting, whitewater rafting	Routt (also in Moffat)

Source: CPW 2018.

Although there is a notable majority located in the western and southern regions, reservoirs and lakes for boating exist throughout the state.

Rafting

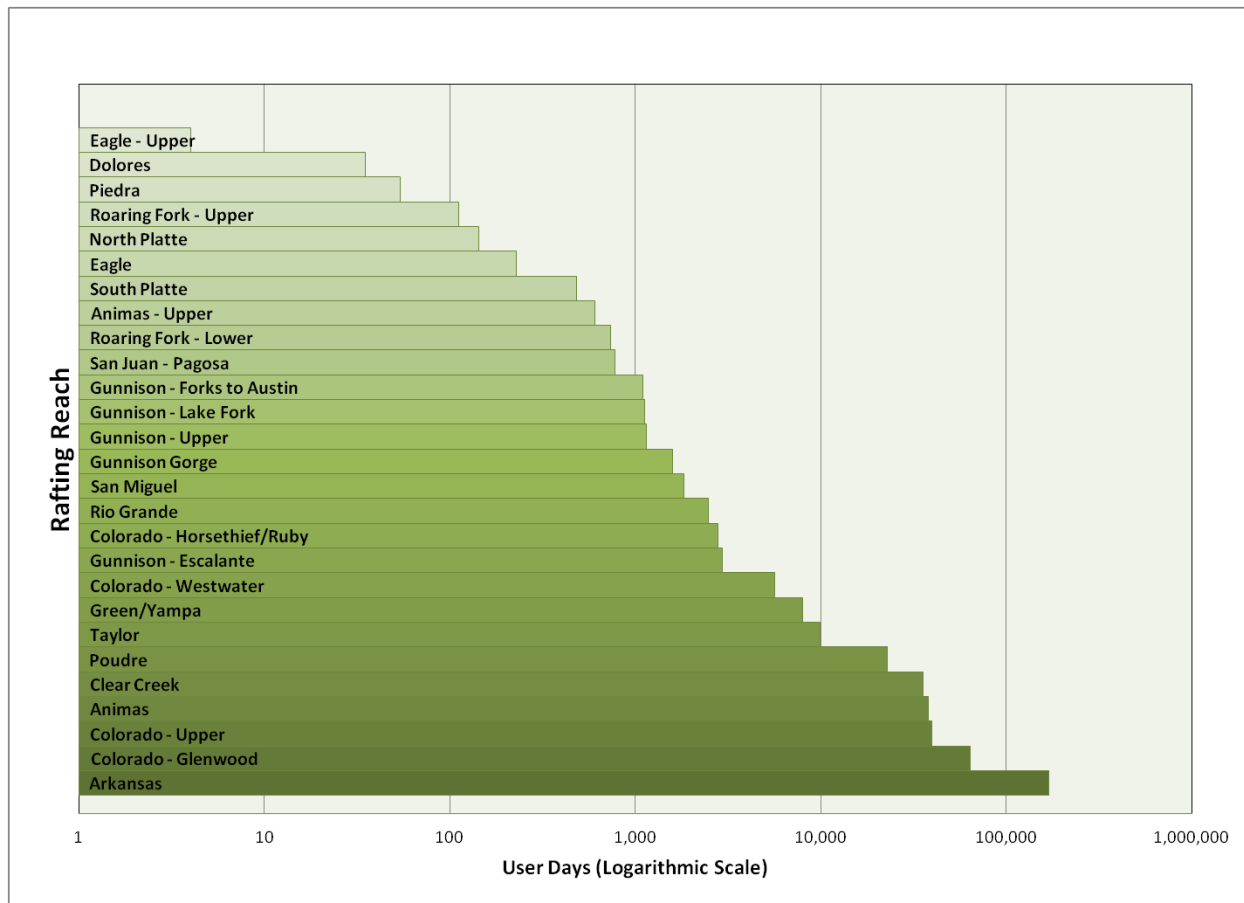
Whitewater rafting, kayaking, and canoeing take place on rivers and streams throughout Colorado. Whitewater rafting in particular is a segment of the tourism industry that has a significant presence in certain areas of the state. Commercial rafting outfitters will be the focus of this sub-sector, and although kayaking and canoeing do have a presence and economic impact in Colorado, they are not discussed here in detail because the data required to disaggregate the rafting numbers are not available.

Figure 10.11 is from the Statewide Water Supply Initiative Phase 2 report (SWSI Phase 2, 2007) and shows “American Whitewater” rafting reaches around the state. More detailed whitewater rafting reaches were identified by river basin in the 2010 NCNA Focus Mapping Report (CWCB, 2010). Figure 10.11 shows the whitewater and flatwater rafting/paddling map generated for the South Platte Basin.

One trade group for commercial rafting outfitters in Colorado is the Colorado River Outfitters Association (CROA), which maintains a variety of rafting data including user days⁴ for commercially-rafted rivers in Colorado. In order to portray a general picture of the rafting industry in Colorado, Figure 10.4 shows the rivers and the user days per river in 2012. User days per river are graphically represented in Figure 10.13, at the end of this section.

⁴ A “user day” is defined as a paying guest on a river for any part of a day (CROA, 2010).

Figure 10.4 2012 Commercial Rafting User Days



Source: CROA 2012.

The Arkansas River is by far the most popular river for commercial rafting in Colorado. The magnitude of these numbers is similar to those of previous years, which are available on the CROA website going back to 1988.

Counties within the Arkansas River Basin (primarily Chaffee and Fremont) experience the most commercial rafting activity due to the number of people who raft the Arkansas River. Reasons for the river's popularity include the range of difficulty of rafting stretches (floating sections to expert-only rapids), the proximity to urbanized areas, and the volume of trips offered by numerous different outfitters (Shrestha, 2009).

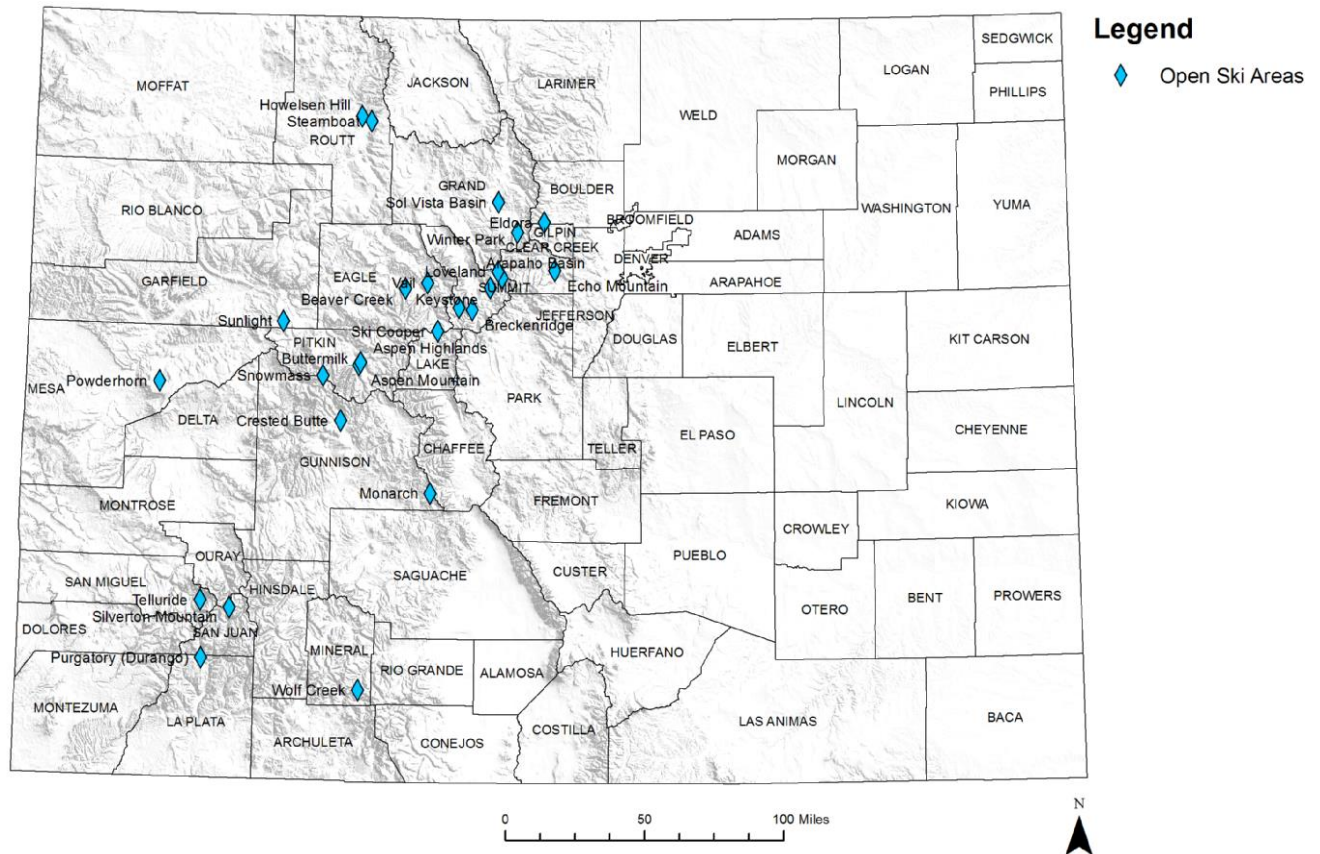
The North Platte River Basin has one commercially rafted reach that sees on average less than 1,000 user days per year, making this basin the least rafted in the state. The Rio Grande Basin is the second least-rafted basin, since there are only a couple of commercially rafted stretches of the Rio Grande that see on average less than 2,400 user days per year (CROA, 2012).

The sub-sectors described above were chosen based on their economic impact to the overall tourism industry and their immediately recognizable vulnerability to drought. Other sub-sectors that are not covered in this report but that are still worth mentioning include:

-
- 1) Touring the State, either through road trips or through other modes of transportation, with the purpose of scenic viewing or other specific activities. Heritage areas (towns, parks, or other areas with rich and publicized history) are a notable draw to the state. Another touring activity is aspen tree leaf viewing in the fall.
 - 2) Bicycling, hiking, and other trail-based activities. Although these activities are not covered, they could be potentially impacted during a drought due to park/land closures, increased wildfire risk, and/or decreased air quality, decreased “scenic” quality of landscape, and decreased quality of unpaved hiking and biking trails.
 - 3) Cross-country and back country skiing, snowshoeing, and 10th Mountain Division hut trips. The revenue from these activities is generally much less significant in comparison to downhill skiing at established resorts.
 - 4) Kayaking and canoeing are water-based recreation activities that could be included in future studies. Stand-up Paddle Boarding (SUP) is another growing water sport that may be worth considering in future analyses.
 - 5) “Agri-tourism,” which is tourism centered on agricultural attractions. A prominent example of this is the growing wine industry in Mesa County. As of 2018, this is a small economic portion of the Recreation Sector, but may warrant attention in the future.

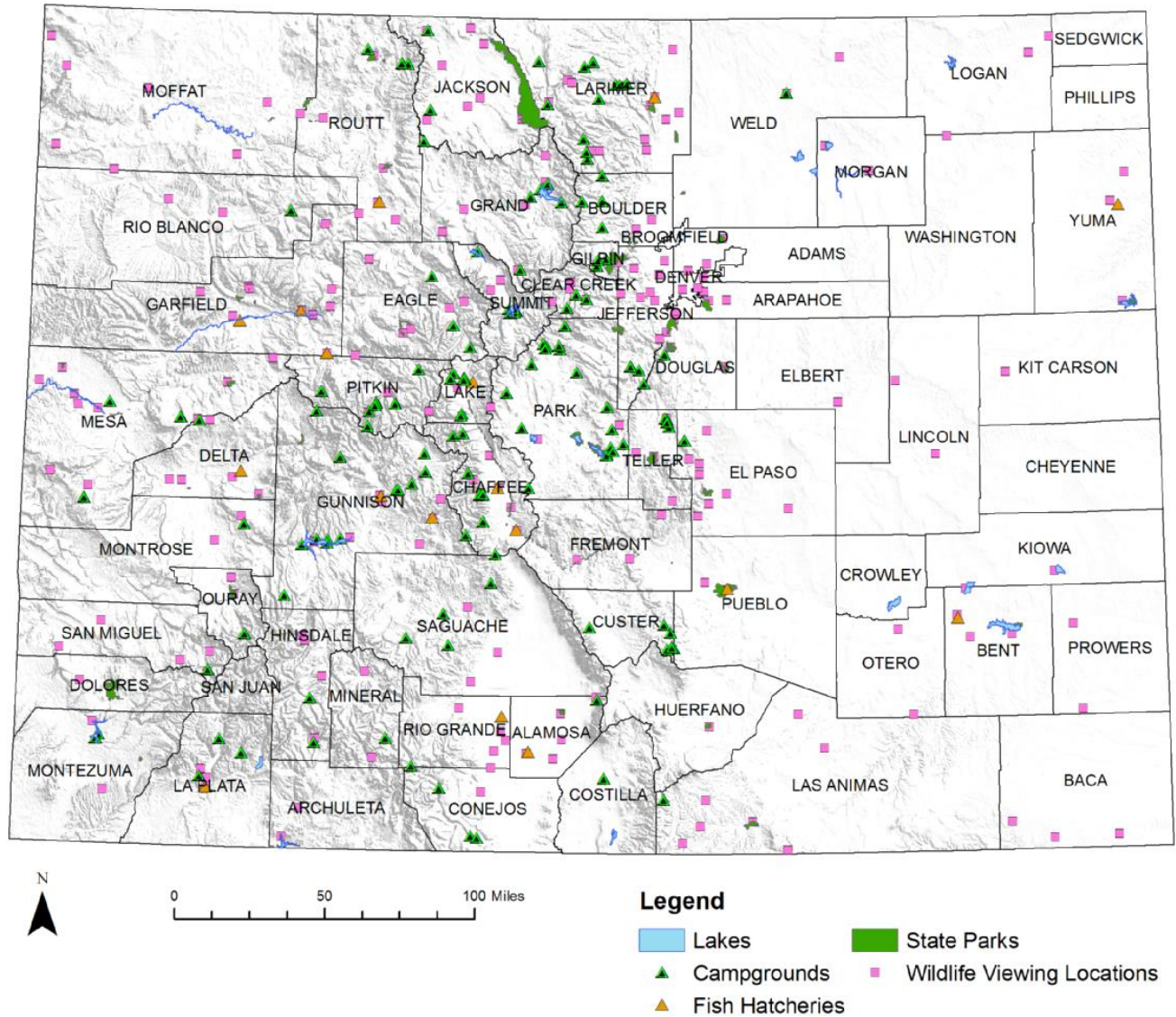
As evidenced by the previous discussion, the Recreation Sector is quite diverse, and ties into numerous other sectors of the economy and state; namely the Environment, State Assets, and Agriculture Sectors. The following sections discuss aspects of vulnerability to drought in the Recreation Sector and cover adaptive capacities used to mitigate the impacts. For a general description of the vulnerability assessment approach refer to Chapter 2 of Annex B.

Figure 10.5 Ski Resort Locations in Colorado



National Operational Hydrologic Remote Sensing Center 2009 and individual ski resort websites

Figure 10.6 CPW Wildlife Viewing Areas



Source: DOW 2010

Figure 10.7 Waterfowl Hunting/Viewing and Habitat, South Platte Basin (NCNA 2010)

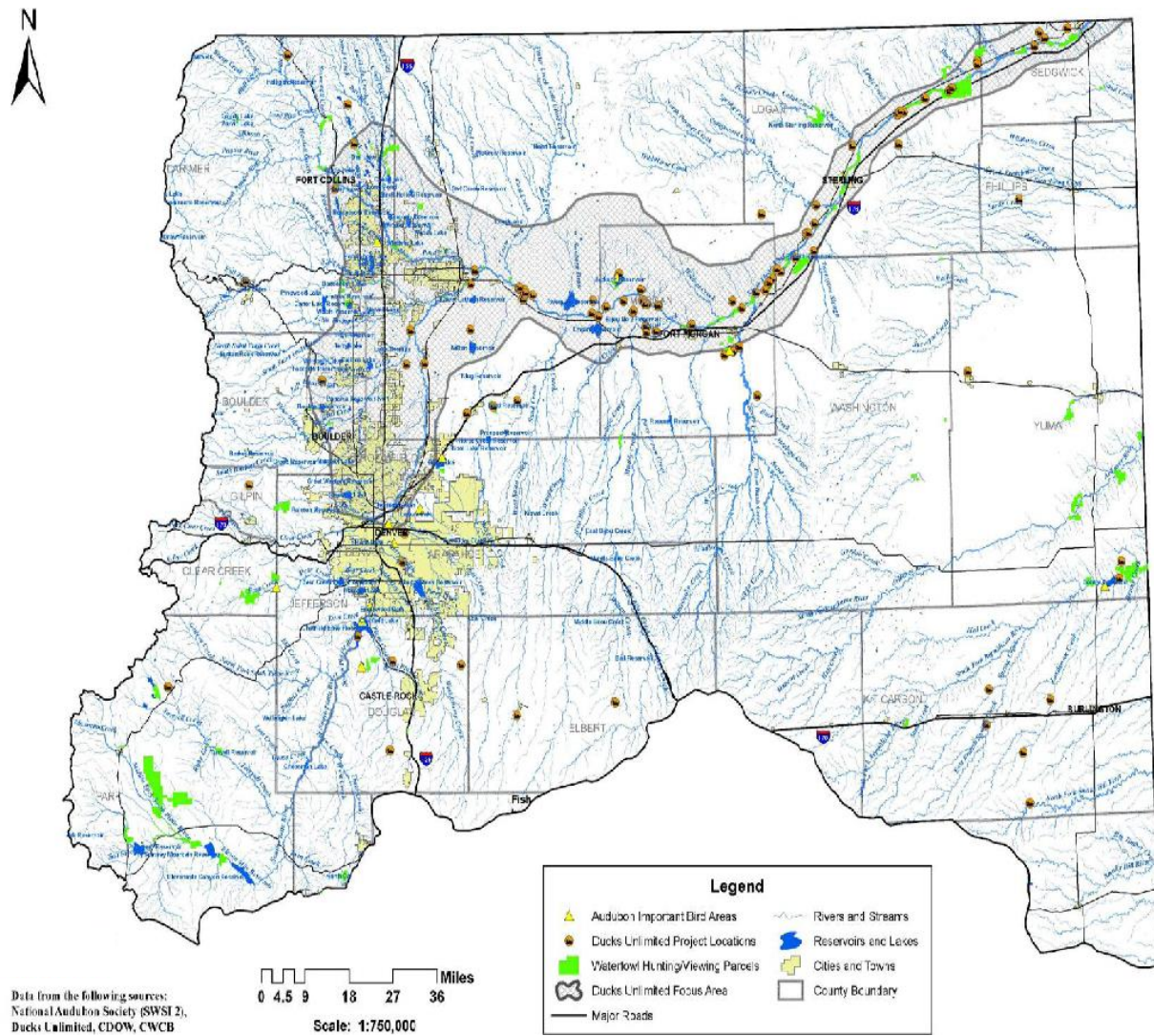


Figure 10.8 CPW Owned or Managed Lands in Colorado

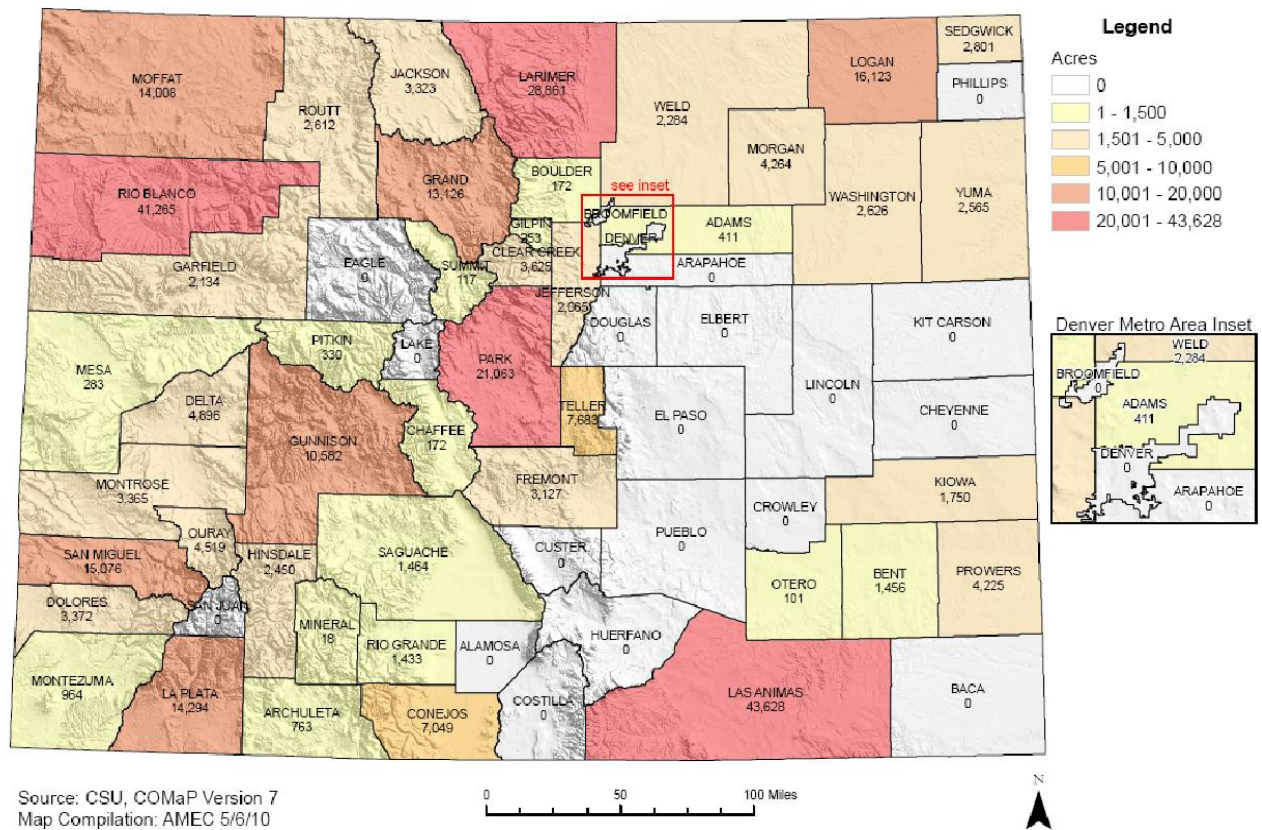


Figure 10.9 Golf Courses in Colorado

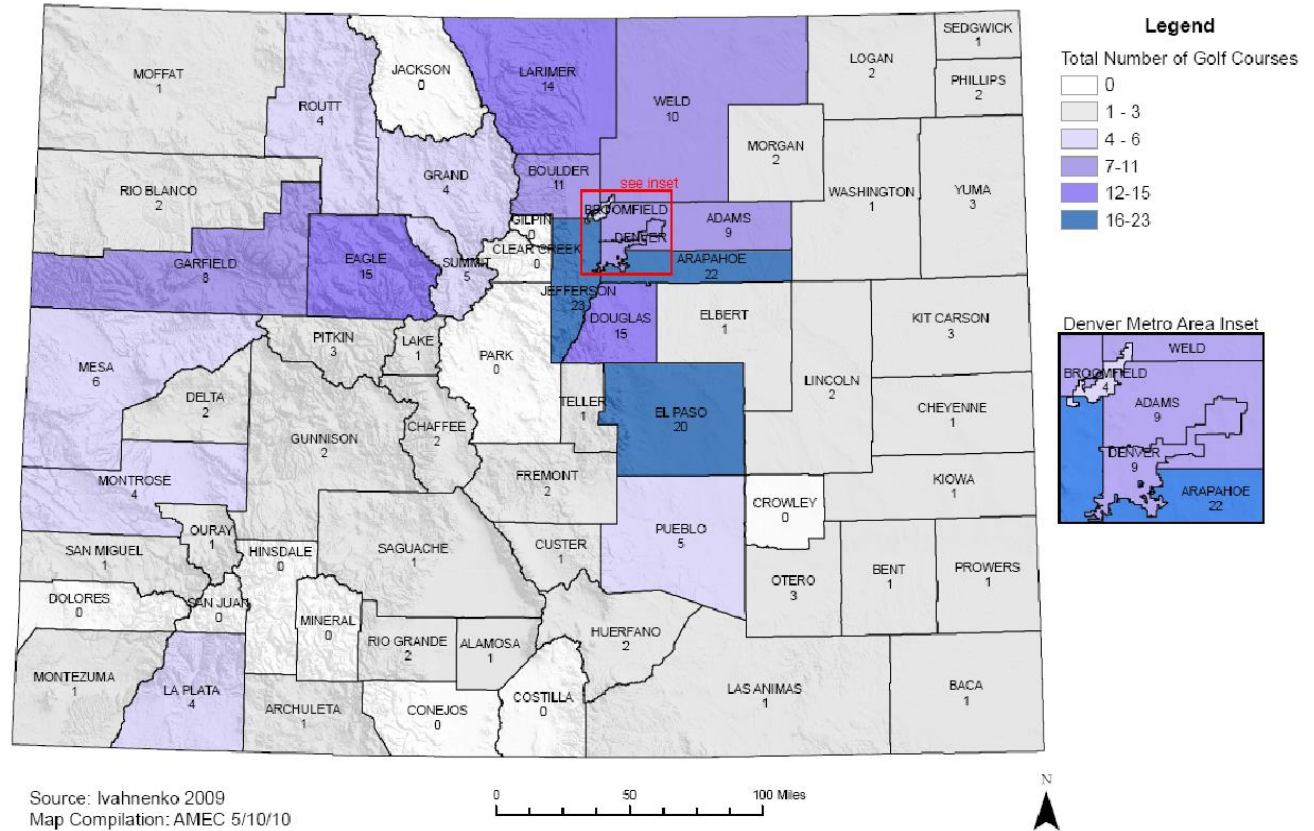
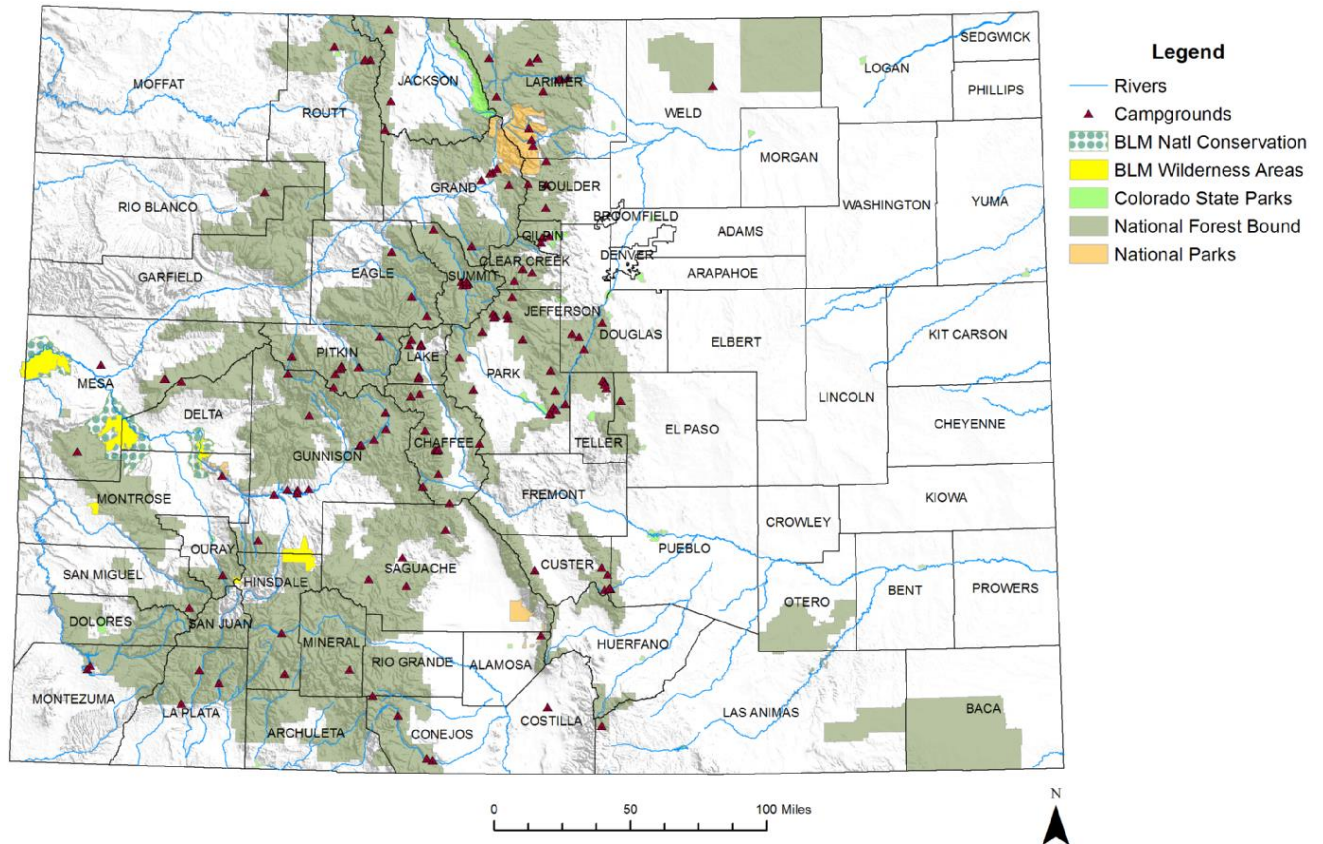
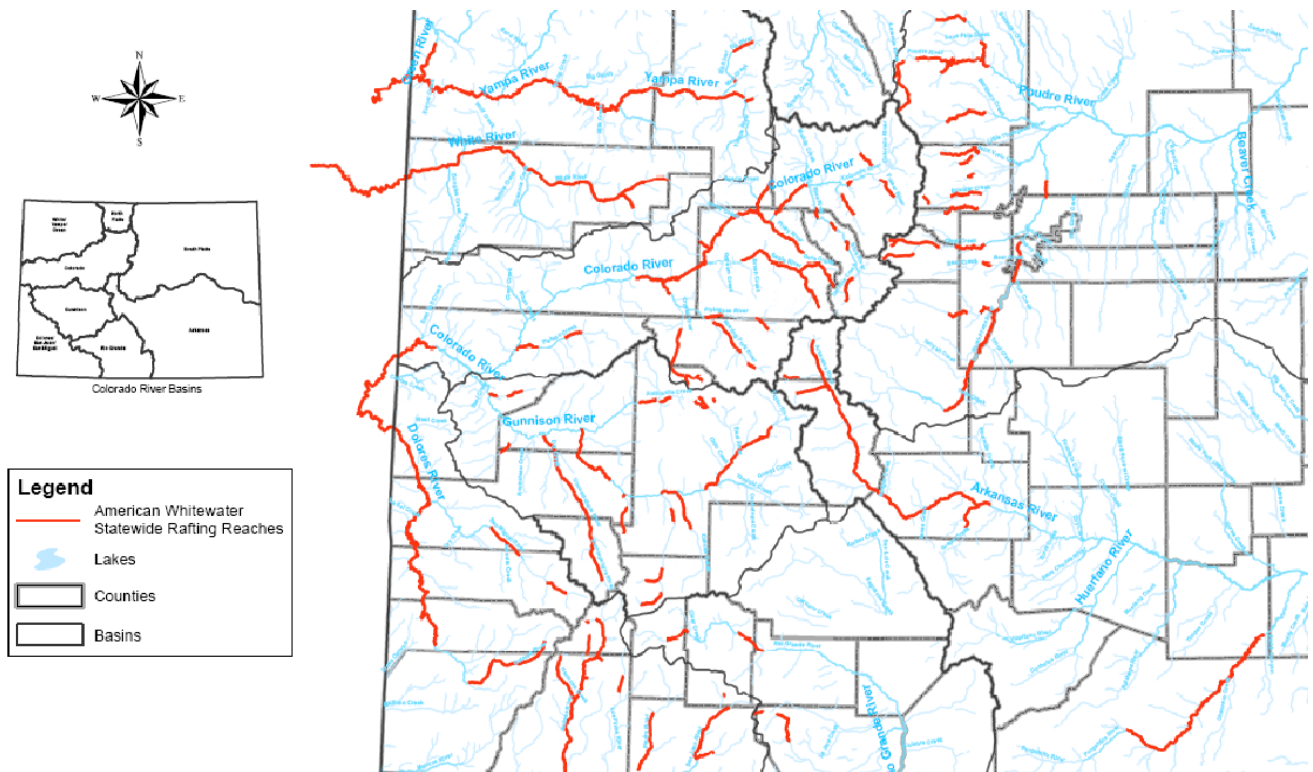


Figure 10.10 Recreation Areas in Colorado



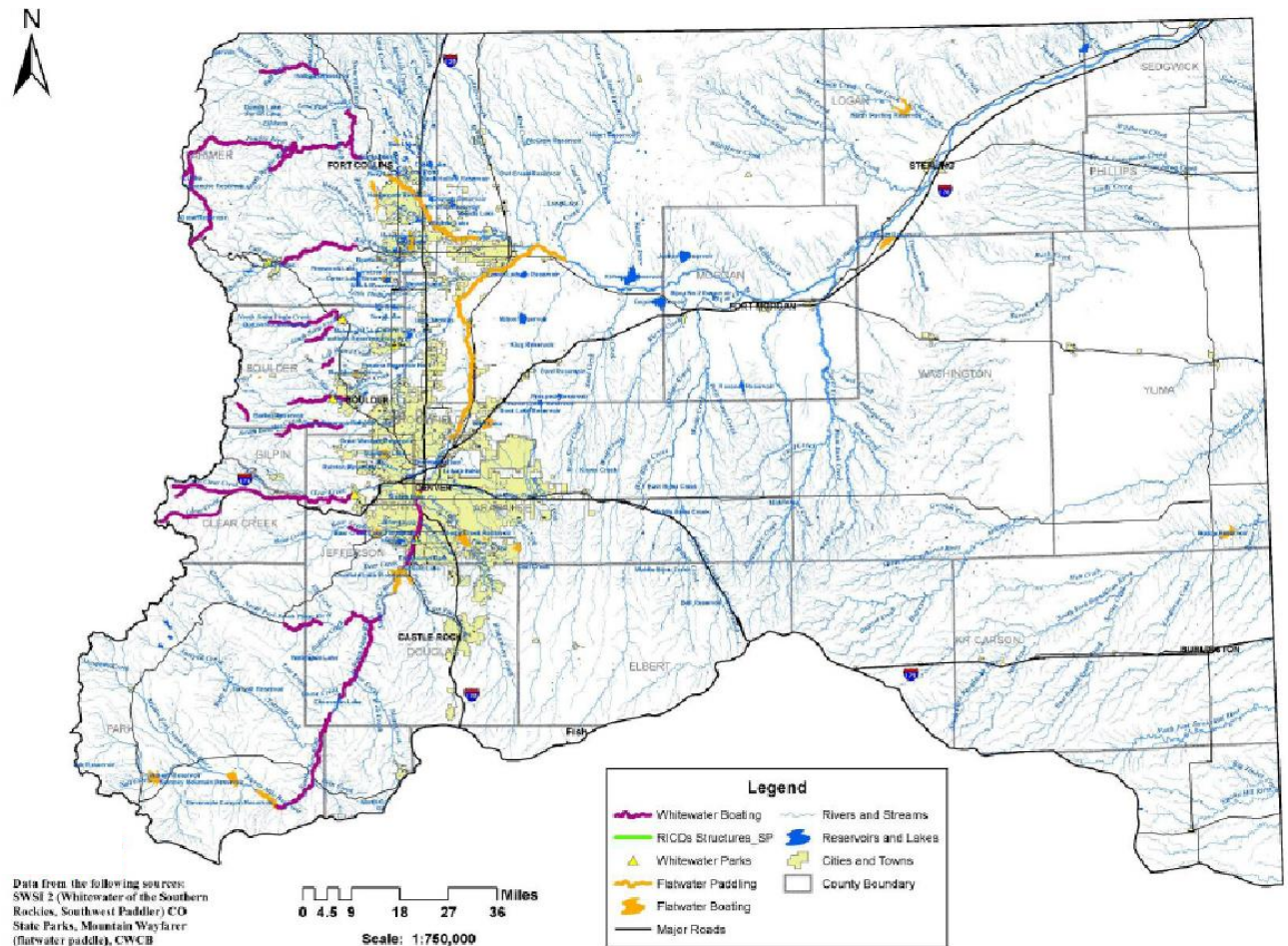
Source: BLM, NFS, State Parks

Figure 10.11 American Whitewater Statewide Rafting Reaches



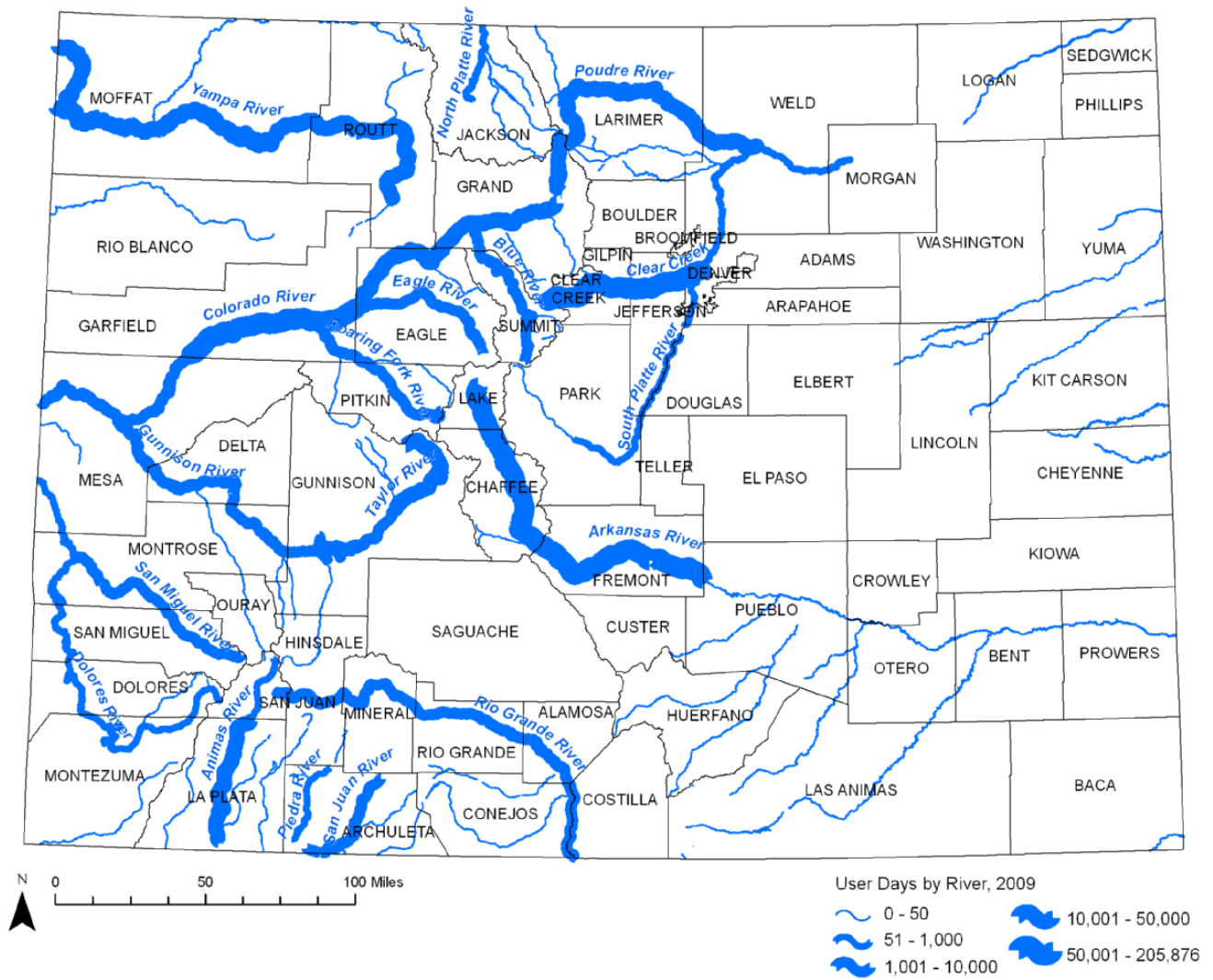
Source: SWSI Phase 2 (TNC, SWSI, CWCB, 2007)

Figure 10.12 Whitewater and Flatwater Paddling Reaches, South Platte Basin, NCNA 2010



Source: CWCB 2010 (Data from the following sources: SWSI Phase 2 [Whitewater of the Southern Rockies, Southwest Paddler] CO State Parks, Mountain Wayfarer [flatwater paddle], CWCB)

Figure 10.13 Commercial Rafting User Days per River, 2009



Source: CROA 2009 (This graphic not updated as the pattern of relative use between rafting reaches has not significantly changed for 2012 or 2018.)

10.2 Vulnerability of Recreation Sector to Drought

10.2.1 Aspects of Vulnerability

Potential drought impacts to the Recreation Sector vary based on the activity, location, and season (as shown in Table 10.1). The impacts and adaptive capacities discussed in this section were obtained from previous studies done on drought in the tourism industry (listed in the sector bibliography) and from conversations/interviews with people working in or representing the particular sub-sector.

Table 10.5 gives a broad view of how each sub-sector is impacted by drought.

Table 10.5 Drought Impacts to Recreation and Tourism

Sub-sector	Potential Impacts
Skiing	<p>Winter season drought (i.e., less-than-normal snowfall) can impact ski area revenues if potential skiers are deterred.</p> <p>Ski areas could experience higher operating costs if forced to increase snowmaking – both due to increased need for man-made snow and to the additional energy costs of making snow in warmer temperatures.</p> <p>Seasonal staff could be laid off if skier visitation stays low.</p>
Wildlife viewing	<p>Stress to animals due to lack of water, loss of vegetative cover, and/or heat could keep them away from traditional viewing areas.</p>
Hunting, fishing, and camping	<p>Stress to animals due to lack of water, reduction in forage, loss of vegetative cover, and/or heat could keep them away from traditional viewing areas and decrease the overall health of the population.</p> <p>Animal scarcity and/or loss of vegetative cover could detract hunters and result in decreased hunting license revenue for the CPW.</p> <p>With less resources (food, water, habitat) available, population production and recruitment will likely decrease for many species.</p> <p>A reduction in water resources will generally influence the behavior of all game, but waterfowl numbers specifically are likely to decrease with a reduction in habitat.</p> <p>Fish populations could decline due to lower streamflows, lower reservoir and lake levels, decreased dissolved oxygen, too-warm water temperatures, and otherwise degraded water quality.</p> <p>Fish scarcity could detract anglers and result in decreased fishing license revenue for the CPW (public perception).</p> <p>Fish hatcheries could incur higher operating costs if they have to either transfer their fish to a different location, or go to streams, rivers, and lakes to retrieve endangered species that were released in the wild but now are at risk due to decreased natural water quality and availability.</p> <p>Forced closure of campsites due to lack of water (from on-site wells) but more prominently due to risk of wildfires and/or hazard trees (trees that are dead or dying and are at risk of falling).</p>
Golfing	<p>Water scarcity and/or municipal restrictions could cause parts of course to become harder to play, go brown, or otherwise become stressed.</p>

Sub-sector	Potential Impacts
	<p>Drought-stressed turfgrass has diminished playability and performance, resulting in fewer golfers and a loss of revenue.</p> <p>As putting greens become drier, they become more firm. Firm greens increase the challenge to golfers, which can result in fewer golfers if playing conditions are too difficult.</p> <p>Golfer participation could decrease due to negative perception of course aesthetics, and/or courses could face higher operating costs to maintain existing turf.</p> <p>Increased time and expense to golf courses following the drought to induce damaged turfgrass to recover. These expenses are incurred immediately after a period of limited revenue, which can place courses in a difficult financial position.</p>
Boating	<p>Lower reservoir and lake levels could detract boaters from visiting and/or registering their boats for a season.</p> <p>State Parks could experience decreased revenues due to lower visitation and registration.</p>
Rafting	<p>Lower streamflows could force rafting outfitters to use smaller boats, resulting in less revenue per trip.</p> <p>Negative public perception of drought and associated hazards (e.g., wildfires) could result in decreased rafting customers and/or cancellations.</p>

These impacts can be offset through adaptive capacities. The recreation industry has experienced drought before, and each time the ability to adapt and mitigate the impacts becomes more refined as companies diversify and figure out what they need to do to remain in business through the drought. Table 10.6 lists some adaptive capacities that have been developed and utilized during past droughts.

Table 10.6 Recreation and Tourism Adaptive Capacities

Sub-sector	Adaptive Capacities
Skiing	<p>Use snowmaking machines to better predict and control season opening date; this also helps mitigate against lack of natural snow later in the season.</p> <p>Cloud seeding has been used by Vail Resorts since the 1970s. They identify cloud seeding impacts to total snowfall as being in the range of 15 to 18 percent over the course of the ski season.</p> <p>The comparative investment is \$58,000 a month for three months of seeding compared to \$50,000 each night that snowmaking is used for eight acres of land (Sink 2003).</p>
Wildlife viewing	<p>CPW feeding programs to avoid catastrophic animal loss.</p>
Hunting, fishing, and camping	<p>CPW feeding programs to avoid catastrophic animal loss. Conversely, the CPW can release more hunting licenses than they would have otherwise, with the rationale that the animals are likely to die anyway due to drought (Luecke et al. 2003).</p> <p>CPW can implement drought specific herd management principles for priority game species (CPW, 2012).</p> <p>Fish hatcheries can transfer fish to streams, lakes, and/or other hatcheries that are not as negatively impacted.</p> <p>Campsite managers can advertise areas that are not impacted (if such areas exist).</p>

Sub-sector	Adaptive Capacities
Golfing	Many of these adaptive capacities are already widely used in golf course management and include: use of chemical wetting agents to increase uniform water distribution in soil column, eliminate irrigation in selected areas, reduce rough irrigation, hand-water tees, and control the growth of grass by not cutting it as short and adjusting fertilization practices.
Boating	Use lower water levels as an opportunity to do maintenance on boat ramps; advertise areas in the state that are not heavily impacted (if such areas exist). CPW can work with local, state, and federal agencies to maintain certain flows for recreational purposes as there is a direct correlation between adequate water levels and state park revenue (CPW, 2012). Conversely, halt maintenance to save money and reduce staff.
Rafting	Diversify business by offering trips on more rivers, offer different lengths of trips to attract new customer base, and/or offer kayaking or fishing trips that may not need as high a flow volume in the river. Cut back on staffing. CPW can work with local, state, and federal agencies to maintain certain flows for recreational purposes as there is a direct correlation between adequate water levels and state park revenue (CPW, 2012). Focus on a different demographic that may be attracted to lower-flow, less physically demanding trips. Rafting organizations can also work with the government and media to control the message relayed to the public. This would help to maintain a positive public perception of rafting throughout the drought.

10.2.2 Previous Work

A review of previous works dealing with drought impacts in the Recreation Sector was conducted to assess vulnerability and adaptive capacities. Most of these works discuss the 2002 drought, as it was the most recent complete drought event.⁵ Impacts during the 2012 drought were similar. Table 10.7 summarizes the impacts reported for both the 2002 and 2012-2013 drought events.

Table 10.7 Summary of Previous Works

Sub-sector	Previously reported impacts	Source
Skiing	Out of 25 Colorado ski resorts and ski areas, 21 made snow early in the season (from October to December). Overall though, the direct winter impacts were minor compared to the summertime impacts on other sectors of the recreation and tourism industry.	Wilhelmi et al. 2004
	For the 2011/12 season, skier visits to Colorado Ski Country USA (CSCUSA) resorts were down 11.9%.	CSCUSA, 2012
		CSCUSA, 2013

⁵ Estimates put the frequency of the 2002 drought as a 300- to 500-year event (Luecke et al., 2003). Although the summer of 2002 was severe, the overall drought was relatively short with respect to previous multi-year droughts recorded in Colorado.

Sub-sector	Previously reported impacts	Source
	A decrease in skier visits continued into the 2011/12 season with CSCUSA resorts noting a 4.2% decrease through February 28 th , 2012.	
Wildlife viewing	<p>Documented cases of birds shifting their migratory grounds in response to environmental changes, including higher temperatures often associated with drought.</p> <p>It is unknown the extent to which extreme climatic events, especially heat waves and drought, will push different species physiological tolerances for heat and dehydration to or above their limits, resulting in increased mortality.</p> <p>Animals may move to higher elevations to avoid warm temperatures during summer drought.</p>	<p>Audubon 2009</p> <p>Audubon 2010</p> <p>Kohler 2010</p>
Hunting, fishing, and camping	<p>The State released 16,000 extra cow elk licenses in September for fear that the elk would die over the winter anyway.</p> <p>The fishing industry fought a battle of perception all summer. According to representatives from three separate fishing shops, their biggest obstacle was convincing people that the fishing was actually very good. Low water level and high water temperatures led to good fishing in certain areas.</p>	<p>Luecke et al. 2003</p> <p>Schneckenburger and Aukerman 2002</p>
Golfing	<p>Estimated that a typical Front Range golf course would need to increase their irrigation by about 25% to offset the effects of high temperatures and low precipitation to provide the aesthetics, performance, and playability golfers expect during non-drought years.</p> <p>Note that the estimated 25% increase in irrigation needs is for illustration purposes. In practice, during the drought in 2002 golf courses used approximately the same amount of water as in non-drought years by employing water conservation techniques (see Table 10.6) such as not irrigating parts of the golf course (usually the rough) and reducing irrigation on other parts of the golf course (usually fairways).</p>	<p>Watson et al. 2004</p> <p>Communication with Golf Course Superintendents Association of America 2010</p>
Boating	<p>Boating in general was down. Water-based state parks reported reductions between 20% and 53% in revenues as boat ramps were left unusable by low water levels. Estimated loss of about \$140 million. Extremely low levels in many reservoirs and rivers throughout Colorado presented a major challenge for this sub-sector.</p> <p>Due to the 2002 drought, State Parks was forced to close several lakes and reservoirs early due to low water levels and the inability to launch boats.</p>	<p>Luecke et al. 2003</p> <p>Wilhelmi et al. 2004</p> <p>Schneckenburger and Aukerman 2002</p>
Rafting	<p>Trip cancellations and significant customer declines; forced to lay off staff; increased injury among guides due to low water levels.</p> <p>According to the Colorado River Outfitters Association, a 39 % drop in whitewater rafting days was evident as compared to 2001 levels. This equates to a difference in over 200,000 user days (523,587 in 2001; 319,562 in 2002). Each user day is estimated to provide \$391 of revenue.</p> <p>The total number of user days for the state for 2012 decreased 17.1% compared to 2011, which saw a 0.5% decrease from 2010.</p> <p>The total estimated economic impact of the 2012 drought on the rafting industry was approximately \$128 million</p>	<p>Shrestha 2009</p> <p>SWSI Phase 1 2004</p> <p>CROA, 2012</p> <p>CROA, 2012</p>

The 2012 Drought Assessment for Recreation & Tourism (DART) study was funded by the CWCBC and is a pilot project intended to examine the relationship between drought and recreation and

tourism in southwestern Colorado. While initial goals of the report included evaluating the metrics used in the Colorado State Drought Mitigation and Response Plan and identifying existing data to be used for drought management, baseline data from which to work was found lacking. Data required to evaluate the metrics from the drought plan were not available in many cases. Ultimately, the DART Report authors were able to propose a model of stakeholder engagement that both echo, and can be used to address, several recommendations made in the 2010 Drought Mitigation and Response Plan. The DART report thus provides some details of drought vulnerabilities and impacts to the sector in southwestern Colorado, but also is a guide about how best to begin collecting data through stakeholder involvement in order to determine and assess the impacts of drought on recreation and tourism.

The 2012 DART Report offers insights to the assessment of drought impacts to the recreation/tourism sector in southwestern Colorado. The report builds upon several of the conclusions and themes established in the 2010 CWCB Drought Plan and establishes a general framework for future studies. While many of the methods will likely be transferrable, the recreation and tourism sectors in other parts of the state may function differently, requiring alterations to the approach. Overall the report makes clear that little is known about the linkages between drought and the recreation/tourism sector, and thus this focused study is a significant step forward to improving this situation.

Key summary conclusions from the DART are as follows:

- The diversity of the sector presents some challenges, but also provides a great capacity for adaptation. Communities that can offer many different options for recreation and tourism will be better off than those that cannot.
- In order to control the negative public perception associated with drought, wildfires, etc., communities will need to effectively market the diversity of options they can present to tourists. In association with a diverse marketing strategy, public relation plans will also be important in order to prevent a negative public perception of the drought event.
- A level of awareness about the linkages between drought and the recreation/tourism needs to be communicated and developed at the stakeholder level.
- The linkages between drought and primary impacts to the recreation/tourism sector are obvious in some cases and more obscure in others. In many cases, the secondary impacts are unknown. Data collection and information dissemination are key to understanding trends and providing evidence for informing planning and policy. Drought specific methods and metrics need to be developed in order to understand how drought impacts the sector. One possible way to determine these metrics is to follow the framework developed for the stakeholder involvement model.
- Successes from each sub-sector need to be identified and translated into best practices that other business can follow or employ as part of a drought that includes strategies for preparedness, response, mitigation, and recovery.
- Studies addressing past drought events include CWCB's Drought Water Supply Assessment (DWSA) in 2004 which had the goal of determining the State's preparedness for drought conditions. This study aimed to determine how prepared Colorado has been for drought and to identify limitations, and related measures, to better prepare for future droughts (DWSA 2004).

It entailed a survey in which 537 responses were received statewide regarding specific impacts experienced during the drought years of 1999 to 2003. Various entities were surveyed including power, industry, agriculture, municipal, state, federal, water conservancy and conservation districts, and other entities like tribes and counties. Although the survey did not include any recreation or tourism groups, various case studies were conducted and included a rafting company owner on the Arkansas River. The goal of the case studies was to describe the social impacts that were felt on the business owners as a result of the most recent drought. Impacts reported in those case studies are similar to those reported in Table 10.5 and Table 10.7.

Another previous study that is useful to discuss is the Statewide Water Supply Initiative (SWSI). Although it did not specifically focus on drought as the DWSA did, the SWSI process was directed by the CWCB to understand existing and future water supply needs and how those needs might be met through various water projects and/or water management techniques. As described in the introduction, SWSI used a statewide and basin-level view of the water supply conditions in Colorado and created basin roundtables as a forum for collecting and sharing information and ideas.

The SWSI report in 2010 discussed recreation and tourism as it relates to water availability in Colorado. One of SWSI's recommendations is to "enhance recreational opportunities." While SWSI did not provide a detailed assessment of drought impacts to the Recreation Sector, it did identify some areas where water management techniques could be employed, whether in a drought or not, to enhance this important component to not only bring economic vitality to the State, but to also provide quality of life for its residents and visitors. A major finding in SWSI Phase 2, re-emphasized for SWSI 2010, was that population growth in the state would cause the environmental and recreational uses of water to increase, and that there would be competing demands for water across use categories (e.g., domestic, municipal, industrial, and recreational). Conflict will arise between these groups if no mechanism to fund environmental and recreational enhancements exists alongside water projects beyond what is normally required by law during the permitting process. Recognizing this, the SWSI process seeks to maintain a dialogue between stakeholders to identify potential funding sources or options for enhancing recreational and environmental uses when reliable sources of water are developed.

One specific example of cooperative multiple use of water discussed in SWSI Phase 2 is the Yampa River Flow Enhancement program. This project is one where operational flexibility was maintained between major water users and suppliers to mitigate drought impacts to a fishery in the Yampa River. In 2002, flow increases through the upper reaches that were allowed via re-operation/exchange minimized the effects of high water temperatures on the fishery. A similar scenario played out during 2012 when the Yampa experienced severe drought. The Colorado Water Trust and CWCB leased 4,000 acre-feet for instream flows (Smith & Koziol, 2012). The 2010 update to SWSI compiled information from the basin roundtables about their existing and future needs and supplies for both consumptive and non-consumptive uses. This information was then used to project supply and demand through 2050, including non-consumptive use needs, upon

which much of the recreation and tourism sector relies. The Statewide NCNA Focus Map⁶ presents each basin's projected needs which includes 33,000 miles of streams and lakes containing or offering recreational and environmental value.

SWSI Phase 2 provided additional examples of recreational enhancements, including providing instream flows for rafting and kayaking and providing permanent reservoir pools for flat-water recreation. As part of the SWSI process, all decreed instream flow and recreational in-channel diversion (RICD) water rights were inventoried. As discussed in the State Assets section, the CWCB, through its Instream Flow Program, protects the natural environment by obtaining instream flow water rights. This program is an important one to ensure certain streamflows and lake water levels are maintained to protect important habitats. While the focus of instream flow rights is environmental protection, there are secondary recreation benefits.

As mentioned above, the NCNA Focus Mapping report (CWCB 2010) discusses non-consumptive water uses in the nine basin roundtable areas of Colorado (eight major river basins and the Denver Metropolitan Area). The NCNA expands upon the existing set of environmental and recreational attribute maps that were developed through the SWSI Phase 2 process and develops aggregated maps of Colorado's critical waters based on the concentration of environmental and recreational qualities. The maps are intended to be a guide for water supply planning, so that future conflicts over environmental and recreational water needs can be avoided. Although the NCNA analysis was done with respect to sub-basins and stream reaches, future work could convert these findings into county designations that could be incorporated into this drought vulnerability analysis methodology.

Most recently, the Colorado Water Plan (CWCB, 2015) addresses the importance of recreational water needs to protect the environmental and recreational areas that are important to Coloradans.

10.3 Assessment of Impacts and Adaptive Capacities

Recreation and tourism is a large and diverse industry in Colorado. For this assessment, focus is placed on water-based activities (e.g., skiing, boating, and rafting) and activities that are secondarily impacted by drought and that comprise a significant portion of the recreation and tourism industry (e.g., hunting, fishing, wildlife viewing, and golfing). In the previous sections, drought impacts and adaptive capacities were introduced. This section expands on that framework.

10.3.1 Impacts and Adaptive Capacities

Skiing

In 1977 there was a severe winter drought. In response, most resorts installed snowmaking machines (considered a mitigation strategy to winter drought). In addition to protecting the ski

⁶ This document, along with the rest of SWSI 2010 can be found at:
<http://cwcb.state.co.us/water-management/water-supply-planning/pages/swsi2010.aspx>

area against little or no natural snow, snowmaking capabilities allowed the resorts to set firm opening dates and better control seasonal staffing and other business-related factors. As a result of the prevalence of snowmaking, the ski industry was not significantly impacted by the lack of snow in the winter of 2001/2002. Also during the mid-1970s, Vail Resorts started a cloud seeding program which has continued to the present. Snowmaking and cloud seeding could be considered adaptive capacities for the skiing sub-sector. It is difficult to determine whether or not snowmaking influenced skier behavior during the 2012 season. Through the end of February 2013 skier visits were slightly down (CSCUSA, 2013), but resorts were able to open prior to sufficient snowfall because of snowmaking capabilities. In 2018, the United States Small Business Administration offered low-interest federal disaster loans to small businesses (including ski resorts) economically impacted by the January to April wintertime drought that occurred in the southwestern part of Colorado (U.S. SBA, 2018). This was the first time such loans have been made available since the 1970s.

The timing of drought is a key factor as to whether ski areas will be impacted (i.e., a drought occurring in the summer will not directly impact the ski season). Spatial variability is also important since a drought in the southeast corner of the State will have little impact on the ski areas. However, because ski areas are concentrated in a small area, the likelihood of a drought affecting many areas at once is high.

The economic make-up of the area surrounding the ski resort factors into how impactful drought is. For counties where ski resorts provide a sizable proportion of jobs, impacts to ski areas during a drought would potentially affect a large segment of the employed population. The adaptive capacities that were described for ski areas in the previous section could help avoid large-scale layoffs during a winter drought.

In some drought situations, snowmaking capacity may be limited by water availability. The ski resorts in Colorado that use snowmaking machines have the capacity to cover between 15 acres and 650 acres of terrain.⁷ Depending on the temperature, each acre-foot of snow generated requires about 160,000 gallons (roughly one-half of an acre-foot) of water (Ratnik Inc. 2010). Therefore, snow generation can require millions of gallons of water annually. Ski resorts have rights for this water but their ability to divert water can be limited by instream flow rights during drought. The impact to specific resorts will vary by location and depending on where diversions occur relative to other rights. Some resorts may not be impacted at all during drought but can still be hurt by public perception of ski conditions.

Colorado Ski Country USA tracks the number of skier visits through the season. Skier visits are metrics used to track participation in the activity, and one skier visit is defined as one person participating in the sport of skiing or snowboarding for any part of one day at a mountain resort (CSCUSA, 2013). As expected, skier visits declined during the 2012-2013 drought period.

⁷ Self-reported snowmaking coverage, individual websites accessed 2010.

Wildlife Viewing

According to a 2011 survey conducted by the US Fish and Wildlife Service (USFWS), there were 1.8 million U.S. residents (16-years-old or older) who fed, observed, or photographed wildlife in Colorado (approximately the same amount as reported in USFWS, 2006). The same survey estimates that wildlife watchers spent \$1.4 billion on wildlife watching activities in 2011 (again, nearly equivalent to figures reported in USFWS, 2006); this includes food and lodging, transportation, equipment rental, and other trip expenses. The average of the trip-related expenditures for participants away from their homes (defined as one mile or more away from home) was \$786 per person in 2011 (up from \$607 in 2006) (USFWS, 2011).

This economic contribution to rural economies could be reduced if a drought caused a decline in wildlife herds. A localized shortage of food and/or water could cause animals to migrate away from traditional habitat. Adaptive capacities such as CPW feeding programs could maintain animal populations and help secure tourist revenue for wildlife watching areas. Many wildlife species in regions of Colorado where drought is common are already adapted to it, and can either survive in drought-stressed habitats or are able to migrate to better conditions elsewhere (communication with DOW, 2010). Therefore, one adaptive strategy may be to identify where the animals are and change the wildlife viewing program accordingly.

Hunting, Fishing, and Camping

During 2007, there were roughly 12.7 million hunting and fishing activity days in Colorado, and the estimated total direct expenditures in support of hunting and fishing were approximately \$1.1 billion (BBC Research & Consulting 2008). This level of economic activity is estimated to support approximately 21,000 full-time jobs in Colorado, which especially in rural counties can represent an important part of the economy (BBC Research & Consulting 2008).

In 2012, Colorado Parks and Wildlife have observed a number of impacts related to the hunting, fishing and camping sub-sector for the 2011-2103 drought event (CPW, 2012). Future droughts are expected to produce similar impacts (communication with CPW, 2018). Overall, park visitations dropped by an estimated 25%, which corresponds to a revenue loss of over \$1 million. Visitations and revenue for the Northwest and Southwest regions (18 state parks) was reduced by 20-35%, and for the Northeast and Southeast regions, reduced 15-30% (24 state parks).

CPW has found the drought has generally reduced the resources available to many species (CPW, 2012). This has lowered animal fat reserves, reducing the likelihood of winter survival. Production and recruitment are expected to be reduced for upland game birds, waterfowl, lesser prairie chicken, sage-grouse, and pronghorn antelope. CPW is concerned about the availability of wintertime forage for big game, and thus the survival of several species, especially mule deer (CPW, 2012).

In order to combat these concerns, CPW has implemented population monitoring programs and drought-specific herd management principles for priority game species (CPW, 2012).

Impacts to the fishing sub-sector include fish kills, loss of flow or water level, and damaging floods (CPW, 2012). Fish kills at reservoirs, lakes, ponds, and streams have resulted from high water temperatures, anoxic conditions, excessive ash from recent wildfires, and high sediment loads. A heavy precipitation event on July 24, 2012 flushed sediment and debris into a reach of the Colorado River above Dotsero, killing a large amount of fish. Wildfires have generally contributed to poor habitat conditions for aquatic species. Ash and sediment from the Track Fire (2011) elevated 2012 water temperatures causing a fish kill at Lake Dorothy State Wildlife Area in Las Animas County. Additionally, habitat in the Poudre River basin has been negatively impacted by post fire sediment loads from the Hewlett Gulch and High Park fires (CPW, 2012).

CPW has initiated several mitigation efforts. These include emergency fish salvages at several reservoirs, voluntary fish closures, and emergency evacuation of brood stock to other hatcheries. In the White River, CPW worked with the CWCBC and Division of Water Resources to gain approval for an emergency release to maintain in-stream flows in order to protect cold-water species. In response to the High Park fire, catchable sized fish from the Watson Hatchery were relocated to the Horsetooth and Carter reservoirs (CPW, 2012).

A priority of CPW during the 2002 drought was to protect recreationally significant wildlife populations. The State increased the number of elk licenses released and instituted over-the-counter elk licenses due to concern that the elk population was too large and would not survive the winter given the limited forage. This solution was ineffective as it created confusion among hunters and did little to reduce elk numbers (communication with DOW 2010). As a result of the 2002 drought, CPW now has a process to close areas to activity in case of emergency conditions, including drought. This is expected to leave staff better prepared to deal with drought emergencies as they arise by providing a framework in which the staff can respond quickly (communication with DOW 2010).

Significant impacts were also noted for aquatic recreation during the 2002 drought. For example, the Kokanee salmon, a high value sport fishery in Colorado, was threatened by low flows in a critical spawning run on the Gunnison River. Flows were so low during the late summer that the Kokanee salmon run could not swim past a barrier west of the town of Gunnison. CPW staff had to manually transport the fish to the Roaring Judy Fish Hatchery on the East River for spawning operations. They also removed, redesigned, and reconstructed the concrete barrier to better allow for future fish passage (communication with DOW 2010). Reservoir fisheries were also impacted. In 2002 Denver Water completely drained Antero Reservoir to avoid evaporative losses. Antero Reservoir was a rare trout fishery known for producing large trout. The recreational fishery was closed during the drought and remained closed until 2007 when the reservoir was reopened for recreational use. Antero Reservoir was nearly drained again in 2013, but significant April precipitation has allowed Denver Water to keep the reservoir open (Associated Press, 2013).

Voluntary angling closures were also instituted in 2002 due to drought. Public response to these closures was favorable. CPW has continued to implement voluntary closures in the Upper Yampa River near Steamboat Springs in 2004, 2005, 2007, and 2012. When water temperatures reach certain elevated levels in the Yampa, the City of Steamboat Springs puts out a public notice through local media and posts notifications to anglers. This process has worked well and resulted in strong compliance. CPW staff notes that getting word out early and garnering local support is key to their success (communication with DOW 2010).

Golfing

During 2002, golf course superintendents found that it was important that municipalities let golf courses manage a set quantity of water rather than be given strict timing on watering (i.e., the municipality enforcing a schedule of watering on certain days for a closed time period). Golf course superintendents are experienced at managing irrigation and the course will benefit from not having a rigid watering regime (communications with golf course superintendents 2010).

In fall 2002, one municipality required golf courses to stop watering completely for the rest of the season. This had significant impacts. Golf courses experienced decreased revenue due to poor conditions that led to reduced golfer interest. Fall is a popular time of year to play golf in Colorado. Loss of business during this season significantly impacts total annual revenue. Furthermore, turf needs to enter the winter season in relatively good shape in order to make a quick recovery in the spring. Because the golf courses were forced to cut off water early in the fall the turf entered the winter in a water-short condition. As a result, it required more time and expense in the spring to replace/rehabilitate the turf. In general, when favorable temperatures and moisture return following a drought, golf courses often must induce the drought-damaged turfgrass to recover. This requires seed, sod, fertilizer, water, labor, and other inputs. These expenses occur following a period of limited revenue, which places the golf course in a difficult financial position (communication with golf course superintendents 2010).

Where irrigation water comes from plays a part in how vulnerable a golf course is to drought, but it is difficult to make generalizations about this. While it may be true that groundwater is less immediately vulnerable to a drought that causes low streamflows, many groundwater wells are bound by augmentation plans that require them to supplement groundwater withdrawals to prevent injury to senior surface rights holders. Using reclaimed waste water for irrigation is a possible solution, but water purchases are limited by the obligation of the wastewater treatment plant (WWTP) to deliver a certain volume of return flow to the stream. Finally, public attitude towards golf courses could create a conflict over water use during drought. Golf courses are visible users of water, and although they may be recognized as an industry along with other industrial water users, they become easy targets when watering restrictions become an issue.

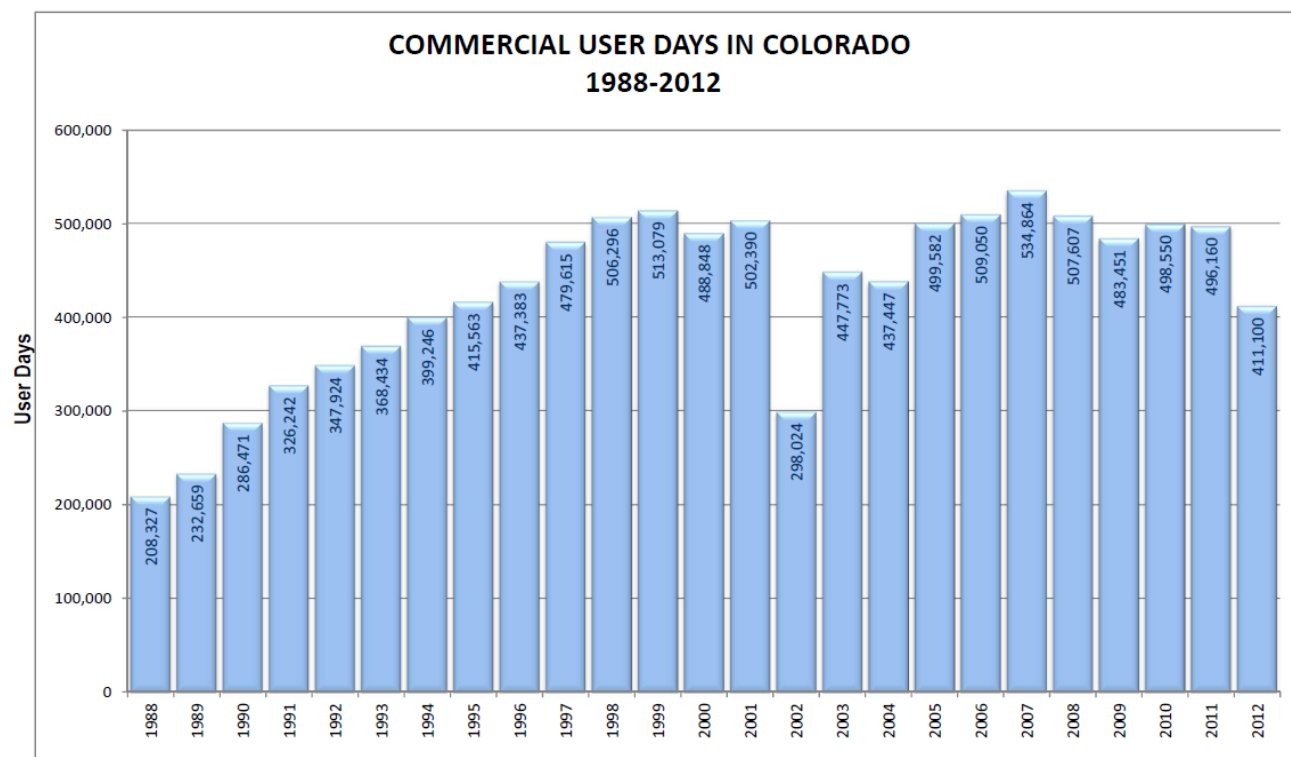
Given that there are multiple options of water sources for golf courses to obtain irrigation water (e.g., surface, ground, potable, and reclaimed), it is safe to say that diversifying the supply would provide a measure of protection against one source being cut off or depleted in a drought.

Rafting and Boating

The commercial rafting outfitters in Colorado reported being most impacted by the negative public perception surrounding the wildfires in the summer of 2002. Most outfitters interviewed about the drought criticized the governor's comments about the wildfires and the subsequent media coverage, and attributed that event to the decline in customers more so than the low streamflows (Shrestha 2009). However, low flows still impact rafting. In 2012, outfitters in the Arkansas Headwaters Recreation Area were forced to reduce the number of rafters per boat, thus impacting revenues (CPW, 2012). Rafting companies also had to transport clients to more raftable reaches. Profit losses were estimated around 25%. Low water levels resulted in many boat ramp closures and/or restrictions all across the State. Impacted reservoirs include the Blue Mesa, Brush Hollow, Horsetooth, Jumbo, and many others (CPW, 2012).

Figure 10.14 below, taken from the 2012 CROA Commercial River Use in the State of Colorado Economic Report, highlights the significant decrease in user days both in 2002 and 2012 (user days on y-axis).

Figure 10.14 Commercial User Days, 1988-2012



Source: CROA 2012

Similar to the ski industry, public perception of river conditions can be a significant factor for rafting revenues. Rafting companies can be impacted when droughts are publicized regardless of flow conditions for their specific operations. To combat this issue, the professional organization CROA hires a public relations (PR) firm every year. This helps them control the message reaching

the public and stay ahead of any negative perception that may be developing. The PR firm also helps respond to other threats to the rafting industry like public perception of wildfires or fatalities on the river. CROA (2012) speculates that impacts to the rafting industry for 2012 could have approached 2002 levels had they not maintained a positive public narrative throughout the season.

Additionally, CPW has worked with local, state, and federal agencies to maintain certain flow levels in the Arkansas River when limited water is available. As state park revenue levels correlate well with water resources levels, CPW has made in-stream flows a high priority (CPW, 2012).

CROA (2012) estimates the economic impact of the drought by multiplying direct expenditures by the number of user days and an economic multiplier (2.56) that estimates the number of times a dollar is spent in the local area before leaving that area. Direct expenditures are defined as the amount spent on rafting and associated goods and services spent in the local area by one river rafting customer in one day. Applying this relatively simple method, Table 10.8 shows the calculated economic impact by river. The Arkansas has suffered the most economic impact, which might be expected given the basin has been hit particularly hard by the drought. However, they also benefit from the greatest number of user days, thus have good potential to mitigate for reduced income from rafting by providing alternative activities (a key recommendation from the CWCB Drought Plan and the DART Report). Since the majority of the rafting in Colorado takes place on the Arkansas, impacts to that basin will proportionately impact the industry as a whole. Table 10.9 shows the relative change in user days from 2010 through 2011 for each of the rivers. Note that many of the lesser used rivers suffered dramatic decreases in user days, potentially shutting business down on these basins (CROA, 2012).

Table 10.8 2012 Impact by River (CROA, 2012)

RIVER	USER DAYS	DIRECT EXPENDITURES	ECONOMIC IMPACT
Animas	38,000	\$4,605,954	\$11,791,241
Animas - Upper	603	\$73,089	\$187,108
Arkansas	169,486	\$20,543,280	\$52,590,798
Blue	0	\$0	\$0
Clear Creek	35,422	\$4,293,476	\$10,991,299
Colorado - Glenwood	64086	\$7,767,820	\$19,885,618
Colorado - Upper	39,645	\$4,805,343	\$12,301,678
Colorado - Horsethief - Lomaz	2792	\$338,416	\$866,346
Colorado - Westwater	5,623	\$681,560	\$1,744,793
Dolores	35	\$4,242	\$10,860
Eagle - Upper	4	\$485	\$1,241
Eagle - Lower	227	\$27,515	\$70,437
Green/Yampa	7,983	\$967,614	\$2,477,092
Gunnison Gorge	1579	\$191,389	\$489,957
Gunnison - Upper	1,150	\$139,391	\$356,840
Gunnison - Escalante	2950	\$357,567	\$915,373
Gunnison - Forks to Austin	1,100	\$133,330	\$341,325
Gunnison - Lake Fork	1123	\$136,118	\$348,462
North Platte	143	\$17,333	\$44,372
Piedra	54	\$6,545	\$16,756
Poudre	22,780	\$2,761,148	\$7,068,539
Rio Grande	2486	\$301,326	\$771,395
Roaring Fork - Above Basalt	112	\$13,575	\$34,753
Roaring Fork - Below Basalt	736	\$89,210	\$228,378
San Juan - Pagosa	778	\$94,301	\$241,410
San Miguel	1828	\$221,571	\$567,221
South Platte	484	\$58,665	\$150,183
Taylor	9891	\$1,198,881	\$3,069,136
Totals	411,100	\$49,829,146	\$127,562,613

Table 10.9 Individual River Commercial Rafting Statistics – 3 Year Range (CROA, 2012)

RIVER	2010 USER DAYS	2011 USER DAYS	2012 USER DAYS	% CHANGE '10 - '11	% CHANGE '11 - 12	2010 % MARKET SHARE	2011 % MARKET SHARE	2012 % MARKET SHARE
Animas	41,000	45,000	38,000	9.8%	-15.6%	8.2%	9.1%	9.2%
Animas - Upper	411	411	603	0.0%	46.7%	0.1%	0.1%	0.1%
Arkansas	211,150	208,329	169,486	-1.3%	-18.6%	42.4%	42.0%	41.2%
Blue	1,181	6,580	0	457.2%	-100.0%	0.2%	1.3%	0.0%
Clear Creek	51,301	60,644	35,422	18.2%	-41.6%	10.3%	12.2%	8.6%
Colorado - Glenwood	61,890	44,007	64,086	-28.9%	45.6%	12.4%	8.9%	15.6%
Colorado - Upper	41,626	32,842	39,645	-21.1%	20.7%	8.3%	6.6%	9.6%
Colorado - Horsethief - Loma	2,718	2,907	2,792	7.0%	-4.0%	0.5%	0.6%	0.7%
Colorado - Westwater	7,621	6,069	5,623	-20.4%	-7.3%	1.5%	1.2%	1.4%
Dolores	194	515	35	165.5%	-93.2%	0.0%	0.1%	0.0%
Eagle - Upper	1,640	1,286	4	-21.6%	-99.7%	0.3%	0.3%	0.0%
Eagle - Lower	1,710	4,362	227	155.1%	-94.8%	0.3%	0.9%	0.1%
Green/Yampa	4,803	4,218	7,983	-12.2%	89.3%	1.0%	0.9%	1.9%
Gunnison Gorge	1,390	2,148	1,579	54.5%	-26.5%	0.3%	0.4%	0.4%
Gunnison - Upper	2,669	2,669	1,150	0.0%	-56.9%	0.5%	0.5%	0.3%
Gunnison - Escalante	1,784	2,749	2,950	54.1%	7.3%	0.4%	0.6%	0.7%
Gunnison - Forks to Austin (n	0	0	1,100			0.0%	0.0%	0.3%
Gunnison - Lake Fork	149	284	1,123	90.6%	295.4%	0.0%	0.1%	0.3%
North Platte	482	850	143	76.3%	-83.2%	0.1%	0.2%	0.0%
Piedra	190	190	54	0.0%	-71.6%	0.0%	0.0%	0.0%
Poudre	37,392	37,869	22,780	1.3%	-39.8%	7.5%	7.6%	5.5%
Rio Grande	2,016	2,016	2,486	0.0%	23.3%	0.4%	0.4%	0.6%
Roaring Fork - Above Basalt	2,404	6,672	112	177.5%	-98.3%	0.5%	1.3%	0.0%
Roaring Fork - Below Basalt	1,366	912	736	-33.2%	-19.3%	0.3%	0.2%	0.2%
San Juan - Pagosa	4,986	6,171	778	23.8%	-87.4%	1.0%	1.2%	0.2%
San Miguel	1,762	1,900	1,828	7.8%	-3.8%	0.4%	0.4%	0.4%
South Platte	383	430	484	12.3%	12.6%	0.1%	0.1%	0.1%
Taylor	14,332	14,130	9,891	-1.4%	-30.0%	2.9%	2.8%	2.4%
Totals	498,550	496,160	411,100	-0.5%	-17.1%	100.0%	100.0%	100.0%

10.4 Measurement of Vulnerability

Vulnerability metrics are quantifiable factors that begin to portray the vulnerability of the sub-sectors. These factors are offset by existing or future adaptive capacities. The following section presents the vulnerability metrics suggested for each sub-sector. Some of these metrics have existing data. However, other metrics require additional data and future collection efforts are recommended. Refer to Section 3.1 of Chapter 3 (Annex B) for a general description of the numerical methodology.

10.5 Vulnerability Metrics

10.5.1 Skiing

Spatial Density Metric

Location

The location of the ski resorts is spatial data obtained from the ski resorts' addresses and general location based on their websites and maps. Ski resorts that existed in the past but are now closed were not considered.

Only 15 out of the 64 counties contain one or more ski areas, making the typical percentile thresholds invalid. The thresholds were adjusted for the spatial density and the impact metrics to create equal bins for the non-zero data set.

Impact Metrics

The two metrics used to assess vulnerability at ski areas are ski area acreage and the acreage covered by snowmaking. Data for these two metrics are available from the individual ski resort websites and the trade group Colorado Ski Country USA.

Acreage of ski area

The acreage of all ski areas within the same county was summed to arrive at total acreage per county. The acreage of a ski area can be an inverse indicator of vulnerability because larger resorts tend to have other amenities that make them an appealing destination for non-ski activities like dining, shopping, spas, skating etc., and resorts offering a wide variety of activities are better able to adapt to poor snow conditions because they have diversified revenue sources. The smaller ski areas are assumed to be less diversified.

Snowmaking ability

Snowmaking allows ski resorts to artificially compensate for poor natural conditions that may result from a winter drought. Snowmaking machines generally only cover a small percentage of the total ski area acreage and cannot completely mitigate a bad snow year.

New since 2013, the number of acres that are covered by snowmaking equipment now exists publicly for all of the snowmaking resorts in the state. The snowmaking acreage of all ski areas within the same county was summed to arrive at total snowmaking acreage per county.

Total ski area acreage was weighted 50% and acreage covered by snowmaking was weighted 50% for the overall impact score calculation. This is a change from the 2013 version of Annex B, where total ski area acreage was weighted 70% and snowmaking capability was weighted 30%. The additional information that acres of snowmaking capacity brings to the analysis warrants

equalizing the metric weighting. The analysis could be further enhanced by incorporating the relative seniority of the ski resorts' snowmaking water rights and the spatial relationship of diversion points to instream flow rights, but this was not readily available for the 2018 update. Recommendations for other impact metrics are presented in Section 10.6.

10.5.2 Wildlife Viewing

Spatial Density Metric

Areas of Suggested Viewing

Wildlife viewing can occur wherever there is wildlife in the State, but the list of suggested viewing areas on the CPW website provides a starting point to understanding the spatial distribution of viewing areas. The viewing area coordinates (latitude/longitude) were input in a GIS and aggregated by county. The data entered into the vulnerability spreadsheet represents the count of viewing areas per county.

Impact Metric

Wildfire Threat Ranking

The Colorado State Forest Service maintains an online data portal that contains a number of wildfire specific datasets.⁸ Wildfire threat is defined as the annual probability of a wildfire occurring. Threats were divided into six main categories: very low, low, moderate, high, very high, and none. To isolate the high-risk areas, moderate to very high raster points were extracted and tallied by county. Counties were ranked according to the percentage of high-risk area relative to the total size of the county.

10.5.3 Hunting, Fishing, and Camping

Spatial Density Metric

Direct Spending per County (Hunting & Fishing only)

Direct spending per county for hunting and fishing activity was obtained through a research report completed for the CPW in 2008. The estimates are based on data from a number of different sources, including CPW game harvest information for 2007, a survey of Colorado anglers conducted by CPW in early 2008, CPW expenditure data for the 2007 fiscal year, and the USFWS 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (BBC Research & Consulting, 2008). The data, in dollars, were normalized by county population. Updated economic data was not available for the 2018 update.

⁸ <http://www.coloradowildfirerisk.com/>

Impact Metrics

Wildfire Threat Ranking

As with wildlife viewing, wildfire can impact hunting, fishing, and camping. High wildfire risk can lead to fire bans which may be a deterrent for camping. When wildfires do occur, access will be closed for the affected areas and the resulting smoke will severely impair air quality in a much larger area. This dataset was processed and used as described in the Wildlife Viewing sector above. This impact metric was weighted equally with the beetle infestation extent metric (50%), because neither metric has a clear advantage over the other.

Beetle Infestation Extent

Bark beetle infestation continues to have a profound effect on the health of Colorado's forests. The U.S. Forest Service and CPW have been forced to close campgrounds in order to clear beetle-damaged trees in danger of falling, and spray high-value trees in an attempt to protect them (Finley, 2010). Data for the extent of beetle infestation is available from the USDA Forest Service, Forest Health Technology Enterprise Team,⁹ which maintains an online spatial database of forest health data that can be queried and downloaded. The datasets containing survey data from 2012 are still (as of 2018) the latest versions. The database was queried for areas of beetle infestation (all beetle types) for the entire period of record (1997-2012). Forty-five of the 64 counties have no bark beetle infestation data. Therefore, the thresholds were adjusted to create equal bins for the non-zero data set.

10.5.4 Golfing

Spatial Density Metric

Number of Courses per County

The number of courses per county was obtained from the USGS study (Ivahnenko, 2009), which is still the most reliable publicly-available source of information on this topic. Throughout the State there are only 11 of the 64 counties that do not have golf courses. Consequently, threshold values for the impact score calculations were adjusted to account for the zero-data set.

Impact Metric

How many irrigated golf course acres in the county?

The USGS survey collected and tabulated data on irrigated golf course acres per county. This metric identifies the area vulnerable to significant loss if irrigation water is not available during drought. This metric could be further refined by separating out irrigated golf course features like

⁹ <http://foresthealth.fs.usda.gov/portal>

roughs and surrounding landscape that could go without water and not impact the playing experience (aesthetic qualities aside). This is discussed as a recommendation in Section 10.6.

10.5.5 Boating

Boating is difficult to assess, because the activity is still possible even if reservoir levels are slightly lower than normal. However, boating becomes impossible when the reservoir goes completely dry or drops to unacceptable safety levels (i.e., exposed rocks and detritus), or when the boat ramps are rendered unusable by falling water levels. To add to the complexity, reservoir operations are generally dictated by water owners and not recreational users. In a drought, the water rights priority system could cause normal reservoirs operations to change, resulting in recreational impacts.

Spatial Density Metric

Location of Water-based State Parks

The location of the water-based state parks serves as an inventory metric for flat water boating activity. This information was obtained from CPW and tabulated by county (as a count).

Impact Metric

Visitation numbers at water-based state parks

Park visitation numbers were updated with data obtained from CPW for FYs 2012 through 2017. The intent is to assess which parks had the greatest visitation declines in the drought of 2012, as indicated by change in visitation in 2012 compared to annual average visitation for FYs 2012 through 2017 and to extrapolate this trend as a potential vulnerability to future droughts..

The main limitation of this approach is attributing a decrease in park visitation solely to drought, when park visitation could be impacted by a number of factors (e.g., wildfires, economy). This analysis assumes that parks impacted by drought in 2012 will be impacted again. Based on conversations with CPW employees this is a reasonable assumption. Still, future work could investigate the operations of specific parks and determine if any adjustments are warranted.

The visitation data were available on a FY basis, which, for the State of Colorado, begins on July 1 and ends on June 30. This means that impacts to visitation from the drought of 2012 were largely captured in FY 2013. Out of the 64 counties, 42 do not contain a water-based state park. Therefore, the thresholds were adjusted to create equal bins for the non-zero data set.

10.5.6 Commercial Rafting

Spatial Density Metric

American Whitewater Rafting Reaches

American Whitewater is a national nonprofit dedicated to conserve and restore whitewater resources and enhance opportunities to enjoy them (American Whitewater, 2010). A map of American Whitewater rafting reaches was included in the SWSI Initiative Phase 2 report (SWSI Phase 2, 2007); this map was reworked to tabulate the number of rafting reaches that start and end in each county. This count was entered into the spreadsheet as the spatial density metric. The original map from SWSI Phase 2 is included as Figure 10.11.

Impact Metrics

Average annual user days, 2000-2012

Data for average annual user days were obtained from the Colorado Rafting Outfitters Association website. Updated user days were not available for the 2018 update, but the impact of drought on rafting user days is not expected to change. The value of this metric provides a sense of how popular the river is; with more user days implying more commercial rafting outfitters and more secondary industries built around rafting in that region. Therefore, higher user days indicate higher vulnerability. However, it could also be the case, as with the ski resorts, that the more interest in a particular river, the more sophisticated the offerings will become (i.e., more offerings result in diversification; an adaptive capacity). For example, some rafting companies also offer fishing trips.

Relative visitation, 2002 compared to 2000-2012 annual average

Similar to the boating metric, relative rafting visitation provides information on which rivers experienced the biggest drop in visitation in 2002. Some limitations include: future drought likely will not occur in the exact same manner as 2002; drought could hit one portion of the State but not another; adaptive capacities could change; and non-related variables such as wildfires and the larger economic issues likely also contributed to the overall decrease in visitation for the rafting industry.

10.5.7 Results

Results presented here are based on an overview of sub-sectors and data gathering from various agencies, industry groups, and previous reports. In order to rank counties as more, or less, vulnerable than others, generalizations based on research and interviews were necessary, these may not apply to each individual sub-sector. However, the intent of this assessment is to present concentrations of recreation and correlate them to vulnerability on a county level. These results, and the data required, should be regularly updated for future review, assessment, and focusing of drought mitigation resources. Table 10.10 summarizes the vulnerability assessment results.

Table 10.10 Results of Vulnerability Assessment

Counties	Overall Vulnerability Score
Alamosa, Bent, Broomfield, Cheyenne, Costilla, Crowley, Custer, Denver, Dolores, Elbert, Gilpin, Jackson, Kiowa, Lake, Lincoln, Otero, Phillips, Prowers, Sedgwick, Teller, Yuma	1-1.9
Adams, Arapahoe, Archuleta, Baca, Boulder, Chaffee, Clear Creek, Conejos, Delta, Douglas, Eagle, El Paso, Gunnison, Hinsdale, Huerfano, Jefferson, Kit Carson, La Plata, Las Animas, Logan, Mineral, Montezuma, Montrose, Morgan, Ouray, Park, Pitkin, Rio Blanco, Rio Grande, Saguache, San Juan, San Miguel, Summit, Washington	2-2.9
Fremont, Garfield, Grand, Larimer, Mesa, Moffatt, Pueblo, Routt, Weld	3-3.9
None	4

These rankings indicate different levels of recreational activity within counties and varied levels of adaptive capacity in those activities. Below is a discussion on each ranking.

Counties ranked “1” for overall vulnerability:

A “1” ranking implies one of the following situations:

- Recreation industry existing in this county is small compared to the overall population and/or land area;
- Recreational activity has a measure of adaptive capacity that insulates it from drought vulnerability;
- There is a diverse offering of recreational activities; and
- The recreational activity is not prominent in this county.

Many of the counties in this category (e.g., Cheyenne, Kiowa, etc.) are located in the eastern plains, which is more prominent for agricultural activity than recreation and tourism.

Counties ranked “2” for overall vulnerability:

A “2” ranking implies one of the following situations:

- There may be a distinct recreational draw to the county, but it is small compared to the population; and/or
- There is a diverse offering of recreational activities.

Most of the counties in this category (e.g., Boulder, Gunnison, and Saguache Counties) do have a distinct appeal to tourists, but they are not prominent tourism-centric counties and/or their economies do not rely heavily on tourism. Several of the counties in this category have a distinct recreational draw (e.g., ski resorts in Park, Pitkin, and Summit Counties), but their ranking is low due to adaptive capacities (e.g., diversified offerings at ski resorts).

Counties ranked “3” for overall vulnerability:

A “3” ranking implies a distinct recreational draw to the county that is significant compared to the population. There may be adaptive capacities or sufficient diversification that a county has recreation exposure, but not necessarily high vulnerability to drought. Counties in this category include Fremont, Larimer, and Routt.

Counties ranked “4” for overall vulnerability:

A “4” ranking implies a distinct recreational draw and perhaps a lack of recreational diversification that would act as an adaptive capacity to offset drought impacts. No counties are ranked a “4”, but the hypothetical county would have a fairly low population, be strongly dependent on tourism for economic activity, and would have low recreational diversity. The following section includes maps showing the spatial distribution of the recreation and tourism sub-sectors.

Figure 10.15 Skiing Inventory and Impact Scores

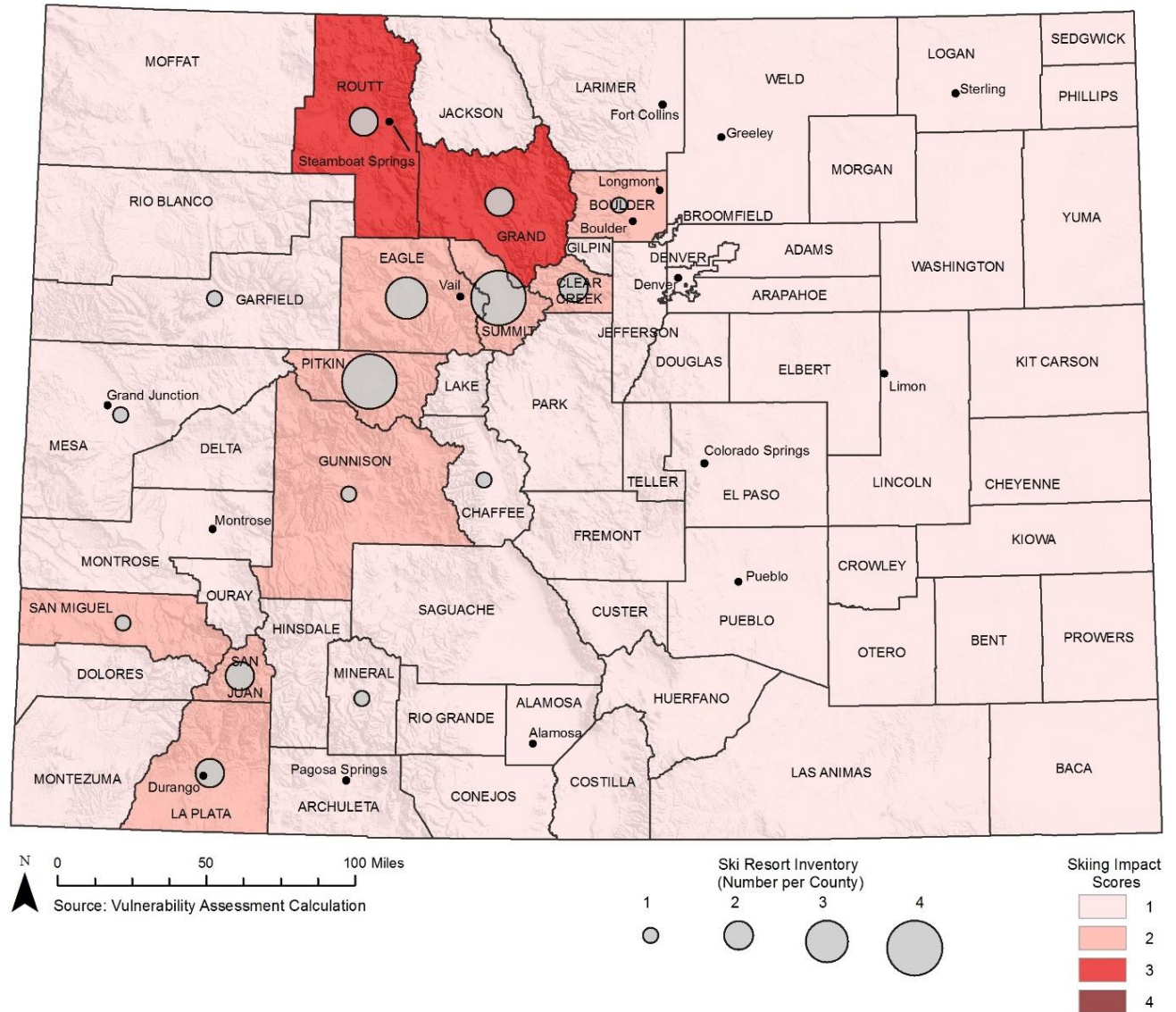


Figure updated 2018.

Figure 10.16 Wildlife Viewing Inventory and Impact Scores

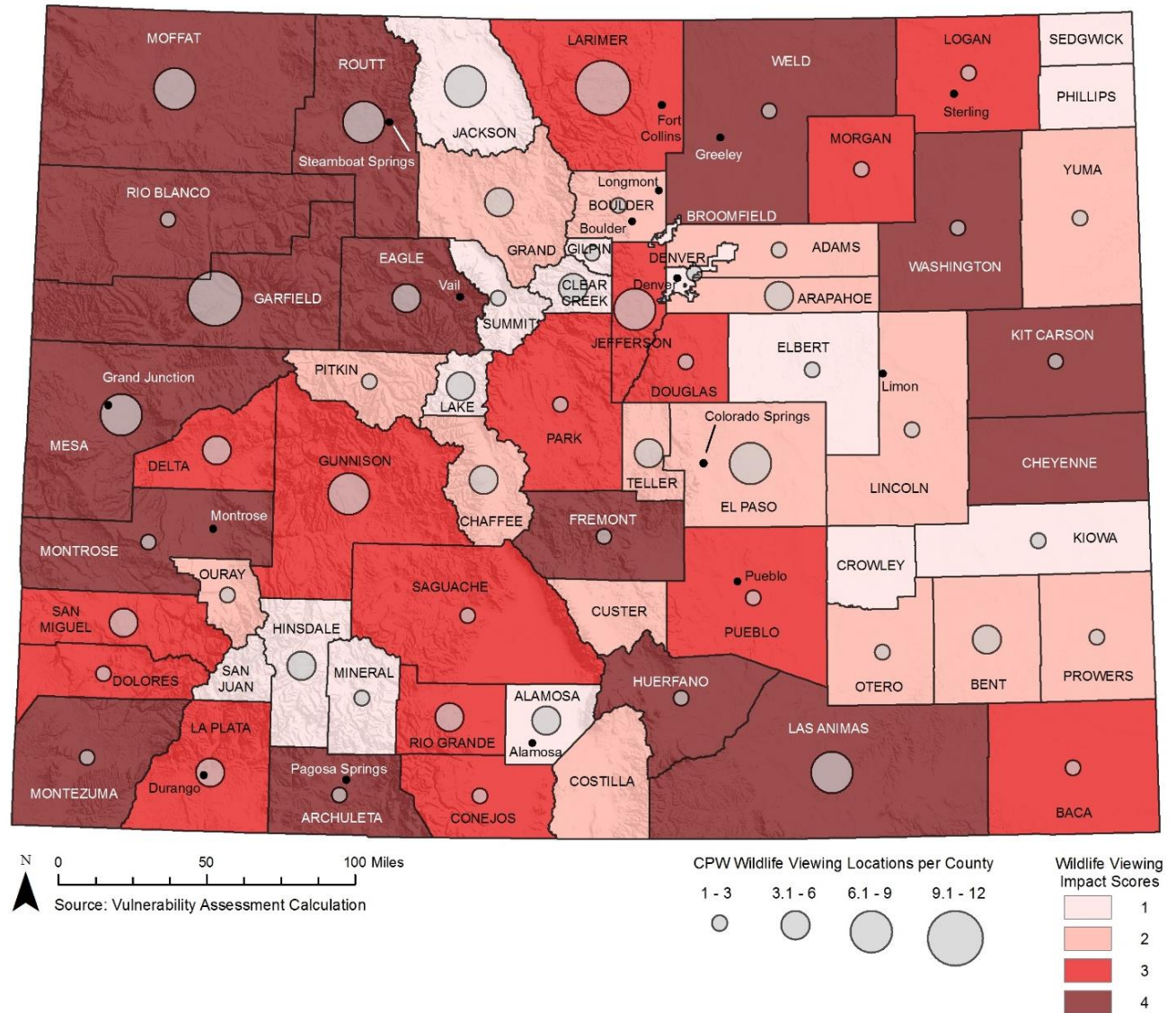


Figure Updated 2018

Figure 10.17 Hunting, Fishing, and Camping Inventory and Impact Scores

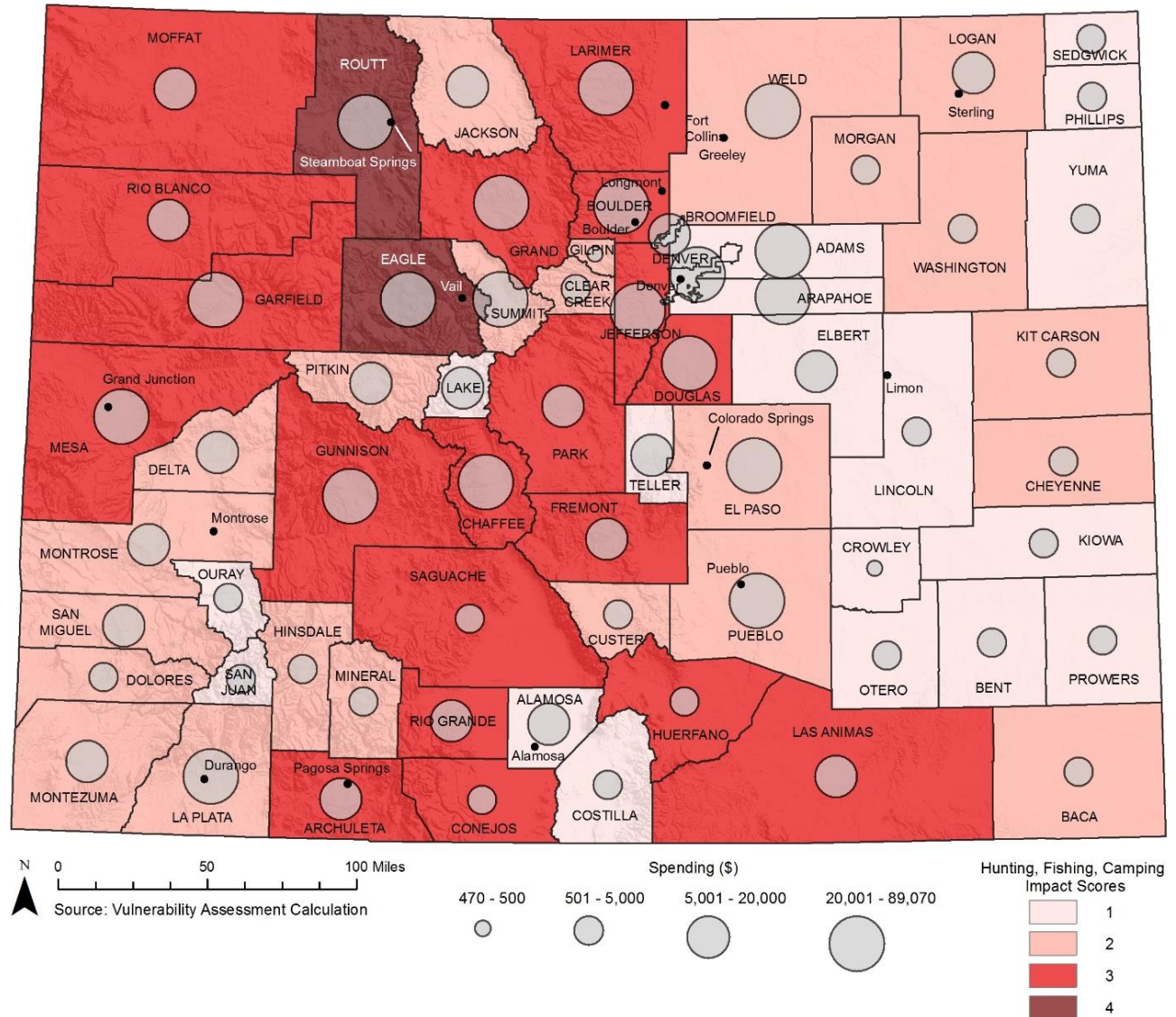


Figure updated 2018

Figure 10.18 Golf Course Inventory and Impact Scores

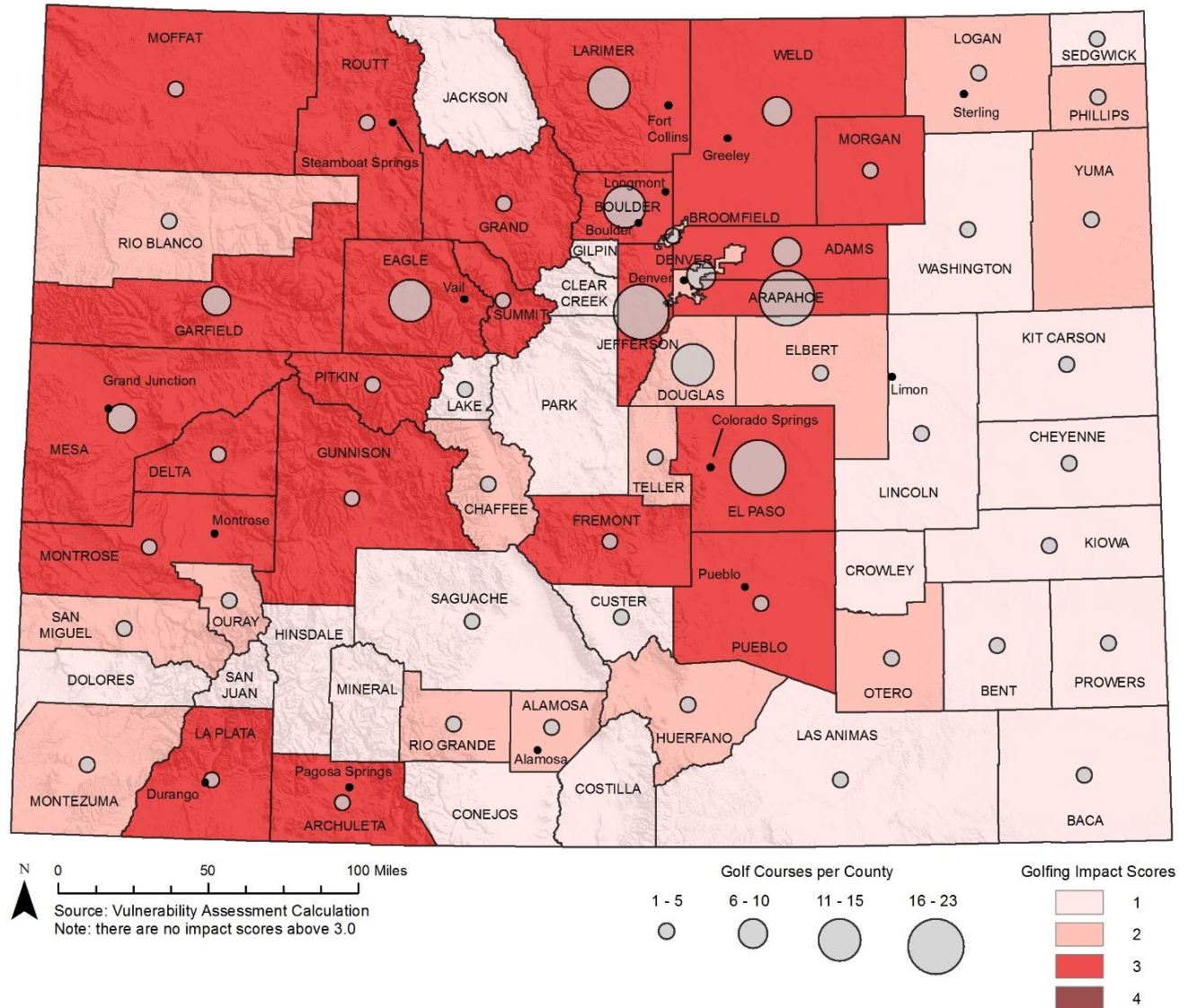


Figure updated 2018

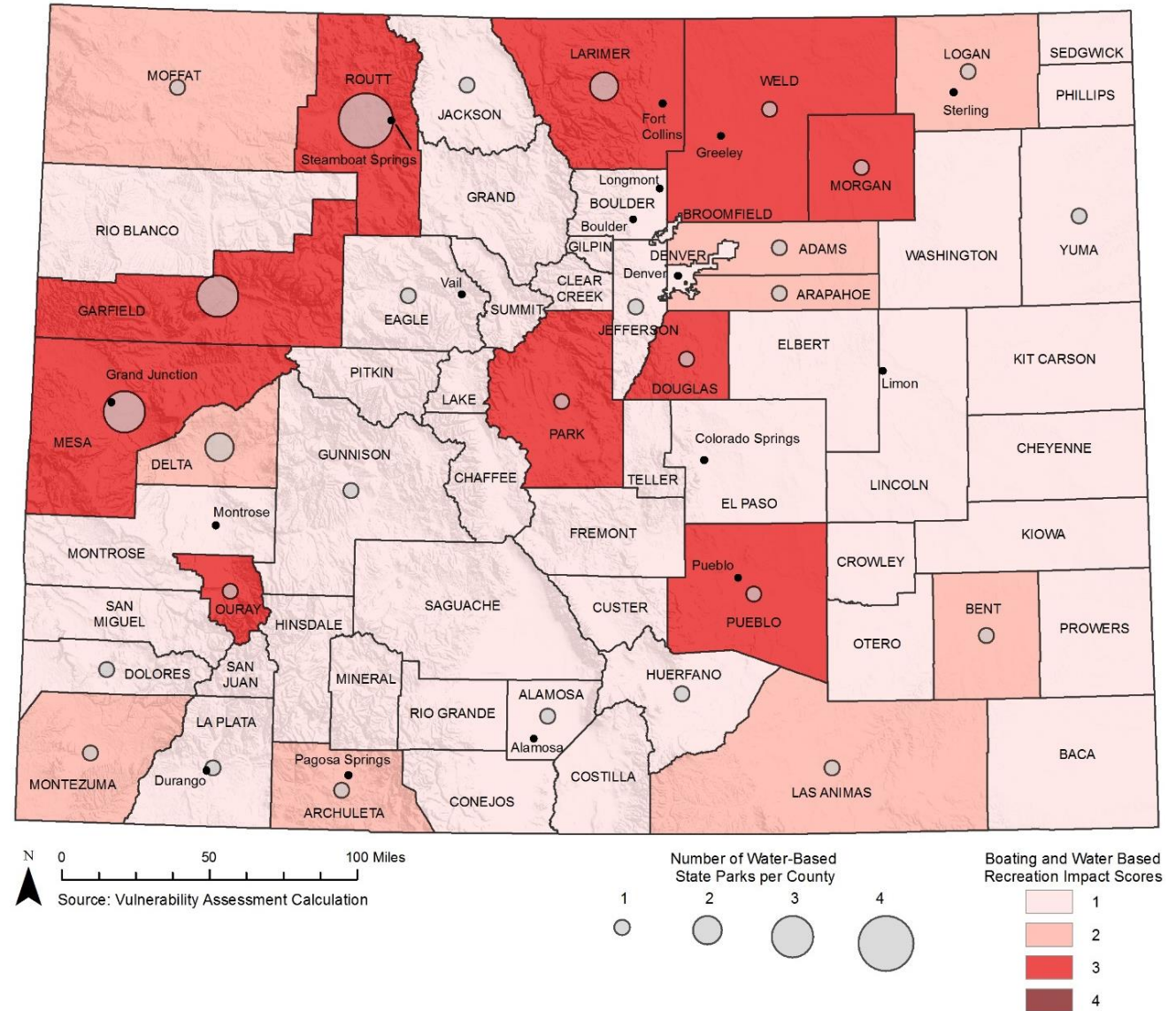


Figure updated 2018

Figure 10.20 Rafting Inventory and Impact Scores

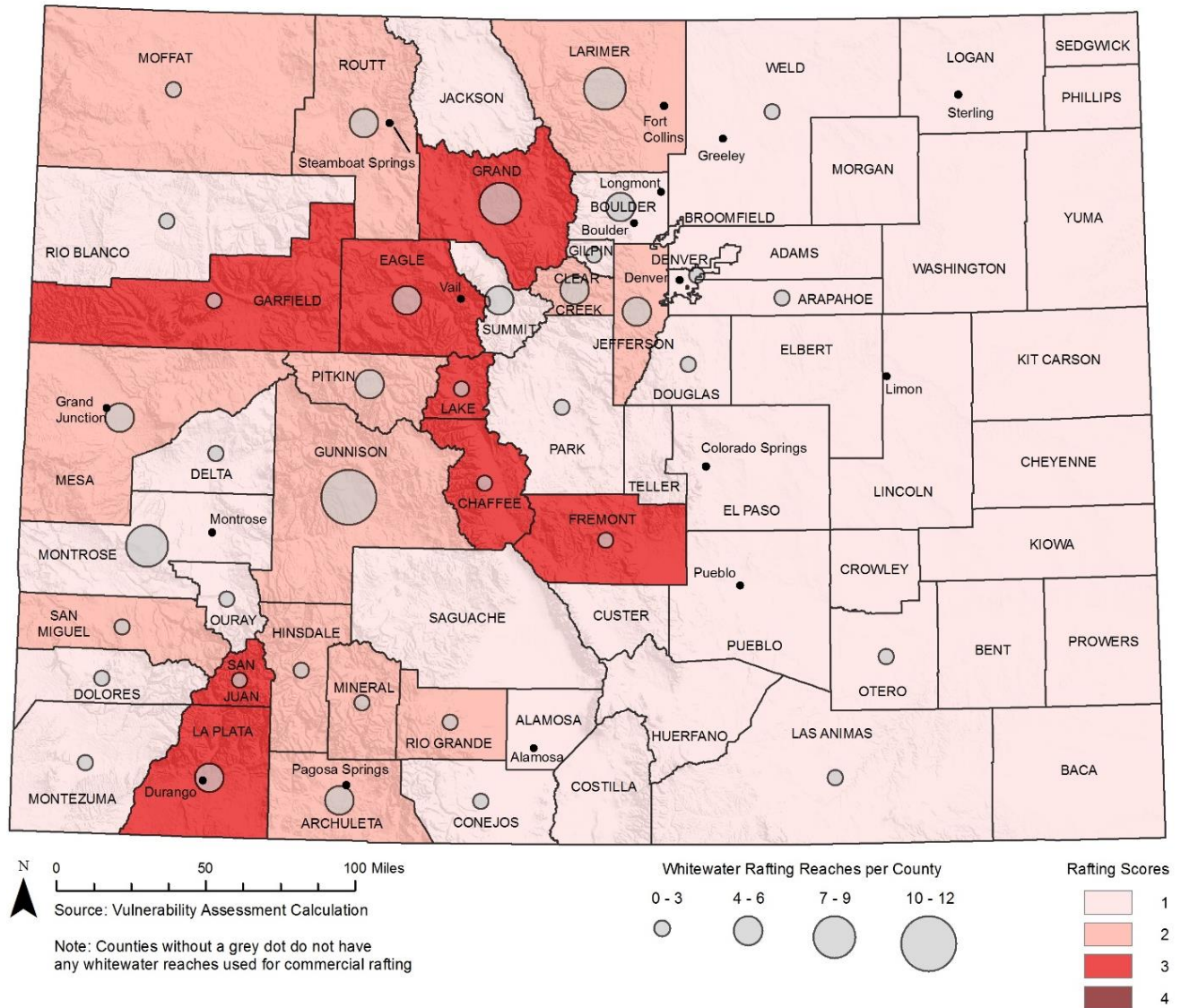


Figure revised 2018; no change to 2013 data.

10.5.8 Spatial Analysis

Spatially, the recreation and tourism sub-sectors are fairly concentrated in the western, southern, and southwestern portions of Colorado. This is especially true with ski resorts, which exist, with few exceptions, on the western slope and are concentrated in the central-western portion of the State.

Vulnerability for the ski resort sub-sector is naturally centered in mountain counties. The two vulnerability metrics identified for this study were the size of the ski resort and the snowmaking capabilities. Eagle, Summit, and Pitkin Counties stand out with large ski resorts that are not ranked as being particularly vulnerable. This is attributed to the adaptive capacity linked to their size (again, the assumption is that large resorts have invested in diverse activities to appeal to a range of visitors) and that they all have snowmaking in their resorts. Conversely, Routt and Grand Counties have less expansive ski resorts and not all of the resorts have snowmaking capabilities.

Wildlife viewing areas, are not as centrally located as ski areas, but rather fairly distributed around the State. As a result, their vulnerability is well distributed around the State. The inventory is CPW viewing locations, but the vulnerability metric is wildfire susceptibility index. So, the vulnerability map is largely a function of the wildfire threat data used for the analysis. This approach is limited by the dependence upon wildfire data. Other variables, such as beetle kill, may also alter wildlife behavior. More research is needed to identify additional metrics that could be used in the wildlife viewing subsector.

The hunting, fishing, and camping spatial metric is spending per county, an update for which was not available for the 2018 drought plan. As would be expected, the more populated counties have more spending. Here the concentration is along the Front Range, with the urban areas of Fort Collins (Larimer County), Denver (Denver County), and Colorado Springs (El Paso County) probably contributing to the spending in those three counties. The primary vulnerabilities reflect the beetle kill and wildfire data. The vulnerability metric used was the same (wildfire susceptibility index) and the second metric, beetle infestation extent, is impacting the same forested area that is impacted by wildfire.

Golf course concentration by county is another sub-sector with a large presence along the Front Range. There is a strong correlation to the presence of a golf course and the presence of a high-population area. That there are few to no golf courses in the southern portion of the State speaks to this correlation. Golf course vulnerability is dependent on the number of golf courses and the size of the golf courses (aggregated by county). For this reason, it is fairly logical that the counties with the most golf courses would also have the most golf course acreage and be the most vulnerable to drought. These counties are found along the Front Range and within the more populated regions of the western slope.

Boating vulnerability is dependent on the inventory (i.e., existence of a water-based state park) and the relative decrease in visitation between FY 2013 (encompassing the drought of 2012) and

the FYs 2012-2017 average. This is one sub-sector of recreation that appears on the eastern plains of the State as well as the western half. In fact, some of the more vulnerable counties (e.g., Pueblo, Douglas, and Jefferson) are located east of the mountains.

Like skiing, rafting is concentrated in the mountainous regions of the State. The inventory is American Whitewater (AW) rafting reaches (as shown in Figure 10.11), and the metrics are average annual user days (to establish volume of visitation) and percent reduction in the 2002 drought (to establish which rivers saw a more dramatic drop in visitation), as obtained from commercial visitation data compiled from the CROA. Given the vulnerability metrics, rafting vulnerability correlates to both the presence and the popularity of a commercially rafted river. The difference between the AW reaches and the CROA visitation data are apparent in Boulder, Rio Blanco, Weld, Gilpin, and Ouray Counties. These counties have an inventory of AW reaches but are not assigned an impact score because the set of commercially-rafted river stretches does not pass through them.

The sub-sector impact scores discussed above were combined to one overall sector vulnerability score. Figure 10.21 on the next page shows these results for each county.



Overall, the results show the main vulnerabilities to be located in the northwest portion of the State. Skiing, hunting/fishing/camping, and wildlife viewing are all large sub-sectors for the northwestern counties and contribute to their high ranking. El Paso and Douglas Counties have high scores for golf, which contribute to a high overall ranking. Archuleta received a high vulnerability rating because of a high wildlife viewing vulnerability score – a result of the updated wildfire dataset. Fremont and Pueblo counties received higher scores because of golf and the updated wildfire data increasing vulnerabilities in the wildlife viewing and hunting, fishing, and camping sub-sectors. The counties on the eastern plains are ranked as lower vulnerability since recreation and tourism do not contribute as much to their economy. Those counties in the eastern plains with a ranking of 2.0-2.9 generally received those scores as a result of the updated wildfire data.

10.5.9 Compound Impacts

Compound impacts are secondary or indirect impacts brought about by changes in sectors that are directly impacted. For example, direct drought impacts to the Recreation Sector may entail loss of revenue to ski resorts, golf courses, tour guides, and state agencies such as CPW. This loss of revenue can in turn contribute to an overall slowing of the local economy as workers are laid off, leading to less local spending on gasoline, groceries, restaurants, retail, hotels, and more; thus compounding the initial impact. When recreation and tourism in Colorado suffer, so do the services that depend on this industry (Schneckenburger and Aukerman, 2002). If the stakeholder involvement model laid out in the 2012 DART Report is applied in a drought impact assessment, it will be important to include these secondary services as stakeholders in the process. These services potentially offer important metrics for tracking the impact of drought on these recreation and tourism based economies.

Recreation-based economies are found in the central mountain region, the south, and the southwest portions of Colorado (WATF, 2002). These sub-sectors all contribute to the local economy, which can be strained in compound ways if one or more sub-sector is negatively impacted by drought. As discussed in the DART Report (2012), communities can help themselves by marketing different options to visiting tourists. While one specific industry may be more impacted than others during a drought event (e.g., rafting), communities can help absorb those impacts by offering alternative activities (e.g., mountain biking). Probably the closest link to another sector is to environment, since these activities depend on a healthy environment to make them possible/enjoyable.

State assets, like CPW, are highly dependent on recreation and tourism. Both divisions' revenues are dependent on people recreating in Colorado. The socioeconomic impacts of drought can cause people to reduce recreation, which in turn impacts state assets and the tourism industry. State revenue can decrease with a decline in park visitation and hunting/fishing license sales. During a drought, CPW may need to increase their management effort, whether for wildlife feeding programs or for reservoir maintenance that comes with lower water levels. These efforts require funding, which during a drought could be lower than average; further stressing the agencies.

Another compounding factor is the water rights system in Colorado. Boating and rafting may be aided by instream flows, and there were documented instances during the 2002 drought when senior calls to the river caused portions of it to flow that otherwise would have been dried up by junior rights holders. Earlier in this report it was discussed that ski resorts can mitigate with snowmaking, but need senior water rights to do so. If there is increasing competition for water during a drought, ski resorts may see growing opposition to snowmaking and other water diversions. Golf courses can be affected by water rights as well. The majority of golf courses in Colorado are on surface water, but that does not mean that they necessarily own the rights. In some cases, the course will lease the surface water rights from the municipality, which can leave it vulnerable to watering restrictions.

10.6 Recommendations

10.6.1 Adaptation to Drought

One overriding theme from the 2010 drought plan was that public perception is a primary concern. The recreation sector applied lessons learned from the 2002 drought event to the 2012-2013 drought, and now the recreation industry retains public relations firms to help educate the public about recreational opportunities during drought. The next area of adaptation appears to be climate change. The ski industry, in particular, has been an early adapter of climate change mitigation strategies. For example, Aspen captures methane from a nearby coal plant to power its snow guns (Hansman, 2015). Vail Resorts has set a “zero footprint” sustainability goal of zero net emissions, zero waste to landfill, and zero net operating impact to forests and habitat by 2030 (Vail Resorts, 2018), and Arapahoe Basin joined the National Ski Areas Association Climate Challenge, a voluntary program dedicated to helping ski areas reduce greenhouse gas emissions, in 2011 (POW, 2018). Ski areas also focus on strategically placing snow fences to ensure that natural snow stays where it is most beneficial. These actions, while not specifically in response to drought, do provide a degree of preparedness in the event of reduced winter snowfall.

In addition to effective marketing and reducing vulnerability through climate change initiatives, another important adaptation strategy for all sub-sectors is diversifying activities. Recreation companies who offer activities throughout the year and not just in one season are less impacted by short droughts. Similarly, recreation-based towns and communities will benefit from marketing a range of activities that are not dependent upon drought-impacted resources (Thomas & Wilhelmi, 2012). Communities can also coordinate with neighboring counties to combine marketing efforts. Including attractions in nearby counties as well as local attractions in recreation marketing efforts increases the audience for each area, and may prove doubly beneficial by attracting new visitors interested in a range of activities that can only be found by traveling within two or more counties. It is also important to diversify across sectors. Economies that are highly dependent on recreation and tourism are more vulnerable to drought and other disaster events. Developing stronger interrelationships between resort communities and surrounding agricultural areas can improve economic diversity and reduce overall vulnerability to drought (Wilhelmi et al. 2004).

Lastly, there is also opportunity for improved policies and mitigation efforts at a county level. Because climate change and drought have the potential to impact the recreation sector more so than other sectors in the economy, local governments could be key partners in presenting a united front to the public, both in terms of messaging and in terms of concrete actions to increase sustainability. It is important that local agencies are on the same page in order to prevent conflicting messages about recreation activities during the drought. Local governments working together can advertise more activities and create a bigger tourist draw by promoting neighboring counties.

10.6.2 Improving the Vulnerability Assessment

To improve the drought vulnerability assessment, key data gaps or limitations for the Recreation Sector are identified below and followed by recommendations for future data collection and analysis.

Skiing

Vulnerability is more complex than the size of the resort and its snowmaking capabilities. In general, snowmaking covers a small percentage of the total resort area, and is subject to the water rights priority system, which means that a drought occurring in the fall *and* winter could prevent a ski area from making snow. Also, snowmaking is not a comprehensive adaptive capacity. While snowmaking is an important tool for covering area early in the season and setting firm opening dates, it cannot cover the entire resort area or compensate completely for decreased snow throughout the season. Also, some groups argue that snowmaking is detrimental to the environment. If this becomes a significantly contentious issue it could impact the ability of resorts to secure water rights in the future.

Future work should analyze historic snow telemetry (SNOTEL) records in close proximity to ski resorts and at similar elevations. These data are readily available but would require analysis. Additionally, many resorts collect snow data as part of daily ski patrol operations. This information is likely much more useful as it is collected by professionals at the resort. Using base elevation along with historic snowfall could identify areas that receive more snowfall, and could point out ski areas that are more or less prone to decreases in snow pack. These data should also be evaluated with respect to climate change projections. A report about climate change in Colorado completed in 2008 by CU-NOAA Western Water Assessment noted that ski resorts above 10,000 ft are less vulnerable to climate change and increasing temperatures, but many resorts in Colorado have base elevations lower than that.

Wildlife viewing

The only vulnerability metric used at present is viewing areas within wildfire hazard zones. Future work should investigate the competing water demands that can influence habitat (is there competition from other sectors, such as agricultural or municipal withdrawals?). The wildlife viewing sub-sector could also incorporate beetle-kill data as reports suggest that some species alter

their behavior as a result of the dead forests¹⁰. Also, the level of protection through state or federal laws, and the adaptive capacities of specific species should be determined. Wildlife viewing corresponds strongly to the Environmental and State Assets Sectors, so insight gained in those sections can be related to this sub-sector and vice versa.

Work completed in the NCNA could help improve the inventory data for water-based wildlife viewing areas. Viewing areas have been assessed in all basins, and future work could concentrate on summarizing the findings across the State in a manner consistent with this methodology and analyzing the results using a drought-specific outlook. For example, the Rio Grande basin used “waterfowl hunting” alone as a recreational non-consumptive need, while the Southwest basin included waterfowl hunting/viewing, Audubon Important Bird Areas, waterfowl hunting/viewing parcels, and Ducks Unlimited Projects. These data sets, while certainly relevant to the basins in which they apply, would need a degree of manipulation in order to apply them in a meaningful way to a drought vulnerability analysis.

Additionally, in some basins the NCNA tallied rare or imperiled plant communities and riparian plants. If these data are assessed state-wide with respect to drought impacts they could be combined with water-based wildlife viewing areas to determine vulnerability. However, some assessment would also be required to determine if rare or imperiled plant communities and riparian plants are the most vulnerable to drought. It is likely that this metric would need to be combined with several others to capture the information accurately.

Hunting, fishing, and camping

The existing spatial inventory is “dollars spent on hunting and fishing per county,” and does not include camping. Future analysis could benefit from looking at these activities individually. A limitation to this approach is spending in one county does not necessarily imply that is where the activity took place. Because spending appears to be strongly correlated to urban population centers, it is safe to say a portion of people purchased items in those counties and traveled elsewhere for the recreation activity.

This sub-sector is strongly tied to the CPW, so recommendations made in the State Assets Sector will apply to hunting, fishing, and camping as well. The two vulnerability metrics, “acres of beetle kill extent” and “wildfire susceptibility index” could be made more specific by splitting these activities into separate sections. For example, camp sites are sensitive to beetle kill because excess dead trees prompt campground closures, but hunting opportunities may be more closely related to animal stress and the number of hunting licenses the CPW issues in a given year. The wildfire threat database does reflect all three activities as they are all impacted by wildfire.

The NCNA identified fishing as one of its main recreational study areas and has assembled a substantial amount of data. However, as noted in the previous section, the basin-specific data would require manipulation in order to apply them in a meaningful way to a drought vulnerability

¹⁰ <https://wildlife.state.co.us/Hunting/PlanYourHunt/Pages/PlanYourHunt.aspx>

analysis. Future work should use the NCNA findings as a starting point and assemble a uniform county level data set for the entire state. This data set can serve as a fishing inventory metric and may also contribute to impact metrics pending future work that identifies those species and habitats which are most vulnerable to drought.

Golfing

From interviews with golf course superintendents, a large part of water management depends on the individual course and how it is managed. This is hard to quantify but factors into whether or not a golf course will be injured during a drought. Golf course managers who increase efficiency (decrease water demand) under normal conditions are better able to respond during drought. Another factor is the vulnerability of the municipal water providers servicing golf courses and their policies on water restrictions. Golf courses should work with their water provider to develop plans to limit water use in an efficient way during drought.

A suggested metric for future vulnerability assessment efforts is: “How many acres of the golf course consist of essential areas?” Here, “essential” is defined as the tees, fairways, and putting greens. The proportion of critical areas to the total could be calculated to understand how many acres a golf course could stop irrigating before the course were severely impacted. Certainly, it could be included in a county or statewide plan, but this information would also be useful to golf course managers as a way to identify vulnerability of specific courses.

Boating

The boating sub-sector is strongly related to CPW, so further research could be done in tandem with the State Assets Sector. The boating registration data used for this plan are for the entire state, and a suggested vulnerability metric is “boating registrations by county.” The benefit of this information would be two-fold: 1) it would provide a spatial picture of any boating “hot-spots” around the State; and 2) registrations could be tracked by year to detect any changes that could be explained partly by drought. Limitations to this metric include: 1) the county where the boat is registered does not indicate the county where the boating occurs and 2) from conversations with State Parks employees, boating registrations are more impacted by the economy (i.e., in a recession less people register their boats). Since the 2002 drought also occurred during a minor economic recession, boating registration numbers may give the false impression that drought was the reason for lower registrations. A similar sentiment was conveyed by CPW staff (CPW, 2013) for the 2012 drought – boat registrations were likely more impacted by the economic recession than the drought.

Another suggested vulnerability metric is to look at any compacts a lake or reservoir is subject to (i.e., the John Martin Reservoir provides storage for the Arkansas River compact between Kansas and Colorado, 1949 [KSDA, 2010]). These compacts could dictate a specific reservoir volume that would facilitate boating in a drought, or conversely, they could cause a reservoir to drain below normal levels in order to fulfill the water delivery.

As noted in the wildlife viewing and fishing sections, data assembled in the NCNA process could improve the boating inventory metrics. Future work should use the NCNA findings as a starting point and assemble a uniform county level data set for the entire state.

Rafting

One limitation for the rafting sub-sector is correlating river reaches to specific counties. There are reaches that encompass multiple counties, and there are also cases where rafting outfitters meet with customers in one county, then drive to an adjacent county to begin the trip. In either case, although the river passes through a county, that county does not necessarily see an economic benefit from the rafting industry. Further analysis is recommended to identify counties that have been included in the rafting spatial distribution metric but that do not experience a strong benefit. Also, since the industry is fairly small and concentrated to the western half of the State, it would be feasible for someone with intimate knowledge of rafting to identify towns and/or counties that are highly dependent on rafting as an economic driver.

A thorough analysis of existing instream flows, water flow agreements, recreational in-channel diversions and their respective seniorities could point to rivers that are more or less vulnerable to being depleted below raftable levels during a drought. An example of an existing water flow agreement is the 2006 agreement between the Southeastern Colorado Water Conservancy District, the Colorado Department of Natural Resources, CPW, Chaffee County, Arkansas River Outfitters Association, and Trout Unlimited to manage the flow on the Arkansas River above the Pueblo Reservoir to allow for recreational and fishery purposes.

As noted in the wildlife viewing and fishing sections, data assembled in the NCNA process could improve the rafting inventory metrics. Future work should use the NCNA findings as a starting point and assemble a uniform data set for the entire state that could be summarized by county.

Future data collection efforts should seek to find drought specific metrics following the model presented in Thomas & Wilhelmi, 2012. Educating and coordinating stakeholders in data collection would not only help measure drought impacts, but would also serve to help outfitters identify their own personal vulnerabilities.

The bullets below offer some suggested vulnerability metrics that could enhance this assessment in the future.

- **Skiing:**
 - What is the base (or peak) elevation of the resort
 - Analyze historic SNOTEL record and records kept by resort snow scientists
- **Wildlife viewing:**
 - Rate the sensitivity of habitat
 - Collect information regarding competition for water from other sources
 - Is the habitat protected through state or federal laws (this can be broken out as protected acres per county)

-
- How adaptable and/or mobile is the species in question (refer to Environmental Sector for additional discussion)
 - Hunting, fishing, and camping:
 - Collect data regarding fish hatchery operations (refer to State Assets Sector for additional discussion)
 - Hunting and fishing license records by county and by year
 - Golf:
 - Assess how many acres within the course are considered “essential” for irrigation
 - Boating:
 - Collect registration data by county
 - Analyze storage agreements and/or interstate compacts as they relate to reservoir water levels
 - Rafting:
 - Use expert input or demographer data to identify towns and/or counties where economy is highly dependent on rafting
 - Analyze instream flows, water use agreement, and recreational in-channel diversions as they relate to streamflows
 - Suggest inclusion in future survey efforts

11 SOCIOECONOMIC SECTOR

Key Findings

- Socioeconomic impacts fall into three main categories; secondary economic impacts, behavioral health impacts, and public health concerns.
- There are a number of counties in Colorado whose economic base is more than 60% agriculture or tourism. The economic reliance of these counties on particularly drought vulnerable industries increases the vulnerability of the county as a whole.
- Most of the counties in Colorado have federally identified Health Professional Shortage Areas for behavioral health. Much of the state will have a difficult time responding adequately to the increased behavioral health issues that can occur due to drought and related impacts.
- Drought induced public health issues can include: impaired drinking water quality, increased incidence of mosquito-borne illness, respiratory complications resulting from impaired air quality, and an increase in wildlife-human confrontations.

Key Recommendations

- Economic diversification is a key mitigation strategy for drought. This should occur both on a regional level and in individual business plans.
- Cooperative alliance and community planning that occurs before a drought can greatly increase the efficiency and effectiveness of drought responses.
- Many of the behavioral and public health issues resulting from drought are coordinated by governmental entities. Statewide agencies should increase their understanding of societal impacts tied to drought and focus on collaborative opportunities to mitigate drought impacts.

Most counties in Colorado are designated Mental Health Professional Shortage Areas (Colorado Department of Public Health and Environment [CDPHE], 2015), and most of these designations are due to geographic distance from the nearest provider. Additional local medical facilities and services are necessary in these counties to meet behavioral health needs, particularly in times of enhanced stress and hardship such as during a drought.

- Significant data gathering and additional monitoring are required to spatially characterize social vulnerability. Refer to Section 11.6 for more detailed data gathering recommendations.

11.1 Introduction to Sector

As stated throughout this report, drought is a slow-moving, far-reaching hazard that can affect nearly every aspect of society. As such, it is not adequate to assess only those groups with direct water dependence. Although the socioeconomic impacts of drought are often the most difficult to track and measure, they can reach the largest number of people and linger long after direct impacts have dissipated. For a general description of the vulnerability assessment approach refer to Chapter 2 (Annex B).

Historically, drought has been tied to a broad range of social tensions. The connection between water and conflict is well established throughout human history. Even today, in developing countries drought can result in serious famine, loss of life, and discord. Often the social implications of drought are overlooked in more developed areas because they are not as drastic as those noted in the developing world. However, this is not to say that serious drought-related impacts do not occur in the developed countries. Experience in Australia, which had its worst drought of record from 2006 to 2012, and more recently in Cape Town, South Africa, which has had to implement drastic restrictions in water usage to avoid turning off municipal taps, highlights the breakdown of entire communities that can occur during severe drought. Even in moderate droughts, secondary economic impacts are serious and widespread, and public health issues are real.

In the context of this analysis, socioeconomic impacts fall into the three categories: public health, behavioral health, and secondary economic impacts. These categories are necessarily broad, and in the sections that follow, these categories will be examined in more detail. In many cases, drought impacts are based on specific experiences and reported incidents. Comprehensive statewide analyses for most of the issues noted here are not available. Nevertheless, as detailed in this report, socioeconomic drought impacts have the potential to impact the most people and create compounded impacts with the other sectors. As such, continued attention on this sector will be valuable in the future, even with the limited data currently available.

11.2 Vulnerability of Socioeconomic Sector to Drought

11.2.1 Aspects of Vulnerability

The probability of drought-related health impacts varies widely, and largely depends upon drought severity, baseline population vulnerability, existing health and sanitation infrastructure, and available resources with which to mitigate impacts as they occur. The socio-economic environment in which drought occurs influences the resilience of the affected population (Stanke, Carla et al., 2013).

Table 11.1 outlines the key socioeconomic impacts and adaptive capacities covered in more detail in Section 11.3. Societal drought impacts can include: decreased public health, greater unemployment, reduced income, poor housing sales, residential and business relocations, weakened tax base, diminished quality of life, and increased crime rates (Klein and Udall, 2004). A decline in public health can result from “compromised quantity and quality of potable water, increased recreational risks, effects on air quality, diminished living conditions, compromised food and nutrition, and increased incidence of illness and disease” (Kalis, Miller, and Wilson, 2009). Environmental degradation and the financial implications of drought often cause increased stress, which can result in behavioral health issues and even suicide.

Among the hypothesized adverse effects of drought are exacerbations of respiratory diseases (e.g., asthma, allergies, dust pneumonia, bronchitis) resulting from increased airborne dust and

particulate matter; increases in vector-borne disease incidence because of environmental degradation; increases in waterborne diseases attributable to worsening surface water quality or increased groundwater catchment areas when wells are over-pumped; and infectious diseases resulting from compromised hygienic practices (CDC, 2010¹). Air quality can be degraded by increased particulates in the air. In the “Dust Bowl” of the 1930s the air quality was so impaired that cases of dust pneumonia were reported. Aerosolization of spores in soil can increase risk of infectious diseases like coccidioidomycosis (Valley Fever). Air quality can also be impaired by wildfires. Smoke from fires can exacerbate chronic respiratory illness and increase the risk of acute respiratory infection (Kalis, Miller, and Wilson, 2009).

Under drought conditions, rainfall and runoff often decrease while effluent discharges remain the same. This can have impacts on surface water quality. Total dissolved solids may increase (especially with runoff from wildfires), and pathogen levels may become dangerous. Incidence of vector-borne disease could also increase as water bodies shrink and stagnate, creating optimal breeding grounds for mosquitoes. In some cases, lack of surface water can force mosquitoes to increase breeding in swamp or bog ecosystems. This results in a convergence of mosquitoes and avian hosts. During previous droughts, these circumstances have been associated with outbreaks of St. Louis Encephalitis, Eastern Equine Encephalitis, and West Nile Virus (Kalis, Miller, and Wilson, 2009).

Table 11.1 Key Impacts and Adaptive Capacities

Key Impacts	Key Adaptive capacities
Secondary economic impacts	<ul style="list-style-type: none"> ● Economic diversification ● Cooperative alliances and community planning
Behavioral health impacts	<ul style="list-style-type: none"> ● Increased public awareness about possible drought implications and the signs of behavioral health issues ● Increased funding for behavioral health professionals especially in high vulnerability areas
Decreased water and air quality and resulting public health concerns	<ul style="list-style-type: none"> ● Increased monitoring and spatial analysis of drought-related impacts ● Increased awareness and drought preparation by public agencies ● Implementation of environmental and water conservation measures along with sanitation strategies and educational outreach to reduce public health issues during droughts

¹ Centers for Disease Control and Prevention. US Environmental Protection Agency, National Oceanic and Atmospheric Administration, American Water Works Association. When every drop counts: protecting public health during drought conditions—a guide for public health professionals. 2010

11.2.2 Previous Work

The Environmental Health Services Branch (EHSB) at the Centers for Disease Control (CDC) conducted a literature review of drought-related public health studies (Kalis, Miller, and Wilson, 2009). The CDC study noted that, in general, public officials are under-informed on the expected impacts of drought. The literature review effort pointed out that this effect is true in Colorado. There is monitoring of many air and water quality parameters as related to various hazards including drought, but there has been minimal work to assess the implications on public health and social justice issues stemming from these hazards. More recently, however, that same branch of CDC updated this and similar studies regarding drought and public health, highlighting notable health implications due to drought: compromised quantity and quality of drinking water; increased recreational costs; effects on air quality; diminished living conditions related to energy, air quality, and sanitation and hygiene; compromised food and nutrition; and increased incidence of illness and disease (CDC, 2017; ATSDR/NCEH Fact Sheet, 2018).

In 2017, a study published in the *Proceedings of the Royal Society B* documented findings that drought has played a significant role in determining the magnitude of a West Nile virus epidemic. Researchers from the University of California Santa Cruz, Stanford University, and the New York State Department of Health analyzed 15 years of data on human West Nile virus infections from across the United States, and found that epidemics were much larger in drought years and in regions that had not suffered large epidemics in the past. The study examined impacts at both national and state scales to understand climatic and intrinsic drivers of continental-scale West Nile virus epidemics, with an emphasis on the relationship between temperature and transmission potential of mosquitos. The results demonstrate that drought (rather than within-season, winter temperatures, or precipitation independently) has been the primary climatic driver of increased West Nile virus epidemics in many regions previously unaffected. The positive correlation between drought and West Nile Virus infection prevalence in Colorado mosquitoes suggests that drought alters transmission patterns in this state, not by reducing mosquito abundance, but by increasing infection prevalence. The exact correlation between drought and West Nile transmission is still an ongoing research question, though the mentioned study provides a few potential explanations. One possibility is that droughts cause people to use more artificial sources of water, drawing birds and mosquitoes to man-made oases of freshly watered lawns, and concentrating the birds, disease-bearing-mosquitoes, and humans in one place. Another factor might be that drought stresses bird populations, taxing their immune systems and leaving them more vulnerable to infection. Additionally, mosquitoes carrying the disease, all in the *Culex* genus, have a slightly longer life cycle than other mosquito populations, which makes them more likely to pass on the disease during drought years (Paull et al., 2017).

In Florida, a study was conducted to analyze the connection between St. Louis encephalitis outbreaks and drought using a dynamic hydrology model. This study found that springtime drought can force *Cx. nigripalpus* mosquitoes to breed in densely vegetated marsh habitats in close proximity to wild birds. The convergence of mosquito vectors and avian hosts provided the ideal situation for rapid amplification of the virus (Shaman, Day, and Stieglitz, 2002). While this type

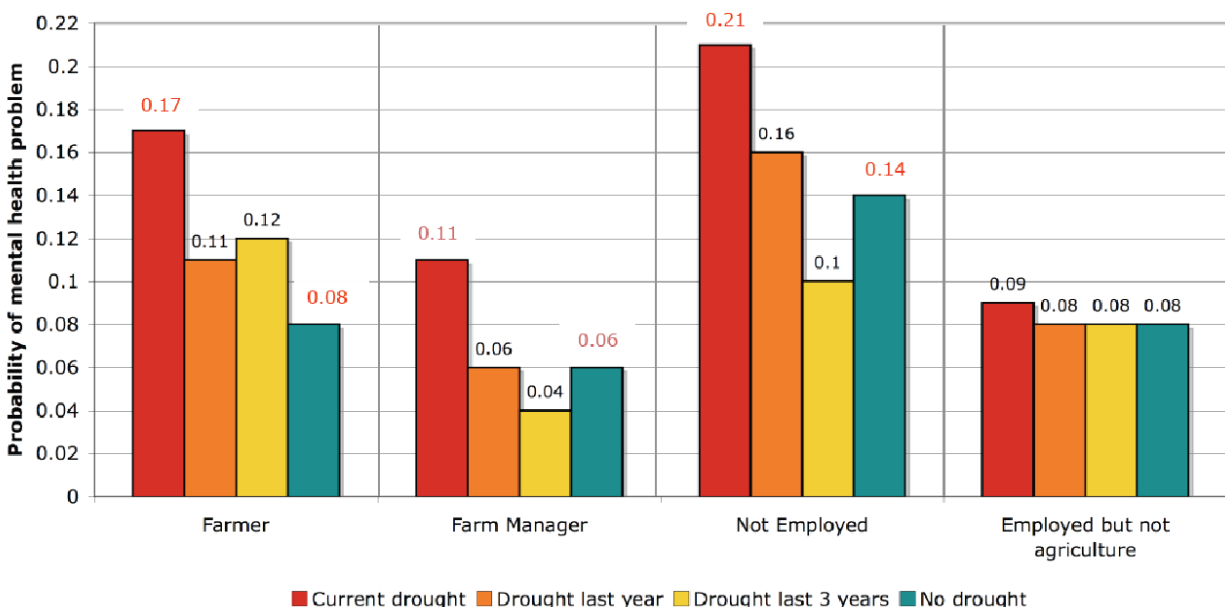
of mosquito is not present in Colorado, one of the conclusions of this report is that the same amplification mechanisms may be relevant in other outbreaks like West Nile Virus. Future work should analyze the relevance of these findings to Colorado.

Over the past 60 years, Australia has experienced the worst droughts on record; these events serve as examples of the negative long-lasting and far-ranging effects that drought can have on communities, but particularly their populations. Sustained severe drying has been occurring in eastern and southwest Australia. Financial hardships caused the government to declare “exceptional circumstances.” For example, one lake dried up so much that the remaining water turned into sulfuric acid as lake-bed soils got exposed to the air. There were fears that people in the area could be exposed to acid dust blowing off the lake (Kraemer, 2009).

The unprecedented duration and intensity of the drought resulted in serious social consequences. Large agricultural areas were rendered completely unproductive, threatening not just production but the way of life. Social repercussions gained the attention of the government and researchers.

The Australian Institute of Family Studies sponsored a study on the effects of drought on behavioral health and related alcohol use. Figure 11-2 shows some results from this study. The probability of behavioral health problems for those unemployed or employed in agriculture drastically increased during the drought. For farm employees and managers, the probability of behavioral health problems in the drought was nearly double the probability with no drought. Those employed in other fields only showed marginally increased probability.

Figure 11-1 Relationship between Drought and Behavioral Health by Employment



 Australian Government
Australian Institute of Family Studies
Source: Edwards, Gray, and Hunder 2009

The recent drought in southern parts of the African continent also serve to highlight the negative consequences suffered by society upon exposure to droughts. Since 2015, the Western Cape province of South Africa has experienced a severe water shortage, most notably affecting the city of Cape Town. Restrictions were imposed in January and February of 2018, which ultimately limited consumption to 50 liters per person per day. The town additionally launched an online water dashboard that tracks water usage and supply on a weekly basis. Largely due to these water-saving initiatives, the city has been able to push their projection of “Day Zero” to 2019 (City of Cape Town, 2018). This is the projected time when municipal water supply will largely be shut off, if water supply stays at current levels. When this occurs, residents will rely on water collection points around the city to collect a daily ration of 25 liters of water per person. Water supply will be maintained in the city's central business district, and prioritize serving critical facilities and essential services. As an anecdotal relationship with our local climate characteristics, it is worth to note that both Cape Town and the state of Colorado are heavily impacted by the El Niño/Southern Oscillation (ENSO) patterns; the discussed drought effects on the southern African continent could be very relevant for us to understand possible negative outcomes during future droughts.

A Reuters article published in February notes, “for hard-pressed residents in the port city of 4 million, fear and anxiety stalk the lines as people consider what might happen when large crowds are forced to line up for emergency water rations at collection points” (Roelf, 2018). One resident was interviewed by South Africa News24 about the same issue, stating that “it's not just about the water, it's about the social impact of not having access to a resource. It's going to amplify inequalities... We already experience it here - the tensions and the conflict” (Fairuz Mullagee [News 24 article], 2018). A survey conducted by the Cape Chamber of Commerce and Industry found that 7% of businesses plan to close down if the taps are shut off, and nearly 80% of companies say that water shortages significantly threaten their ability to operate. Residents and business owners across the city are filled with anxiety in anticipation of Day Zero. “It’s going to be terrifying for many people when they turn on the tap and nothing comes out,” says Christine Colvin, freshwater manager for WWF and a member of the mayor’s advisory board (Watts [The Guardian], 2018).

Fortunately, Cape Town officials are making some effort to help vulnerable populations during this crisis. For example, the city plans to keep water running in some poorer neighborhoods, and groups have also begun to organize and plan for Day Zero water deliveries to the elderly. Mayoral committee member JP Smith confirmed that social service facilities will be supplied by tankers or volunteers carrying bottles, although many locals have little confidence in authorities. Nevertheless, an article by South African The Times newspaper reports that for “many residents in Cape Town's impoverished townships, the state's failure to provide domestic tap water is an established fact of life” (News24 and The Times, 2018), inciting some distrust in the local government efforts.

Prior to the 2010 version of the Colorado Drought and Mitigation Response Plan, drought vulnerability for the Socioeconomic sector had not been evaluated for the State. Yet, there were several studies addressing drought and water supply planning. The Colorado Water Conservation

Board (CWCB) conducted a Drought and Water Supply Assessment (DWSA) in 2004 to determine the State's preparedness for drought, and also identify limitations to better plan for future droughts (CWCB, 2004). The details of this work are discussed in Chapter 1 - Introduction. It entailed a survey, or opinion instrument, where 537 responses were received statewide on specific impacts experienced during the dry periods between 1999 and 2003. Various entity types were surveyed including power, industry, agriculture, municipal, State, Federal, water conservancy and conservation districts, and "other" (e.g., tribes, counties).

The all-encompassing nature of the Social Sector does not lend itself to clear survey subjects, and the DWSA did not specifically consider the Socioeconomic Sector through the various case studies it conducted. However, the study incorporated a diverse group of business owners across the state to describe general social/economic impacts that were felt as a result of the 2002 drought. Interviews were conducted with a rafting company owner on the Arkansas River, a farmer and cow calf rancher in the San Luis Valley, a dry land farmer in southeastern Colorado, a nursery/greenhouse owner in the Denver Metropolitan Area, and a truck farmer in the Grand Valley. A common theme among their responses was that impacts were felt in both the short and long term (e.g., business plans had to be redeveloped). Changes included modifications in the way crops were planted, letting go of employees, and making of additional (not regular) purchases. When coupled with other business-related drought strains such as changes in the ways services are provided, these adjustments may have lasting impacts on the business. The long-term impacts identified in the interviews were even more distressing, largely because they entail mostly irreversible actions such as selling the family farm or business. This results in long term financial strains in the form of unemployment and increased debt. Overall, a ripple effect was felt throughout these industries due to the 2002 drought because it not only impacted these businesses, but their local communities, families, and lifestyles as well.

Another relevant Colorado specific study is the Statewide Water Supply Initiative (SWSI, 2010), which, as of 2018, is in the process of being updated. Although this study does not specifically focus on drought, the SWSI process is another important initiative taken and directed by the CWCB to understand existing and future water supply needs and how those needs might be met through various water projects and water management techniques.

The SWSI does not address specific social and economic impacts due to drought conditions, but it does state that the statewide social and economic setting may be greatly affected when water supplies are scarce. This is because the state relies heavily on snowpack for much of its water supplies, which in turn is a driver for the viability of many economic segments such as the urban economy, agriculture, mineral/mining, and recreation and tourism (SWSI, 2010). The SWSI acknowledges the implications drought can have on society by noting that consideration of the social and economic setting should occur in future water supply planning efforts to mitigate any negative implications on Colorado's overall economic health.

The National Drought Mitigation Center (NDMC) was established at the University of Nebraska-Lincoln in 1995. Their mission includes helping people and institutions "...develop and

implement measures to reduce societal vulnerability to drought, stressing preparedness and risk management rather than crisis management.” NDMC maintains the Drought Impact Reporter which is an online database of drought impacts from a variety of sources, including media, government agencies, and the public. Impacts listed in the Drought Impact Reporter, related to the socioeconomic sector during and shortly after the most recent drought (May 2012 to June 2014) are provided below:

- Increased costs to clear tumbleweeds from roads, fences, and irrigation ditches in Crowley and Pueblo counties. Cattle would normally eat the tumbleweed, but drought forced many ranchers to sell parts of their herds, leaving too few animals to control the tumbleweeds.
- An overall degradation of lawns and landscaping in neighborhoods in Colorado Springs. Many lawns have been replaced with bare dirt and/or weed patches. Many trees died. This has the effect of increasing local temperatures, exacerbating the urban heat island effect, contributing to reduced air quality, and reducing the overall quality of the viewshed for some folks.
- Drought dust storms left land barren in southeastern Colorado (Cheyenne, Kiowa and Powers Counties).
- Reduced air quality from blowing dust in Kiowa and Yuma Counties. Reduced vegetative and crop cover generated dust that reduced visibility, forced the closing of highways, and affected breathing.
- In Lincoln County, 9 News reported that a particularly strong windstorm inundated crop fields in six to eight inches of sand.
- Colorado wildlife officials estimated that 300 to 500 mule deer have been making the town of Alamosa home since the 2002 drought. Town residents have filed complaints of the deer feasting on trees and gardens, given their native environments became unsuitable due to drought.
- On Sunday, April 14, 2013 strong winds and blowing dust created hazardous driving conditions on I-25 north of Pueblo, producing multiple car wrecks.
- There were multiple reports of bears breaking into cars, stores, and houses in search of food. Some bears were put down as they posed a danger to people.
- Hay thefts increased as a result of higher hay prices.

11.3 Assessment of Impacts and Adaptive Capacities

Following the same process used in the 2013 update of this plan, Section 11.3 is split into three main impact categories: secondary economic impacts, behavioral health impacts, and public health impacts.

11.3.1 Secondary Economic Impacts

The five sub-sectors analyzed individually in this report were chosen based on importance to the economy of the State as well as water dependency. However, many industries not reliant on water are impacted by drought through their relationships with other sectors. The direct impacts of drought are just the starting point for impacts to propagate. While it is beyond the scope of this

project to do a detailed analysis of the entire Colorado economy as it relates to drought, results were assembled from economic impact studies carried out related to visitation in state parks, as well as hunting and fishing. These are examples of the economic importance of recreation to surrounding communities and secondary industries. Both studies apply to the Recreation Sector but carry aspects of society and general economy. Similar analysis for the other sectors is not available for the State but should be a focus of future work. Three key secondary economic impact categories are provided below.

- Loss of business for industries dependent on those groups that are directly impacted by drought. For example, tourism-based businesses in the vicinity of state parks or decreased business to landscaping companies as the demand for sod goes down.
- The multiplier effect of decreased business revenue can impact the entire economy. When an individual's income decreases or is lost, all of the goods and service providers they usually support will also be impacted.
- Business downturn can decrease property value and erode the tax base.

Colorado Parks and Wildlife (CPW) maintains an economic impact model for hunting and fishing activities. According to CPW, in 2017 the total economic output associated with outdoor recreation amounted to \$34.5 billion dollars, contributing \$19.9 billion dollars to the Gross Domestic Product of the state. This economic activity supports over 313,000 jobs in the State, which represents 13.2% of the entire labor force and produces \$12.4 billion dollars in salaries and wages. In addition, this output contributes \$4.9 billion dollars in local, state and federal tax revenue. When drought events take place, hunting and fishing activities significantly diminish, consequently hurting the economy, secondary industries, and way of life.

To put into perspective how central of a role outdoor recreation and other such activities play in the State's primary and secondary economies, a study conducted in 2013 by Southwick Associates for CPW quantified the economic contribution of outdoor recreation in Colorado (breaking it up into seven regions). The regions are displayed in the figure below.

Figure 11-2 Southwick Associates Study Region



Of the \$34.5 billion of total economic input from outdoor recreation, the Northwest and North Central regions account for over half of the total economic output, salaries and wages, GDP contribution, taxes, and jobs. Table 11.2 shows the distribution of economic impacts from hunting and fishing for all seven regions and the state, in millions of dollars. In the Northwest region alone, nearly 92,000 jobs are supported by the total economic contribution of outdoor recreation, representing one third of the entire adult population in that region.

Table 11.2 Outdoor Recreation-Based Economic Contribution, in Millions of Dollars

Region	Output	Salaries & Wages	GDP Contribution	State/Local Taxes	Federal Taxes	Jobs
Northwest	\$9,284	\$3,355	\$5,432	\$697	\$718	91,822
North Central	\$8,295	\$2,940	\$4,734	\$582	\$619	78,521
Metro	\$3,630	\$1,460	\$2,216	\$259	\$295	34,057
Northeast	\$385	\$116	\$294	\$34	\$25	4,528
Southeast	\$1,053	\$324	\$580	\$97	\$70	12,705
South Central	\$4,142	\$1,344	\$2,282	\$341	\$258	47,017

Region	Output	Salaries & Wages	GDP Contribution	State/Local Taxes	Federal Taxes	Jobs
Southwest	\$2,173	\$714	\$1,242	\$182	\$148	24,568
TOTAL	\$28,962	\$10,253	\$16,780	\$2,192	\$2,133	293,218

Source: Southwick Associates, 2013

Outdoor recreation includes a diverse set of activities; however, the study by Southwick Associates looks more closely at the economic impacts of fishing, hunting, and wildlife watching. These three activities together produce over five billion dollars of economic output. Wildlife watching alone contributes 2.2 billion dollars in economic output per year, supporting over 19,000 jobs in Colorado. The economic output of hunting is estimated at \$0.7 billion, and it supports nearly 10,000 jobs. Even a small-scale drought event that impacted these industries directly (e.g., lack of water-based activities, diminished wildlife populations from impacted ecosystems), as well as other key ones such as winter recreation, could consequently hurt thousands of dollars of revenue, GDP contributions, salaries, and jobs. Tax revenue, in particular, pays for essential services that communities rely upon; any future drought event that impacted recreation and tourism would undeniably have compound/secondary effects on other key economies and facets of Colorado life.

Pursuing big game is the most popular form of hunting in Colorado among both residents of the State and those traveling from other locations. Residents make up the majority of days spent hunting big game in the state, at 66.8% of total big game hunting participants (CPW, 2013). However, the average non-resident big game hunter spends more money per day than locals. As a result, the economic output contributed by nonresident big game hunters makes up nearly 50% of the statewide total. This is relevant to the socioeconomic sector because it highlights the importance of out-of-state visitors to the economy, and how drought related impacts (including perceived ones as portrayed by the media, for example) that negatively affected one facet such as big game hunting, would then further compound to hurt all other interconnected sectors, industries, and economies.

A study conducted by Corona Research found that, from June of 2008 to May of 2009, visitors to state parks spent \$571 million in local communities within a 50-mile radius of the park. As to be expected, local visitors spent less in surrounding areas than visitors coming from farther away. Average spending within the 50-mile radius by local residents was \$48 per visitor, while average spending per non-local visitor was \$80. Lake Pueblo had the highest expenditures, generating nearly \$98 million for local economies (Corona Research, 2009). Table 11.3 summarizes the total expenditures by region. Note that, as with hunting, the relative contribution of spending to the local economy is more important than the total spending.

Table 11.3 Total Visitor Spending within 50-Mile Radius of State Parks by Region

Regional Totals	Total Expenditures
Denver Metro	\$74,627,053
High Plains	\$77,708,457
Rocky Mountain	\$207,610,661
Southeast	\$211,408,310

Source: Corona Research, 2009

There are counties in Colorado that are highly dependent on recreation and tourism, and would hence be extremely hurt by drought and the related impacts. In some regions, tourism accounts for over 50% of total employment in Colorado. In Table 11.4, the percentage of total employment related to tourism was calculated using 2015 data from the Colorado Demography Office. Below are listed the top ten counties with the most substantial employment tied to tourism.

Table 11.4 Top 10 Counties with Substantial Employment Related to Tourism

County	Tourism Employment	Total Employment	Percent in Tourism
Gilpin	5,626	4,700	84%
Mineral	698	375	54%
San Miguel	7,258	3,683	51%
Pitkin	20,731	10,426	50%
San Juan	399	192	48%
Summit	26,310	12,617	48%
Grand	9,627	4,177	43%
Eagle	40,912	17,719	43%
Routt	19,611	6,652	34%
Clear Creek	3,971	1,173	30%

Source: Colorado Demography Office, 2015

A study by Dean Runyan Associates in 2016 evaluates the impacts of travel for four regions: Pikes Peak, Mountain Resort, Denver Metro, and All Other. The distribution of counties by region is listed below:

- Mountain Resort: Eagle, Grand, Gunnison, La Plata, Montrose, Pitkin, Routt, San Miguel, and Summit
- Denver Metro: Adams, Arapahoe, Broomfield, Denver, Douglas, Jefferson
- Pikes Peak: El Paso, Fremont, Teller
- Other: All counties not within Denver, Mountain Resort or Pikes Peak regions

Table 11.5 below outlines the impacts of travel for each region.

Table 11.5 Economic Impacts of Travel Tourism by Region

Region	Total Direct Travel Spending (\$Million)	Industry Earnings Generated by Travel Spending (\$Million)	Industry Employment Generated by Travel Spending	Government Revenue Generated by Travel Spending (\$Million)
Mountain Resort	\$4,233	\$1,265	35,000	\$285
Denver Metro	\$8,932	\$2,720	57,000	\$523
Pikes Peak	\$1,543	\$410	16,000	\$95
Other	\$2,960	\$911	38,000	\$186
TOTAL	\$17,668	\$5,306	146,000	\$1,089

Source: Dean Runyan Associates, 2016

This additional example of how key sectors, like travel tourism, provide for Colorado's economy further highlights the potential detrimental secondary effects drought can have on local economies, lifestyles, and state revenue.

The Colorado Tourism Office reported that 77.7 million visitors to the State in 2015 spent an all-time high of \$19.1 billion, generating \$1.13 billion in state and local taxes, an increase of almost 7% from 2014. Over half (51%) of all overnight travel spending occurs in the Denver Metro region, followed by the Mountain Resort region (24%). However, when compared to the regions' total respective earnings, the normalized proportion of travel-generated spending is actually much lower in the Denver Metro region as compared to the Mountain Resort region, likely because the Mountain Resort region receives a higher amount of tourists and people seeking recreational opportunities.

The studies discussed above provide quantitative information on how specific activities can connect to the larger economy. Results show that recreation and tourism in Colorado generate much more revenue than the licensing and park entrance fees alone. Overall spending is highest in counties with the largest population, but per capita, spending is highest in rural counties where proportionally more jobs and businesses exist to serve the recreation and tourism industry.

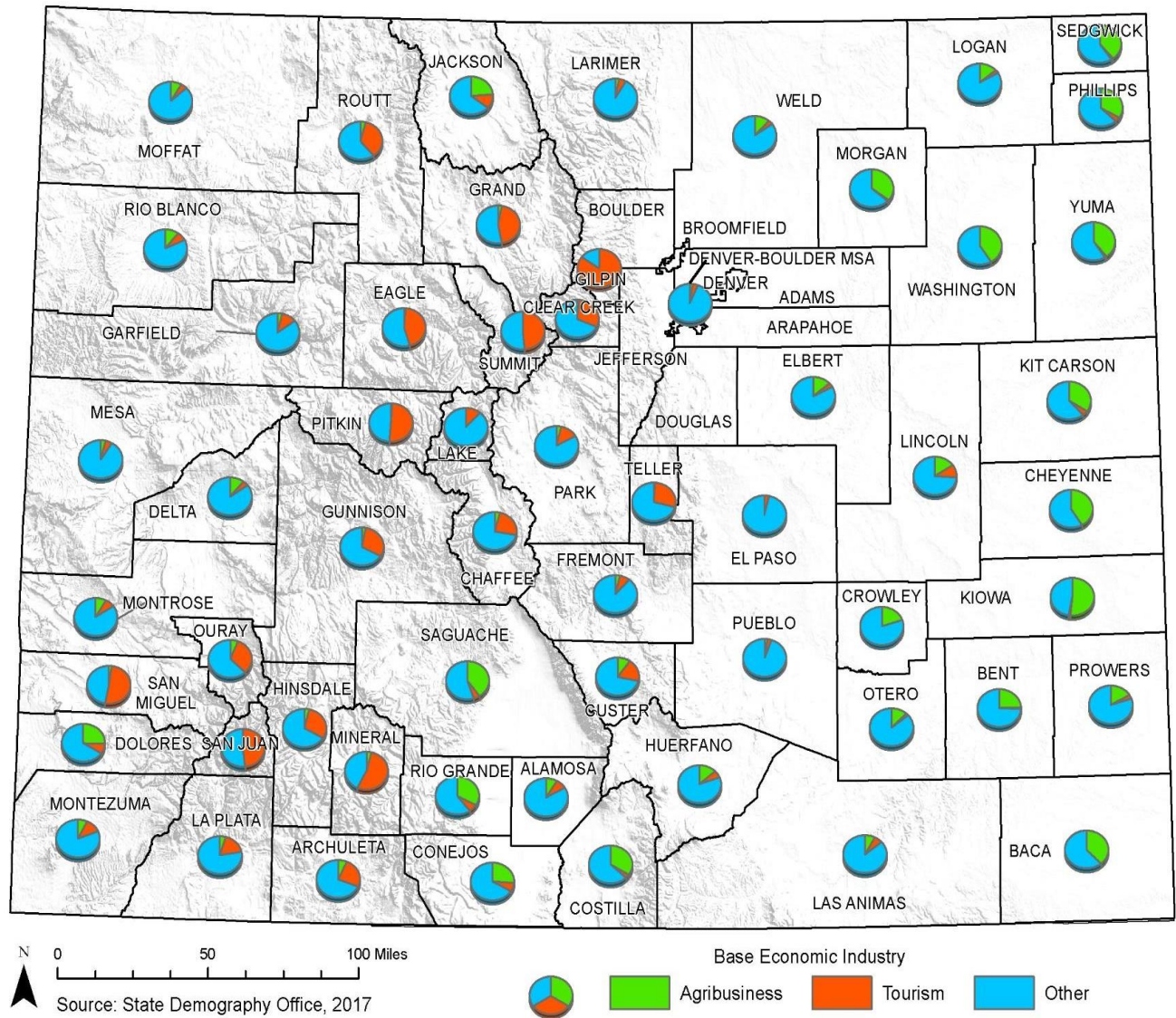
Many of the businesses involved in Recreation Sector are small in scale, and often less able to cope with prolonged stress from hazard events which disrupt their day-to-day routines. For example, in the 2002 drought some businesses in the marine/boating industry experienced revenue reductions of nearly 50%. The flexibility to work with manufacturers on volume-buying programs and inventory control became crucial to continue their businesses (Schneckenburger and Aukerman, 2002). Representatives from fishing shops cited public perception as an important factor in visitation. Even in cases where drought conditions had actually resulted in very good fishing, if people were under the impression that fishing was bad everywhere, they went out of state or avoided the areas perceived to be affected (Schneckenburger and Aukerman, 2002). One potential source of assistance in cases where drought heavily impacts small businesses is the Small Business Administrative (SBA) Economic Injury Disaster Loans program. For example, San Juan County received aid this year (2018) as a result of winter time drought. While it is the first time this has happened since the 1970s, other counties, jurisdictions, agencies, and businesses could

follow San Juan County's lead and seek funding to relief stress due to dry conditions and reduced/damaged business.

The preceding examples indicate the multiplier effect drought can have on general business and industry. Figure 11-3 shows pie charts of the economic base employment by county, based on a regional profile analysis by the State Demographer's Office. This map shows the western half of the State to be tourism driven, while the eastern half is agriculturally driven. In general, a diversified economy is more resilient, so in counties with little economic diversification, all businesses could be impacted by a downturn in the sectors that serve as the primary economic drivers. With relation to drought, agribusiness and tourism have been identified as the most directly vulnerable; as such, county economies with the heaviest reliance on these two sectors are highly vulnerable to far-reaching economic disruptions during a prolonged drought. On a statewide scale this could lead to increased unemployment, declining housing markets, and loss of industry. Particular attention must be paid to differentiating drought-related impacts from other causes of business or economic decline. For the 2011-2013 drought event, consideration should be given to how national and international economic issues can be both separated from the regional impacts of drought, and factored in as a compounding or exacerbating variable. For instance, international food markets can have a significant impact on the local agricultural economy, particularly when the local economy is reliant on those external drivers (e.g., transportation of goods required for planting). Secondary economic impacts are very complex and a broad range of compounding factors can play a crucial role.

It is difficult to define specific adaptive capacities for such a broad range of activities. Communities that are diversified and businesses that are flexible are best able to respond to stress, such as that brought about by drops in tax revenue necessary to maintain community services. To better prepare for drought, individual businesses need to consider the industries they are dependent on and how drought impacts on others could propagate to their operations. However, businesses can take actions to insulate their own operations. Communities can help businesses by forming cooperative alliances and coordinating public relations. One example of this is the Community Agriculture Alliance (CAA) that was established in 1999 to serve Routt County and the Yampa River Valley, in Northwestern Colorado. The CAA has been involved in many community relations programs and has helped create a cooperative working relationship between agriculture, Steamboat Resort, and associated tourism-based businesses. Enabling collaborative efforts and alliances such as this is best if carried out before a drought occurs, so that working relationships are already established before stress arises.

Figure 11-3 Economic Base Employment by County



State Demography Office, 2017

11.3.2 Behavioral Health Impacts

The economic discussion above illustrated some ways in which drought can negatively spread hardship through society, directly or indirectly. Direct financial stress and general economic downturn can have disproportionate impacts for different demographics, particularly if those demographics are highly reliant on industries like agriculture or recreation and tourism to maintain their way of life. Farmers and ranchers are one of the groups under the most financial stress during drought, but they are not the only people impacted.

There is a large body of literature on “farm crisis in behavioral health.” Financial farm stress can lead directly to psychological distress that can manifest through depression, substance abuse, increased farm accidents, and even suicide (Fetsch, 2007). Colorado’s suicide rate was evaluated by comparing non-drought years to drought years. In 2002, Colorado’s suicide rate was the 7th highest in the nation and the leading external cause of death for farmers and ranchers in the State. During the 2012-2013 drought years, there were 1,053 suicides among Colorado residents, with the age-adjusted suicide rate being 20.3 years. This represents a 16% increase over the number of suicide deaths in previous (non-drought) years. (CDPHE, 2012). For both 2016 and 2017, the largest population groups committing suicide were middle-aged adults and those living in rural areas (America’s Health Rankings, 2017).

In the agricultural crisis of the 1980’s, suicide rates among farmers and ranchers were three times the rates for the rest of the State (Fetsch, 2007). Experience in Australia (refer to Section 11.2.2) also has shown the impact severe drought can have on behavioral health. Awareness and prevention actions are key in preventing suicides. Impacted communities need to be aware that, during times of drought, stress and depression can increase the risk of suicide, so that more attention is paid towards signs of suicidal inclinations. Materials have been developed by many agencies and health organization across the State and nationwide, noting the signs of suicide and how to get help. Increased attention should be paid to farmer, ranchers, and other small business owners who are risk of losing their land or going out of business during times of hardship (e.g., drought).

Central Colorado Water Conservancy District Experiences in the 2002 Drought

The following quotes come from a presentation given by Tom Cech at the Colorado Drought Conference in 2002. Tom was the executive director of the Central Colorado Water Conservancy District until 2011. His comments illustrate the stress experienced by his constituents during the 2002 drought.

We started this spring with hope. I was hopeful that El Niño would kick in during the month of June and bring a substantial rainfall. That was my outlook for the spring... It didn’t happen. We went from hope to fear. The first part of June I got a call from the Division Engineer’s Office, Jim Hall, and he said, “You know what? I think your member wells are going to be shut off, or some other wells in the

neighborhood, in a week or two. We have to do something.” There wasn’t enough replacement water to put back in the South Platte to keep the wells pumping.

We then had a meeting with the Farmers Independent Ditch Company – at Frank Eckhart’s place near LaSalle. Jim Hall showed up – one of Hal Simpson’s assistant division engineers – and met with about ten farmers saying, “If you don’t do something drastic here, your wells get shut off.”

One guy was sitting there looking right at me, a local producer, and I will never forget the look on his face when he heard those words that his well might be shut off. His jaw dropped, no lie, about six inches toward the floor. From the look on his face, he had just lost his farm. That is the human side of drought. Part of this is legal fallout from Empire Lodge, but there are guys out there who will lose their farms because of the drought.

So it is June, 2002 and everyone is fearful. Then Central started having more meetings with local ditch companies. The Greeley No. 3 Ditch Company – we met with them about five times because it appeared that certain shareholders kept taking our water. We were meeting with them because we needed that water to augment our wells. We met in a room kind of like this one in Greeley; there were about 100 people; the president stands up and says, “You know what? We are going to start locking headgates to prevent shareholders from taking too much water” And no one said a word! What does that tell you? Extra water was being diverted. So, they started locking headgates.

Two weeks later we had another meeting with the same shareholder, and you know what? There was not enough water available in the Cache la Poudre River to get to the end of the ditch. The president of the Greeley #3 Ditch said, “we will have to section the ditch – the top half gets water for three days, then the bottom half for three days. That is how we will share our limited water.”

We had another meeting two weeks later. It was so dry on the Poudre River that the ditch company had to section it into thirds. This is a ditch that was built in 1870 by the Union Colony, had never been in sections during that entire period, and here they went from locking the headgates to going to halves, to going to thirds, and by August we quit fighting. There was simply no water to fight about. We were like good ol’ boys, then, commenting on how the ditch was just plain dry. So it went from hope to fear to resolution – “It’s dammed dry out here.”

Let’s talk about fights. I give presentations to school kids and used to say, “You know, there hasn’t been a fight over water in Colorado since 1980 where someone physically got hurt. I think it was the San Luis Valley fist fight. Well, they had a fight east of Greeley by Kersey this past August, in 2002. A fellow broke his leg, fisticuffs in the ditch...”

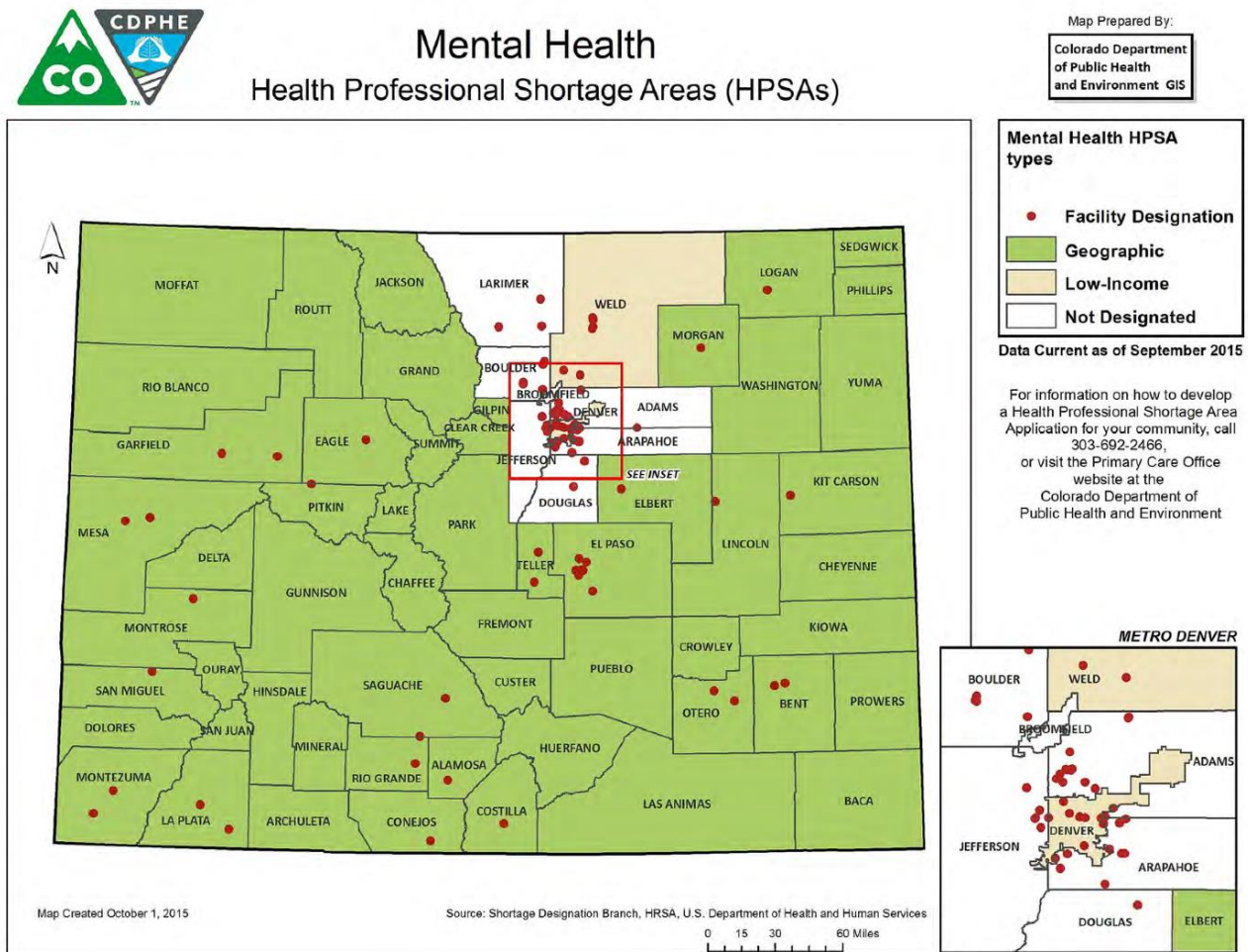
Next year, the wells may not get to pump. That would mean tens of thousands of acres of Colorado's farm ground will dry up and blow away, or there will be a lot of dryland wheat and small grains. We have farmers calling every day asking, "What should I plant? Will I have water next year?" We don't know. "What will the Legislature do?" We don't know. Will the Governor say, "Oh, let the wells pump. Don't worry about the senior ditches." I doubt it, but we don't know. What's the solution? There is none – or no easy solution, that is for sure. These are really tough times, historic times. ... The numbers – streamflows, reservoir levels, etc. - are really important but the human side ... is the fascinating and historic side.

In the urban environment, parks and green spaces are very important to behavioral health, and improve quality of life in a variety of ways. For example, a survey of desk workers found that those with a natural view from their desk found their job more challenging and were less frustrated (Wolf, 1998). Another study found that people who view or are in nature after stressful situations show “reduced physiological stress response, as well as better interest and attention and decreased feeling of fear and anger or aggression” (Wolf, 1998). While neither of these studies specifically considered the impacts of drought on behavioral health, given the proven importance of natural environments in urban areas and how those natural areas may significantly degrade during times of drought, the health costs associated with plant die off or brown out during dry periods should be considered.

Lack of access to professionals able to recognize and treat behavioral health problems, furthermore, makes a community more vulnerable to the potentially devastating impacts natural hazards pose, directly and indirectly. Figure 11-4 shows both low income counties in Colorado as well as those that have been designated as significantly lacking behavioral health professionals, also known as Health Professional Shortage Areas (HSPA) (CDPHE, 2015). Most counties in Colorado are designated as having either a low-income makeup, or are located in a HSPA. Those counties not carrying any type of designation are located around Denver, extending north along the Front Range. Additional local medical facilities and services are necessary in HSAs to meet behavioral health needs, particularly in times of enhanced stress and hardship such as during a drought.

Mitigating the behavioral health impacts of severe drought will require public awareness and intervention. The lack of support and appropriate treatment facilities in these counties could represent a greater vulnerability to drought, especially in communities where agriculture and associated agribusiness are dominant. While, in past years, behavioral health professionals dealt with insufficient resources across parts of the State, Governor Hickenlooper put aside \$20 million to address Colorado's behavioral health shortages in January 2013 (Steffen & Robles, 2013). The need for increased behavioral health resources is on the State's radar, and future stressor events such as times of drought, which again can affect thousands of people statewide both financially and emotionally (especially if those hardships involve employment layoffs, for example), can hopefully be addressed in a more effective manner, to prevent distress and even suicide in vulnerable populations (Fetsch, Koppel, and Fruhauf, 2013; Vickery, 2015).

Figure 11-4 Behavioral Health Professional Shortage Areas in Colorado, 2015



11.3.3 Social Vulnerability

The behavioral health discussion above illustrated some ways in which drought can directly and indirectly contribute to hardship through society. However, not all hardship affects all equally. Social vulnerability to disasters refers to “the characteristics and situation of a person or group that influence their capacity to anticipate, cope with, resist, or recover from the impact of a hazard” (Wisner et al. 2004). Communities have varying capacities to prepare for, respond to, cope with, and rebound from disaster events. In addition to the way in which drought contributes to decreased economic vitality, other significant impacts previously mentioned include challenges in providing water to the population, degradation in water quality, physical and mental health problems, conflicts amongst communities, and increased poverty. These impacts are felt disproportionately based on an individual’s age, health, race, income, and overall access to resources.

Older adults are typically more vulnerable to hazards, particularly those with chronic diseases, disabilities, or who require additional assistance to evacuate or relocate an area, due to accessibility

and health constraints. The impact of damaging events is generally greater for low-income groups as well, or those with fixed incomes (due to the inability to diversify or have flexible income sources). It may take years for those who cannot afford the costs of repair, reconstruction, or relocation to recover from even a moderately damaging event.

A report from the Center for American Progress looks at lessons learned from the recent droughts in California, determining that “enduring effects of racial segregation and the underinvestment in low-income communities—in California and elsewhere—have placed people of color and low-income people in environments that threaten their physical and emotional health. Low-income communities and communities of color are most vulnerable to the effects of climate change due to poor-quality housing and infrastructure, proximity to environmental hazards, and economic instability” (Ortiz, 2015). Water quality issues have been shown to disproportionately affect minorities and residents of lower socio-economic status, particularly community water systems that are not subjected to strict federal and state drinking water regulations. Balazs et al. 2012 found that community water systems serving predominantly low-income and socially disadvantaged groups have high arsenic levels in drinking water and are more likely to receive a Maximum Contaminant Level (MCL) violation. More information on water quality impacts can be found in Section 11.3.4 - Public Health.

Another study from the Pacific Institute found that a large proportion of drought-impacted public water systems and household outages in California were in Disadvantaged and Cumulatively Burdened Communities. Disadvantaged Communities are defined as having a median household income of less than 80% of the state median, while Cumulatively Burdened Communities are those that rank in the top quarter of census tracts in the state for environmental burdens and socioeconomic vulnerability. Of the 92 drought-impacted public water systems, two-thirds served a disadvantaged community, and nearly one-third served a cumulatively burdened community (Feinstein et al., 2017).

The cost of water can go up during a drought if, for example, the water utility company must purchase more expensive supplies, increase treatment for lower quality water, or pump groundwater from greater depths (including the drilling of new wells). Moreover, as water use declines due to mandatory or voluntary restrictions, water utilities may implement a temporary drought surcharge to cover their costs. Such price increases can exacerbate affordability concerns for low-income households. Single-family households earning less than \$25,000 a year paid an average of 1.8% of their household income for basic water service, without taking into account drought charges. This amount increased to 2.1% with drought surcharges, exceeding the State of California and United States Environmental Protection Agency affordability thresholds. The effect was even more extreme for households earning less than \$10,000, raising costs from 4.4% to 5.3% of income. These households have little or no disposable income, so any increase in water costs poses a major problem.

While there are programs and endeavors in Colorado to help support and empower “in building stronger, safer and more resilient [communities] in the face of natural disasters and other major

challenges,” such as noted by the Colorado Resiliency Office under their resiliency framework, drought and climate change issues could unfortunately continue to impact socially vulnerable populations more disproportionately were a lack of momentum in social justice efforts take precedence.

11.3.4 Public Health

Common public health issues during drought can arise from impaired water quality and air quality. The CDPHE is responsible for air and water quality monitoring in the State. Unfortunately, they have not had sufficient resources to analyze the relationship between drought and public health variables. As such, there are not any systematic spatial data available for Colorado. Based on experiences in many locations and qualitative information from Colorado across the years, however, major drought-related impacts can be identified, particularly from the devastating 2002 drought event (though similar issues were also experienced during the 2011-2013 drought). Nevertheless, future work should focus on quantifying and better describing these impacts. The key public health issues identified in this project are as follows:

- Impaired source water quality resulting from decreased dilution as well as sediment loading:
 - Bear Creek between the Evergreen wastewater facility and the Morrison intake experienced decreased flows (decreased dilution), and consequently increased concentration of pollutants in 2002. Fish were killed in the intervening reach, and Morrison was forced to issue a bottled water advisory (Norbeck, 2002).
 - In 2002, the Southern Ute Indian tribe had to shut off its water treatment plant intake on the Pine River because of post-fire mud and debris flows into the Vallecito Reservoir. Turbidity levels rose to 1,000 times higher than normal (Newsome, 2002).
 - Sediment-laden runoff caused concern about contamination from trihalomethane, a potentially carcinogenic compound that forms as a result of the interaction between chlorine, used in water treatment, and dissolved organic carbon, present in runoff from burnt areas.
 - To evaluate the effects of wildfire on water quality and downstream ecosystems in the Colorado Front Range, the U.S. Geological Survey initiated a study after the 2010 Fourmile Canyon fire near Boulder. The findings indicate that high intensity rainfall events in steep, burned watersheds are likely to move large amounts of potentially dangerous suspended and dissolved material into downstream water supplies.
 - Source-water-quality problems lasted more than five years after the 2002 Hayman fire west of Denver, Colorado (Rhoades and others, 2011) and nearly a decade after a wildfire in the Canadian Rockies (Emelko and others, 2011).
 - More recently with the 2011-2013 statewide drought, the effects of the Hewlett and High Park wildfires in 2012 were studied, with relation to water quality of the Poudre River and Seaman Reservoir. The study notes that sediment loading occurred, as well as increased issues with the conductivity, alkalinity, hardness, and pH imbalances of the water (Oropeza and Heath, 2013).

-
- Connections have been drawn in other areas of the world between low reservoir levels and mosquito borne diseases (e.g. West Nile Virus). This connection has not been thoroughly studied for Colorado but should be considered in future work given the state has experienced cases of this virus yearly since 2002, a major drought year (CDPHE, 2017; Shaman, Day, and Komar, 2010).
 - Decreased reservoir levels and increased temperatures can result in algae blooms:
 - In 2002, the water levels in Boyd Lake dropped below Greeley’s water intake line, and the city was forced to draw water from Loveland Lake, which was experiencing a large algae bloom. Many residents complained about the bad flavor of the water (Fanciulli, 2002).
 - Additional water treatment may be required as municipalities are forced to draw water from lower reservoir levels, which may contain higher levels of dissolved solids and have different properties that subsequently impact the treatment process:
 - For example, in the 2002 drought, the Mancos Rural Water Company experienced high mineral levels in their water caused by low water levels in Jackson Gulch reservoir. This resulted in lowered pH, which, when it went through the distribution lines, released mineral deposits from the inside of the pipes (Vaughan, 2002).
 - Increased bacteria loading in water bodies can pose public health risks for those engaging in water based recreation:
 - Viruses, protozoa, and bacteria can pollute both groundwater and surface water when rainfall decreases. Additionally, other infectious disease threats arise when drought leads to the contamination of surface waters and other types of water that are used for recreational purposes (CDC, 2012). During the 2002 drought, bacteria levels in Boulder Creek exceeded standards for recreational use. Officials believed the source of the bacteria was waste from wild animals and domestic pets, and that low water levels increased the concentration. In response to this hazard the city of Boulder placed signs around the creek warning that “unsafe bacteria levels in Boulder Creek may occur at any time” (Vaughan, 2002).
 - Air-borne particulate levels can climb when there are extended periods without rain. If levels get too high, some residents may experience respiratory complications:
 - In 2016, Metro Denver was ranked the 8th most ozone-polluted urban area in America by the American Lung Association. Fort Collins was 10th. Both cities saw a slight improvement in the 2017 rankings, when Denver moved from 8th to 11th and Fort Collins from 10th to 15th (CHI, 2017).
 - During the 2003 California wildfires, levels of PM_{2.5} (fine particulates less than 2.5 micrometers in size) increased to three to six times the EPA limit. Also coinciding with burn periods were significant increases in childhood and adult asthma, bronchitis, pneumonia, and cardiovascular disease hospital admission rates (Delfino, 2009).
 - Drought induced wildfires can significantly decrease air quality and lead to respiratory complications.
 - Smoke carries pollutants such as particulate matter (PM_{2.5}) in the air, increasing the risk of lung cancer, cardiovascular disease, asthma and chronic obstructive pulmonary disease (from which an estimated 180,000 Colorado adults already suffer) (CHI, 2017).

-
- Extreme heat affects cardiovascular and nervous systems
 - Warmer temperatures and low moisture content can cause heat stroke and dehydration. Colorado’s 1.2 million children are especially vulnerable, as they absorb more heat than adults because of their greater skin surface to weight ratio. In addition, the 711,000 seniors over age 65 are at increased risk due to chronic illness and age hindering their ability to regular body temperature (CHI, 2017)

As with the other impact categories for the Socioeconomic Sector, it is impossible to outline specific mitigation strategies without first understanding the specifics of the impacts. Future work should focus on quantitatively correlating drought conditions with impaired air quality and water quality. Understanding these relationships is an adaptive capacity as it allows the State to focus on locations of greatest concern. State health agencies need a clear understanding of the public health issues that could result from drought, and they need be prepared to respond with additional resources. Many water quality issues are currently handled by water service providers, however. Refer to the Municipal and Industrial Sector Annex for additional information on municipal adaptive capacities.

11.4 Measurement of Vulnerability

Impacts to the Socioeconomic Sector cannot be accurately divided into simple impact groups. As such, there are no subgroups analyzed individually. The main spatial density metric used to compare counties to one another and normalize results is total population. Impact metrics used to highlight vulnerability and consequently adaptive capacities from various lenses include the following metrics: projected population growth, economic diversity opportunities, and the Social Vulnerability Index (or SoVI), which is a ranking metric developed using census variables at the census tract level for use in emergency management (Cutter et al. 2003). Refer to Section 3.1 of Chapter 3 (Annex B) for more details on the general vulnerability assessment methodology.

11.5 Vulnerability Metrics

Spatial Density Metric

Total Population

All of the impacts covered for this sector have the potential to affect society as a whole, directly or indirectly, particularly if large populations are exposed to the vulnerabilities (e.g., farming and agricultural regions where people heavily depend on those industries). Therefore, total population was chosen as the spatial density metric. Future assessments will benefit from disaggregating based on potentially more or less vulnerable groups as well as geographies (e.g., high income, low income, young, old, etc.). Population estimates were obtained from the State Demographer’s Office, current for 2016.

Impact Metrics

Three metrics were selected to help assess socioeconomic impacts: projected population growth, economic diversity, and the SoVI. Population growth and economic diversity were both assigned weights of 40% and the SoVI was weighted 20%. The SoVI was weighted less than the other two because the information contained in census-level profiles is not always fully representative of people's actual vulnerabilities or adaptive capabilities. Also, this social vulnerability metric reflects existing circumstances, while future growth could result in other, potentially more relevant changes.

Projected Population Growth/Change

In a study examining social vulnerability to environmental hazards, it was noted that population growth is one of the social vulnerability characteristics most often cited in literature (Cutter et al. 2003). This study highlights how, for example, quality housing and social services often lag behind fast population growth. Also, new residents may not be familiar with the support systems in place, and may not be able to make use of the public or other resources available. All of these factors increase vulnerability. For our assessment, population projections for 2030 were obtained from the State Demographer's Office, and the percentage increase (or decrease) from the 2010 population was calculated. Counties with the lowest levels of projected growth, or with negative growth (between -13% and 4%) were given an impact score of 1, and then the remaining growth rate scores were assigned based on the overall distribution of results. Counties with population growth estimates in the 25th percentile received a score of 2, followed by the 50th and 75th percentiles with scores of 3 and 4, respectively. In the future, counties with negative growth rates should be investigated further, as this could be a sign of economic stagnation which may warrant a higher impact score.

Economic Diversity

Economic diversity is a good indicator of the susceptibility of the general population to impacts from specific sectors. Economic base data were obtained from 2015 reports from the State Demographer's Office website, by county. Percentage of jobs in "agricultural businesses" and "tourism" were calculated by dividing the sum of the two categories by the total economy. Counties were ranked according to percentiles, so that those falling in the lowest percentile would receive a score of 1, those in the second percentile of the total economy percentage get a 2, counties falling in the third percentile receive a 3, and those in in the top percentile, with the highest dependence on agribusiness and tourism jobs compared to their total economic base, would get a 4. Additional analysis using more detailed economic subsector data would be recommended in future assessments, to further differentiate these scores.

Social Vulnerability

General social vulnerability is a useful indicator because it highlights communities' capabilities, as well as the disparities that affect residents' overall resilience and ability to prepare, evacuate,

and recover from disasters (Wisner et al. 2004). Using the Social Vulnerability Index methodology developed by Cutter et al. (2003), the Colorado Division of Water Resources (DWR) Dam Safety Branch conducted a social vulnerability analysis at the census tract level for Colorado.

Local socioeconomic and demographic data were used to geospatially evaluate social vulnerability across the State.

Table 11.6 below outlines the social vulnerability indicators that were used in the Colorado social vulnerability analysis. Indicators with plus signs are positively related to social vulnerability levels. For example, communities with higher percentages of people 65 years or older have higher levels of social vulnerability to disasters. Indicators with minus signs are negatively related to social vulnerability levels, and hence those populations are less vulnerable.

Table 11.6 Social Vulnerability Indicators

Social Vulnerability Factors	Indicators
Age/Elderly	65 years or older, % population (+) People per household (+) Renter occupied, % of housing units (+) Social Security recipients, % population (+)
Special Needs	Group quarters, % population (+) Mobile homes, % occupied housing units (+) Under 18 years old, % population (+) Under 5 years old, % population (+)
Ethnicity	Hispanic, % population (+) Native American, % population (+) Other Races, % population (+) Pacific Islander, % population (+) Linguistically Isolated, % population (+)
Race, Class, Poverty	African American, % population (+) Female Headed Households, % households (+) No Vehicles, % households (+) No High School diploma, % over 25 years old (+) Poverty, % population (+) Unemployment Rate (+)
Wealth	Asian, % population (-) Household earnings > \$200K, % households (-) Housing Density (+) Per capita income (-) Population Density (+) White, % pop (-)

Source: U.S. Census Bureau, 2006-2010 American Community Survey, and the 2010 Census

The counties were ranked from highest social vulnerability to lowest. The top 25% of counties receive a “very high” social vulnerability score, correlating to an impact score of 4. “High” social vulnerability, “medium” social vulnerability, and “low” social vulnerability were assigned scores of 3, 2, and 1 respectively.

11.5.1 Results

As previously discussed, there are no sub-sectors for the Socioeconomic Sector. Therefore, the ratings from the individual impact metrics were mapped instead. Figure 11-5 through Figure 11-8 show the vulnerability ratings for the socioeconomic impact metrics used, along with the county populations (in the first three maps). In these visual representations, red shading corresponds to the impact ratings, while the size of the grey circles indicates the respective county populations. Figure 11-8 shows the overall socioeconomic sector vulnerability scores, combining the three impact metrics. Discussion of these maps is included in the following section

Figure 11-5 Population Growth Impact Score and Population Inventory by County

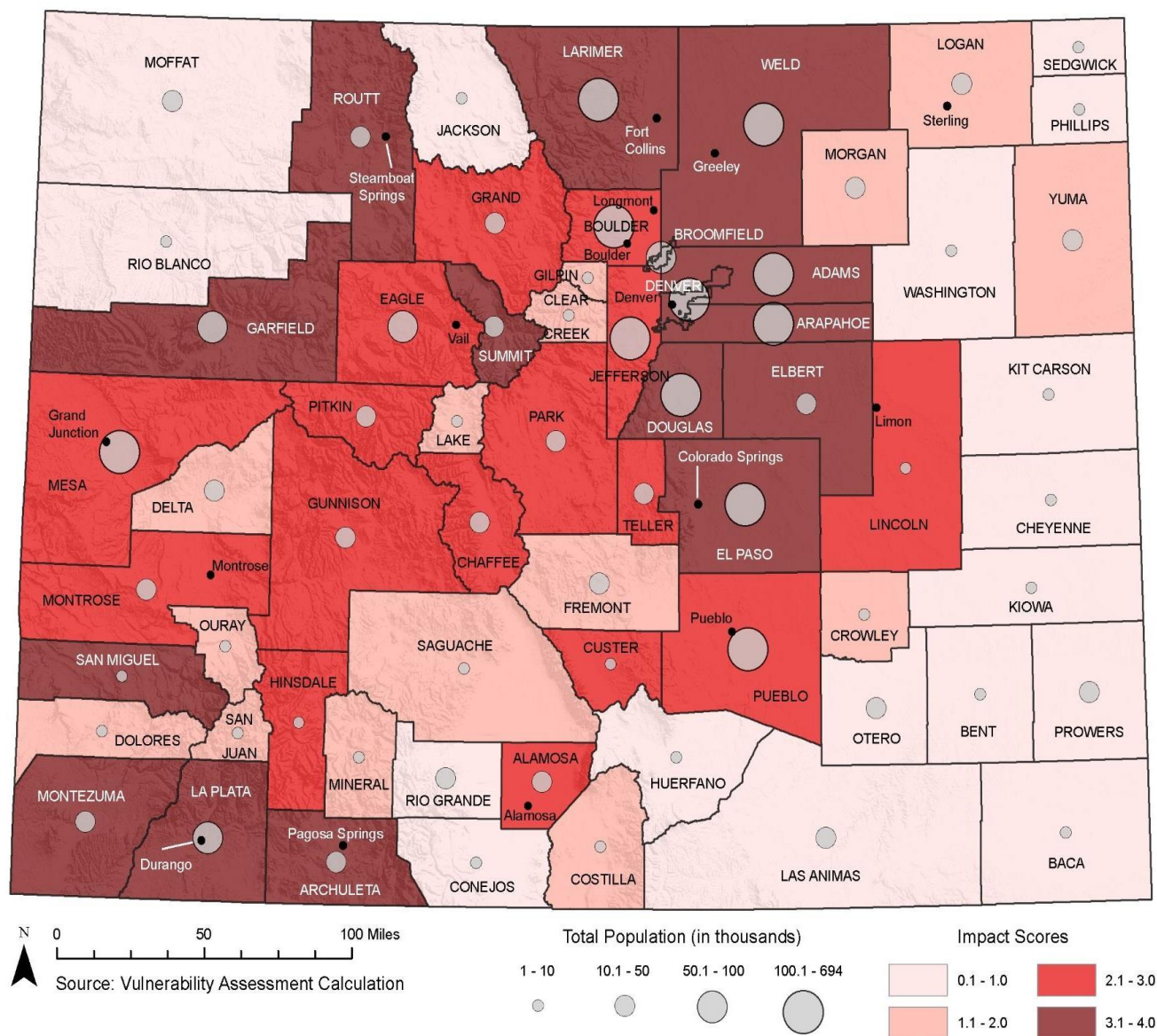


Figure 11-6 Economic Diversity Impact Score and Population Inventory by County

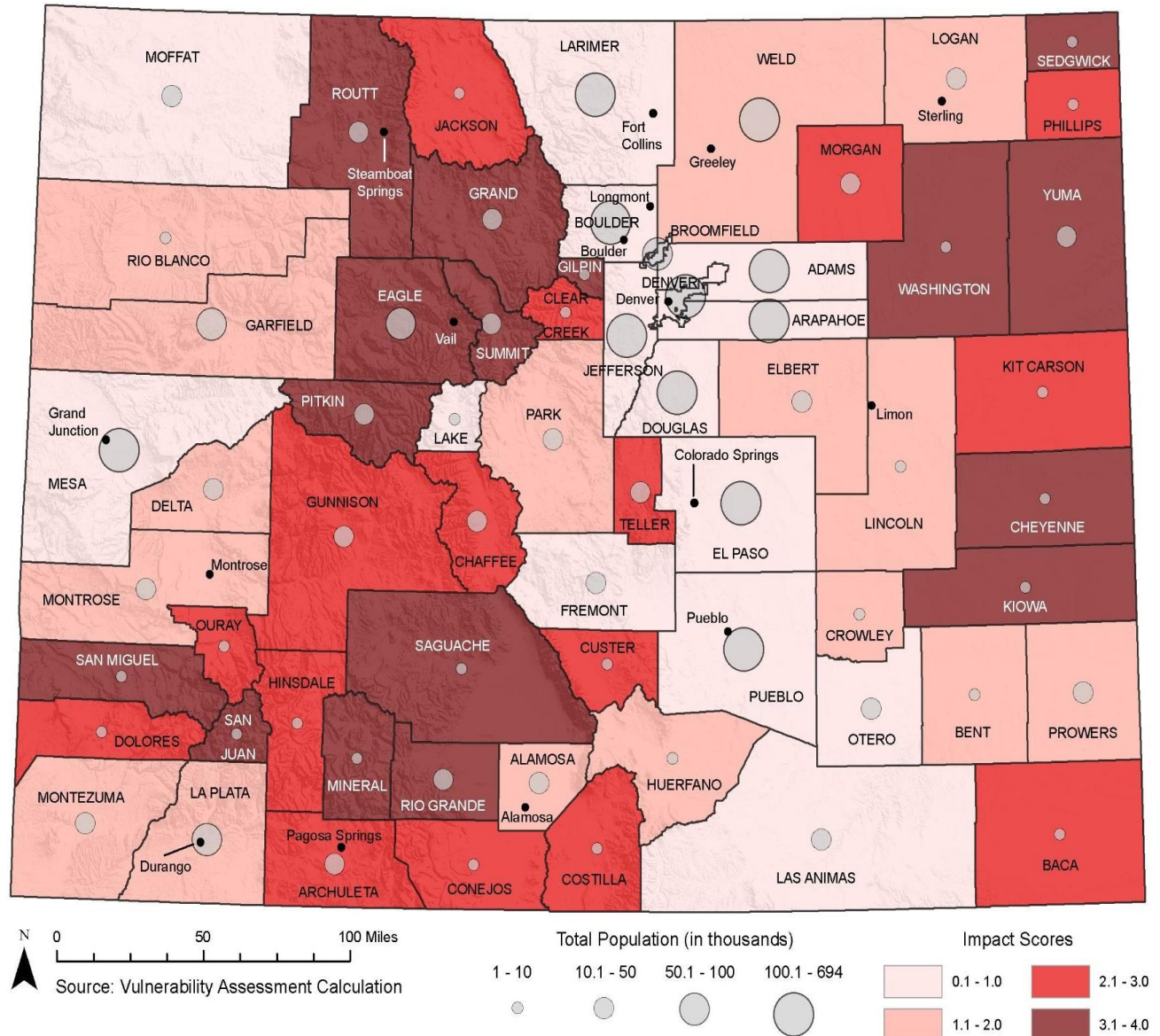


Figure 11-7 Socioeconomic Vulnerability Impact Score and Population Inventory by County

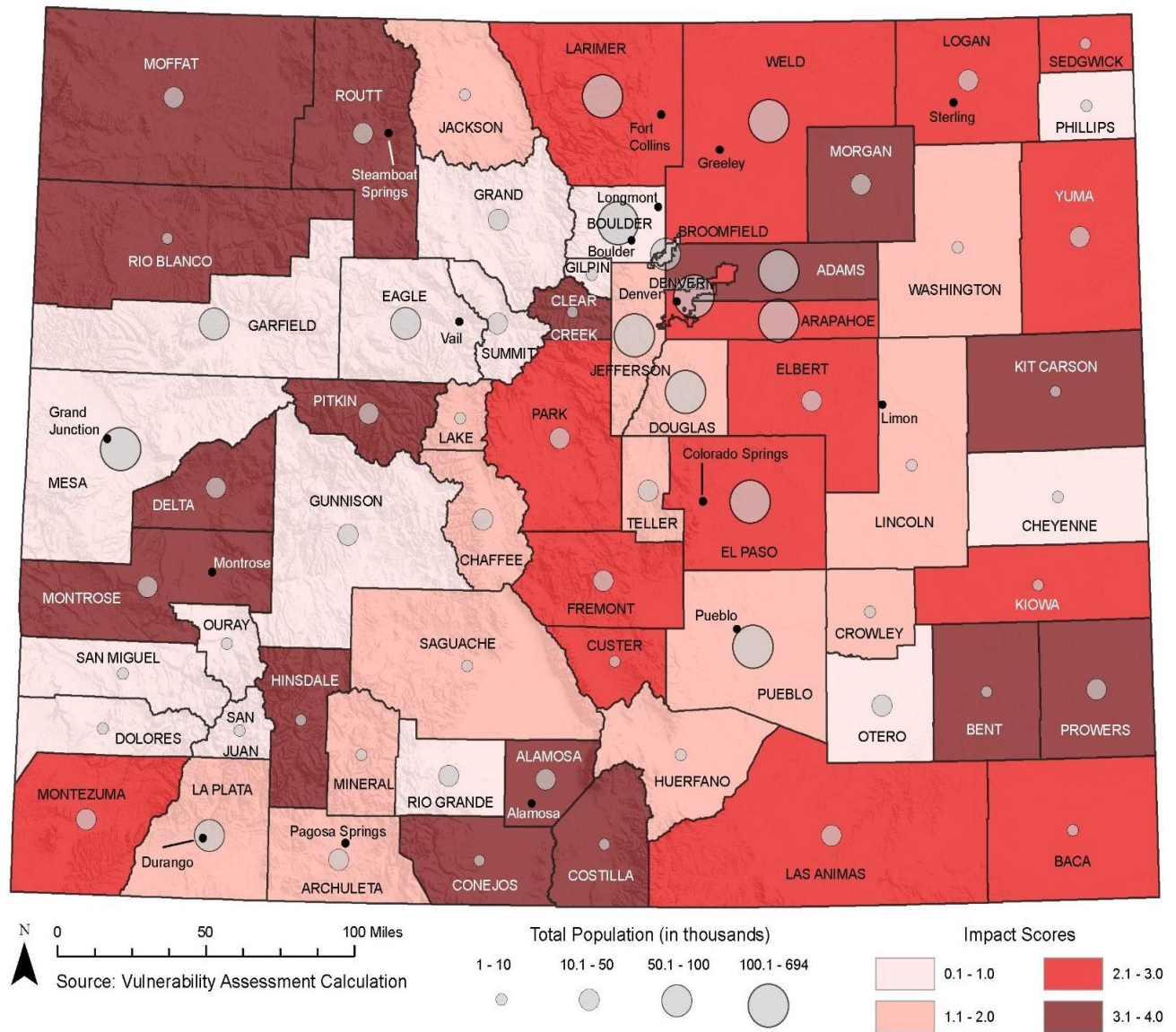
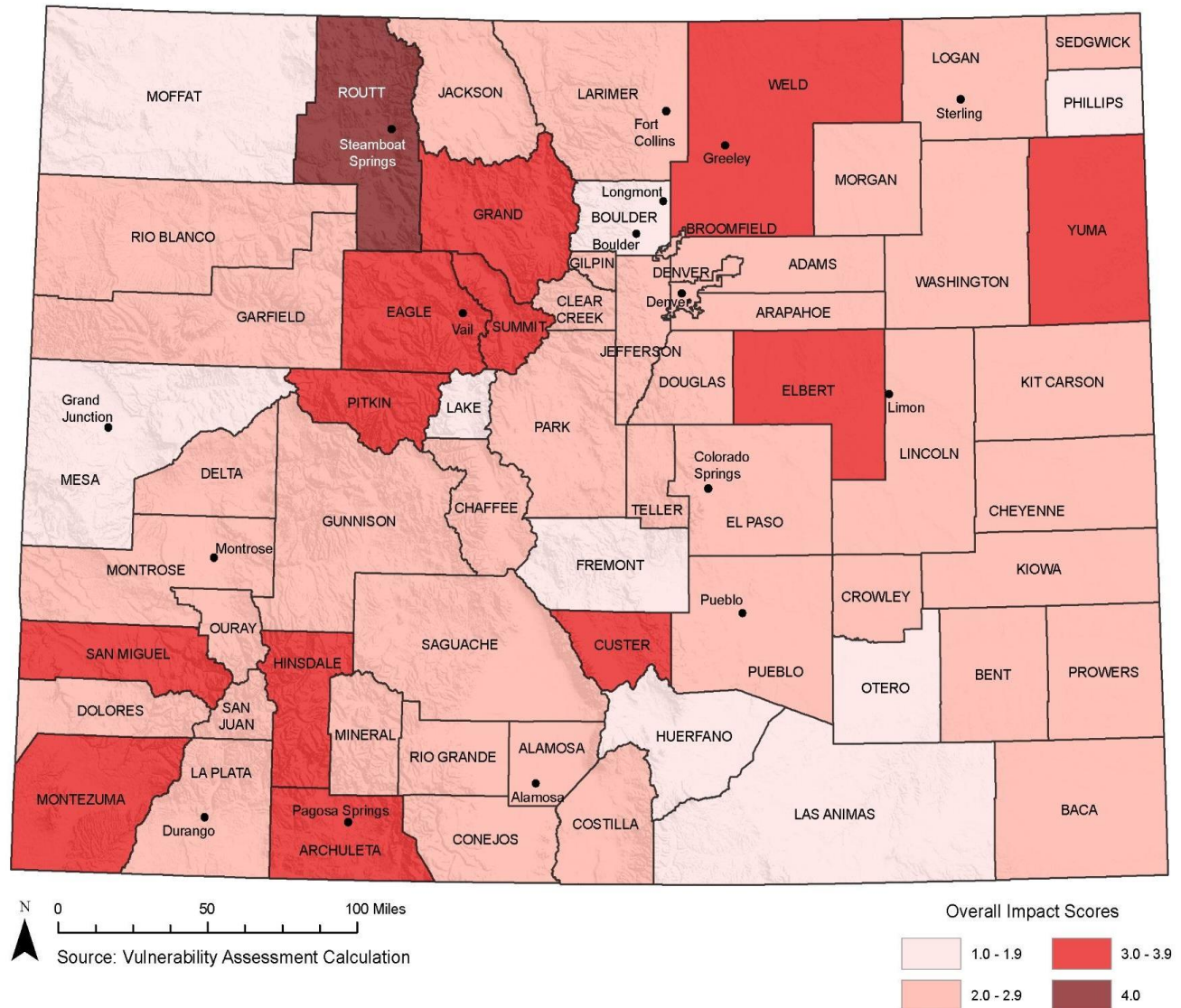


Figure 11-8 Overall Vulnerability Scores in the Socioeconomic Sector by County



11.5.2 Spatial Analysis

Figure 11-5 shows that population growth is expected throughout the state. There are 13 counties where population is anticipated to decrease between 2010 and 2030. With the exception of Jackson and Moffat, the counties with decreasing population numbers are all concentrated in the eastern plains and southeastern parts of the state. Counties along the Front Range and counties in the mountains and the southwest corner of the state have the highest growth forecasts. San Miguel and La Plata counties on the southwest, for instance, are expected to grow by almost 59% and 53%, respectively. However, a county like San Miguel is heavily based on agricultural and tourism-focused economies, as portrayed in Figure 11-6 (given its high impact scores). The growth projections combined with San Miguel's high dependence on vulnerable economies overall makes the county's socioeconomic vulnerability a pertinent issue.

Economic impact ratings were assigned based on the comparison of combined agriculture and tourism employment in relation to overall employment (so that counties heavily reliant on those two industries might be more vulnerable, due to low economic diversity). In this 2018 update, there were 16 counties identified as having low economic diversity, and therefore highest impact scores from this metric (portrayed in Figure 11-6). However, 29 counties were rated with a 1, for having a fairly diverse economy that may be less vulnerable to drought events affecting agriculture and tourism. Once again, while there is not a clearly defined trend in the location of high-ranking versus low-ranking counties in terms of their economic impacts, the Front Range and most populated counties tend towards the low-ranking scores, while several counties towards the east, central-southwest, and central-west seem to rank higher. The high degree of employment in the tourism sector is reflected especially in Gilpin, Eagle, and Summit Counties. Gilpin County is the home of numerous casinos and hotels. Eagle and Summit Counties encompass Arapahoe Basin, Copper Mountain, Breckenridge, Keystone, Loveland, Vail, and Beaver Creek ski resorts, which results in a large concentration of jobs in hospitality and outdoor recreation. Other high impact scores correspond to counties along the eastern plains, with local economies highly reliant on agriculture.

Figure 11-7 shows SoVI scores across the state. Counties with high concentrations of populations considered to have less resources available to respond to a disaster are highlighted. A large amount of the counties with “very high” SoVI scores (e.g., Costilla, Conejos, Bent, Prowers, Adams, Morgan) all have high numbers of Hispanic populations, as well as low-income and geographically isolated individuals (given these counties lie towards the edges and corners of the State). Additionally, Adams County, for example, falls in the “very high” vulnerability category, which reflects its urbanized characteristics such as high population and housing densities with significant numbers of renters, increasing unemployment, and residents who may not have access to amenities like vehicles. There does not seem to be a clear trend in the location of low ranking counties with regards to this impact metric, however.

Figure 11-8 shows the overall socioeconomic vulnerability scores. The highest overall ranking county is Routt, which increased its vulnerability by 43% since the 2013 assessment, largely due to the incorporation of the SoVI in the VAT analysis in the 2018 update. Routt suffers from impacts in all the metrics discussed, meaning that it is fairly reliant on agriculture and tourism, has a large socioeconomically vulnerable population base, and is expected to grow significantly by 2030. Some of the counties on the eastern plains, which have a high reliance on agribusinesses, and many of the central-west mountain counties, which rely on tourism and are projected to experience significant population growth, were ranked 3 in overall vulnerability. This includes Grand, Summit, Eagle, and Pitkin counties, which rely on skiing as a main tourist and recreation attraction. Many of the ski resorts are looking to diversify their economies by adding summer operations (e.g., lift-accessed mountain biking). However, most of the counties in Colorado show medium impact scores of around 2, although there is not a representative pattern in the spatial location of those counties. Future analysis is needed to determine if counties with low projected growth or even negative growth could result in increased vulnerability, as a declining population might be more at risk given reduced access to amenities or services commonly available in largely populated areas.

11.5.3 Compound Impacts

Compound impacts are secondary effects that result from changes in sectors directly impacted. Many of the economic vulnerabilities discussed in this sector are secondary impacts. Section 11.3 describes many of these connections in more detail. Economic impacts are compounding in nature and continue to propagate across the Socioeconomic Sector far beyond the direct drought impacts. Public health issues can translate directly to economic costs. Often the administrative cost of dealing with public health issues falls to the government. This can strain operating budgets and possibly divert funds from programs geared toward other sectors. There are also personal costs incurred to those affected. This could include the monetary cost of seeking treatment, time away from work, or lost income. These costs compound impacts already felt across the economy. The stress of financial strain, dealing with loved ones suffering from health issues, and uncertainty about the future can all result in additional compound impacts, increased vulnerability, or lower adaptive capacity during and after drought events.

11.6 Recommendations

11.6.1 Adaptation to Drought

Socioeconomic drought adaptation should come from cooperation and planning on individual business, community, regional, and statewide levels. Businesses big and small need to consider their operations and how clients and supply chains might be impacted. Long-term planning should take these drought adaptation and potential vulnerability impacts into account, and business operations should be designed to sustain strain during times of drought. An example of a measure that could be taken to fight drought and other hazards is instituting a resilience framework in communities and businesses, so that guidelines and coordination approaches may be in place before a disaster occurs. It is important to establish regional cooperation across sectors during non-drought conditions, so systems are already in place when a disaster occurs. Those who have the ability to be flexible and resilient will be the most adaptive to drought. Resilience and flexibility are easier to display for some groups than others, of course, but in most cases adaptive capacity can be improved by fostering cooperative relationships with other agencies and governments, leading to an increased understanding of the potential drought impacts as well as more capable decision making.

Many of the public health issues resulting from drought are coordinated by government entities. Statewide agencies should increase their understanding of societal impacts of drought and focus on collaborative opportunities to mitigate drought impacts. Social vulnerability analysis is particularly useful for drought planning because it can reveal disparities that affect the ability of residents to mobilize resources and alter their normal habits. The Colorado DWR social vulnerability assessment was designed to improve local decision making, hazard prioritization, and emergency management activities. Though drought usually does not involve widespread emergency response or evacuation planning, it exacerbates pre-existing inequities. For example, if a community has a disproportionately high number of low-income or cost-burdened residents,

drought can intensify conditions and make it increasingly challenging for already vulnerable people. By incorporating social vulnerability into the discussion, local communities are able to identify highly vulnerable areas and tailor their actions to include all residents, including the most sensitive and economically challenged groups. Once vulnerable populations have been identified, specific adaptive capacities can be developed for these communities. By working to assemble this information and incorporating drought into planning efforts, state agencies can improve their response capabilities. In conclusion, agencies should anticipate social issues resulting from drought events, and plan for additional resources during those times.

11.6.2 Improving Vulnerability Assessments

Data for drought-induced public health impacts in Colorado are lacking. Based on individual reports from the 2002 and 2011-2013 droughts in Colorado and studies carried out in other locations, there are clear connections between health and drought that should be further examined. Until these investigations are completed it is not possible to quantitatively or spatially identify public health hazards resulting from drought. A data collection framework should be created so that data on the potential public health impacts, such as those identified in Section 11.3, can be measured during future droughts.

The degree to which drought planning and business cooperation exists was not measured as part of this study. Cooperation efforts among the private sector could be analyzed as part of future work, so that adaptation capabilities already in place can be integrated as an adaptive capacity metric and analyzed accordingly.

The list below outlines possible data collection tasks identified through this study that could improve future vulnerability assessments. In some cases, these data may already exist but require some additional (often complex) manipulation to be used for these purposes. This is by no means an exhaustive list, but is intended to be a starting point for additional work. As previously noted, many of the socioeconomic drought relationships identified herein have not been rigorously tested in Colorado. As future work is completed, changes to vulnerability metrics and data collection tasks will naturally need to occur.

- Data on cross-sector cooperative economic groups
- Identification and mapping of industries most vulnerable to secondary drought impacts
- Spatial mapping of mosquito activity
- Analysis of the water bodies in the State that are most likely to have impaired water quality with drought
- Spatial and temporal details about air quality and related health warnings (e.g., blowing dust advisories, wildfire smoke) that can be correlated with respiratory-related hospital visits as a measure of drought impacts
- Analysis on the vulnerability of municipal water supplies to impaired quality
- Calculation of drought-induced cost increases per person, and related implications for low-income populations (in particular)

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- Assessments of the availability of drought preparedness, awareness, and educational materials aimed at general populations as well as public and private sectors

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CLIMATE CHANGE IMPLICATIONS

ANNEX C TO THE DROUGHT MITIGATION AND RESPONSE PLAN

August 2018

Prepared by
Colorado Water Conservation Board
Department of Natural Resources
in Cooperation with
The Department of Public Safety
Division of Homeland Security & Emergency Management
and the Drought Mitigation and Response Planning Committee

Table of Contents

1	Introduction	1
2	Placing Historical Conditions in Context: Past and Future	3
3	Other Climate Change Findings in Colorado	7
3.1	Colorado River Water Availability Study Phase I	7
3.1.1	Colorado River Water Availability Study Findings	7
3.1.1.1	Temperature	7
3.1.1.2	Precipitation	7
3.1.1.3	Crop Irrigation Requirement (based on acreage and crop types identified in a 1993 acreage inventory)	7
3.1.1.3.1	Crop Irrigation Requirement for Study Basins	8
3.1.1.4	Natural Flow	8
3.1.1.4.1	Historical Hydrology	8
3.1.1.4.2	Extended Historical Hydrology	8
3.1.1.4.3	In very general terms, locations with shorter historical spells should expect longer spells and vice versa	8
3.1.1.4.4	Climate-Adjusted Hydrology	8
3.1.1.4.5	Modeled Streamflow	9
3.1.1.4.6	Water Available to Meet Future Demands	9
3.1.1.4.7	Modeled Reservoir Storage	9
3.1.1.4.8	Modeled Consumptive Use	9
3.1.1.5	Colorado River Water Availability Study Technical Approach Summary	10
3.2	Colorado River Water Availability Study Phase II	21
3.2.1	Climate Model Background	22
3.2.1.1	Climate Scenarios	22
3.2.1.2	Change Factors	23
3.2.1.3	Historical Flows	24
3.2.1.4	Drought Analysis Results	25
3.2.1.5	Summary of Results	39
3.3	The Boulder Climate Change Study	41
4	Incorporating Climate Change into Planning	44
5	References	45

List of Tables

Table 1.1	Challenges Faced by Water Managers and Projected Changes.....	3
Table 2.1	Gauge Locations for Comparisons	4
Table 3.1	Colorado River near Cameo.....	12
Table 3.2	Yampa River near Maybell	13
Table 3.3	Gunnison River near Grand Junction	14
Table 3.4	San Juan River near Carracas	15
Table 3.5	Characteristics for CRWAS-I Future Climate Scenarios	23
Table 3.6	Characteristics for CRWAS-II Future Climate Scenarios	23
Table 3.7	Arkansas River Gages	25
Table 3.8	CRWAS-II Stations	26
Table 3.9	Drought Lengths, Boulder Creek Near Orodell (2030 Conditions)	43

List of Figures

Figure 2.1	Flow Comparison, Yampa River near Maybell	5
Figure 2.2	Flow Comparison, Arkansas River at Salida	6
Figure 3.1	Low Flow Comparison Chart, Colorado River near Cameo.....	16
Figure 3.2	Low Flow Comparison Chart, Yampa River near Maybell	17
Figure 3.3	Low Flow Comparison Chart, Gunnison River near Grand Junction	18
Figure 3.4	Low Flow Comparison Chart, San Juan River near Carracas	19
Figure 3.5	Average Monthly CIR Comparison.....	20
Figure 3.6	Vega Reservoir - 2040 Average Monthly Modeled Storage Contents.....	21
Figure 3.7	Map of Low Flow Stations.....	26
Figure 3.8	Low Flow Comparison Chart, Colorado River near Cameo.....	28
Figure 3.9	Low Flow Comparison Chart, Colorado River near State Line	29
Figure 3.10	Low Flow Comparison Chart, Dolores River at Bedrock.....	30
Figure 3.11	Low Flow Comparison Chart, Gunnison River near Grand Junction	31
Figure 3.12	Low Flow Comparison Chart, Los Pinos River at La Boca	32
Figure 3.13	Low Flow Comparison Chart, San Juan River near Carracas	33
Figure 3.14	Low Flow Comparison Chart, White River near Meeker	34
Figure 3.15	Low Flow Comparison Chart, Yampa River near Maybell	35
Figure 3.16	Low Flow Comparison Chart, Arkansas River at La Junta	36
Figure 3.17	Low Flow Comparison Chart, North Platte River near Northgate	37
Figure 3.18	Low Flow Comparison Chart, South Platte River at Julesburg	38
Figure 3.19	Low Flow Comparison Chart, Rio Grande at Wagon Wheel Gap	39
Figure 3.20	Summary of CRWAS-II Average Center (2050) Results	40
Figure 3.21	Summary of CRWAS-II Driest 2-year Center (2050) Results	41
Figure 3.22	Mean Monthly Flows for Base Case and Climate Change Scenarios, Boulder Creek Near Orodell.....	44

Appendix

Appendix 1: Flow Comparison Charts	1
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1 INTRODUCTION

The hydrology and water resources of Colorado, and hence the economy of the state, are extremely sensitive to climate. Multifaceted stress on water supply such as irrigation, municipal demands, mandated biological flows, and the increasing need for hydropower, coupled with climate variability and change, are increasing the importance of supply forecasting to both water managers and business markets. This section of the Colorado Drought Mitigation and Response Plan was motivated by the question “what could drought look like in the future.” What follows is a high level analysis of possible implications of climate change for drought in Colorado.

The International Panel on Climate Change (IPCC 2007) has indicated that projected changes in mean flow or flow variability could cause physical infrastructure to be inadequate for intended purposes, or increase the risk of failure of the water resource system under extremes of drought. While such risks may be somewhat buffered in large water systems by robustness and resilience in the design of the system, smaller systems may be extremely vulnerable under climate scenarios.

A significant body of work exists considering the effect of climate change on water availability in the western United States (refer to bibliography). While there is a large amount of uncertainty regarding future climate scenarios and how these may translate to physical conditions, it is clear that current climate is not stationary and responsible planning efforts should take into account this uncertainty. Planning approaches that rely on stationary climate and notions of hydrologic history repeating itself are inherently flawed. Water managers need to understand how the nature of drought might vary in the future and incorporate that understanding into their planning processes.

Climate change has implications both in terms of inter-annual droughts and intra-annual runoff patterns. Intra-annual spring warming can shift peak runoff earlier in the year; important for Colorado, where hydrology is driven by snowmelt. Furthermore, many studies agree that higher temperatures could lead to an increased ratio of precipitation falling as rain versus snow as well as a higher snowline, which reduces the natural storage effect of Colorado’s mountain snowpack (i.e., CWCB 2008, CWCB 2012, Knowles et al. 2006, Mote 2006, Saunders 2005, Udall 2007). Consequently, runoff could start earlier and end earlier. If this is the case, reservoirs would fill earlier, and what could not be stored in the spring and early summer would be spilled when agricultural demands are not as great as they are later in the summer. Decreased runoff in the summer would result in additional reservoir drawdown, and many studies agree that higher temperatures and lower precipitation during summer months would further increase agricultural demands, thus causing even more stress on reservoir storage (CWCB 2008, CWCB 2012). These factors could reduce the amount of water available for year-to-year carryover storage, thus increasing drought vulnerability.

The effects of climate change are not expected to be spatially consistent across the state. For example, there may be areas that receive additional moisture even in a “drier” climate.

The Colorado Water Conservation Board commissioned a synthesis report summarizing climate change science as it relates to Colorado's water supply (CWCB 2008). Some of their key findings are copied below. Regional studies suggest a reduction in total water supply in Colorado by the mid-21st century. Temperature increases and the resulting changes in evaporation and soil moisture will also add to a trend of decreasing runoff for most of Colorado's basins (CWCB 2008). However, when all of the available climate projections are considered, about one-third indicate no change or an increase in average streamflow in the Upper Colorado River Basin (i.e. at Lees Ferry Arizona). (Harding et al., 2012)

- In Colorado, temperatures increased about 2° F from 1977-2006. All regions examined within the state warmed during this time period, except the far southeast corner, in which there was a slight cooling trend.
- Climate models project Colorado will warm 2.5° F (+1.5° F to +3.5° F) by 2025, relative to the 1950-1999 baseline, and 4° F (+2.5° F to +5.5° F) by 2050. The 2050 projections show summers warming by 5° F (3° F to 7° F). These projections also suggest that typical summer monthly temperatures will be as warm as or warmer than the hottest 10% of summers that occurred between 1950 and 1999.
- Winter projections show fewer extreme cold months, more extreme warm months, and more strings of consecutive warm winters. Typical projected winter monthly temperature, although significantly warmer than current, are between the 10th and 90th percentiles of the historical record. Between today and 2050, typical January temperatures of the Eastern Plain of Colorado are expected to shift northward by ~150 miles. In all seasons, the climate of the mountains is projected to migrate upward in elevation, and the climate of the Desert Southwest to progress up into the valleys of the Western Slope.
- Projections show a precipitous decline in lower-elevation (below 8,200 ft) snowpack across the western part of the state by the mid-21st century. Modest declines are projected (10-20%) for Colorado's high-elevation snowpack (above 8,200 ft) within the same timeframe.
- Between 1978 and 2004, the spring pulse (the onset of streamflow from melting snow) in Colorado has shifted earlier by two weeks. Several studies suggest that shifts in timing of streamflows are related to warming spring temperatures. The timing of runoff is projected to shift earlier in the spring, and late-summer flows may be reduced. These changes are projected to occur regardless of changes in precipitation.
- Throughout the western part of the state, less frequent and less severe drought conditions have occurred during the 20th century than revealed in the paleoclimate records over the last 1,000 years. Precipitation variations are the main driver of drought in Colorado and low Lake Powell inflows, including the recent drought of 2000-2007, and these variations are consistent with the natural variability observed in long-term and paleoclimate records. However, warming temperatures may have increased the severity of droughts and exacerbated drought impacts.

The drought vulnerability assessment conducted for this project considers vulnerability to drought in a contemporary sense. However, the climate change implications noted above could exacerbate future drought vulnerability for a broad array of water users. Table 1.1 outlines the connection

between climate change and water management issues. As can be seen from this table, impacts touch nearly every sector covered in the vulnerability assessment.

Table 1.1 Challenges Faced by Water Managers and Projected Changes

Issues	Observed and/or Projected Change
Water demands for agriculture and outdoor watering	Increasing temperatures raise evapotranspiration by plants, lower soil moisture, alter growing seasons, and thus increase water demand.
Water supply infrastructure	Changes in snowpack, streamflow timing, and hydrograph evolution may affect reservoir operations including flood control and storage. Changes in the timing and magnitude of runoff may affect functioning of diversion, storage, and conveyance structures.
Legal water systems	Earlier runoff may complicate prior appropriation systems and interstate water compacts, affecting which rights holders receive water and operations plans for reservoirs
Water quality	Although other factors have a large impact, “water quality is sensitive both to increased water temperatures and changes in patterns of precipitation” (CCSP SAP 4.3, p. 149). For example, changes in the timing and hydrograph may affect sediment load and pollution, impacting human health.
Energy demand and operating costs	Warmer air temperatures may place higher demands on hydropower reservoirs for peaking power. Warmer lake and stream temperatures may affect water use by cooling power plants and other industries.
Mountain habitats	Increasing temperature and soil moisture changes may shift mountain habitats toward higher elevation.
Interplay among forests, hydrology, wildfires, and pests	Changes in air, water, and soil temperatures may affect the relationships between forests, surface and groundwater, wildfire, and insect pests. Water-stressed trees, for example, may be more vulnerable to pests.
Riparian habitats and fisheries	Stream temperatures are expected to increase as the climate warms, which could have direct and indirect effects on aquatic ecosystems (CCSP SAP 43.), including the spread of instream non-native species and diseases to higher elevation and the potential for non-native plant species to invade riparian areas. Changes in streamflow intensity and timing may also affect riparian ecosystems.
Water – and snow – based recreation	Changes in reservoir storage affect lake and river recreation activities; changes in streamflow intensity and timing will continue to affect rafting directly and trout fishing indirectly. Changes in the character and timing of snowpack and the ratio of snowfall to rainfall will continue to influence winter recreational activities and tourism.
Groundwater resources	Changes in long-term precipitation and soil moisture can affect groundwater recharge rates; coupled with demand issues, this may mean greater pressure on groundwater resources.

Source: Reproduced from CWCB, 2008

2 PLACING HISTORICAL CONDITIONS IN CONTEXT: PAST AND FUTURE

As a component of the 2013 update to this Plan, projections of future streamflow were obtained for a number of locations in the Colorado, South Platte and Arkansas River basins from the Colorado River Water Availability Study (CRWAS) and the Joint Front Range Climate Change Vulnerability Study (Front Range Study, WRF, 2012). Reconstructions of prehistoric (“paleo”) flows have been made for a large number of stream gauges in Colorado (NOAA, 2013). Sixteen locations were selected where both climate change projections and prehistoric reconstructions exist. These locations, and the sources of data for the comparisons, are shown in Table 2.1.

Table 2.1 Gauge Locations for Comparisons

BASIN	PALEO GAGE	PROJECTED GAGE	
		CRWAS	JFRCCVS
Upper Arkansas			
Arkansas	Arkansas River near Canon City (07096000)	-	UC_Ark_Salida 07091500
Colorado			
Animas	Animas River at Durango, CO (09361500)	ARDUR 9361500	-
Blue	Blue River above Green Mountain Reservoir (09053500)	BRBGM 9057500	UC_GreenMountain 9057500
Colorado	Colorado River near Kremmling, CO (09058000)	CRKRE 9058000	-
Dolores	Dolores River near Cisco, UT (09180000)	DRGAT 09179500	-
Fraser	Fraser River at Granby (09034000)	-	UC_Fraser 09034000
Roaring Fork	Roaring Fork at Glenwood Springs, CO (09085000)	RFGWS 09085000	-
San Juan	San Juan River near Archuleta, NM (09355500)	SJRAR 09355500	-
White	White River near Watson, UT (09306500)	WRCUT 09306395	-
Yampa	Yampa River near Maybell, CO (09251000)	YRMBL 09251000	-
South Platte			
Big Thompson	Big Thompson River at Mouth of Canyon near Drake (06738000)	-	SP_BigThompson 6738000
Boulder Creek	Boulder Creek at Orodell	-	SP_BoulderCreek
Cache la Poudre	Cache la Poudre River at Mouth of Canyon (06752000)	-	SP_Poudre 06752000
South Platte	South Platte River at South Platte (06707500)	-	SP_SouthPlatte
South Platte	South Platte River below Cheesman Reservoir	-	SP_Cheesman
St. Vrain	St. Vrain Creek at Canyon Mouth near Lyons	-	SP_StVrain

At these locations, graphical comparisons of prehistoric, historical, and projected flows were developed that provide context within which to consider the 56-year period experienced from 1950 through 2005. Figure 2.1 shows the comparison for the Yampa River near Maybell. The 56-year running average of the paleo data is the solid blue line. The end of the solid blue line represents average conditions over the most recent 56 years. The dashed lines show the averages for each climate-impacted flow scenario. The highest and lowest 56-year average flows in the prehistoric data encompass most of the climate impacted flow averages, with the exceptions of the warm, wet scenarios for both 2040 and 2070.

Figure 2.2 shows the comparison for the Arkansas River at Salida. In contrast to the Yampa, the prehistoric flows show much less variability, and all but one of the projected scenarios fall outside the maximum and minimum flows of the prehistoric reconstruction. Also in contrast to the Yampa, six of the eight projected scenarios fall below the historical average flow (indicated by the end of the blue trace). This difference is indicative of a trend that is generally apparent in the CRWAS and Front Range Study results, where projections of future flows tend to be wetter in the northernmost portions of the State, and tend to be drier in the more southerly portions of the State.

Figure 2.1 Flow Comparison, Yampa River near Maybell

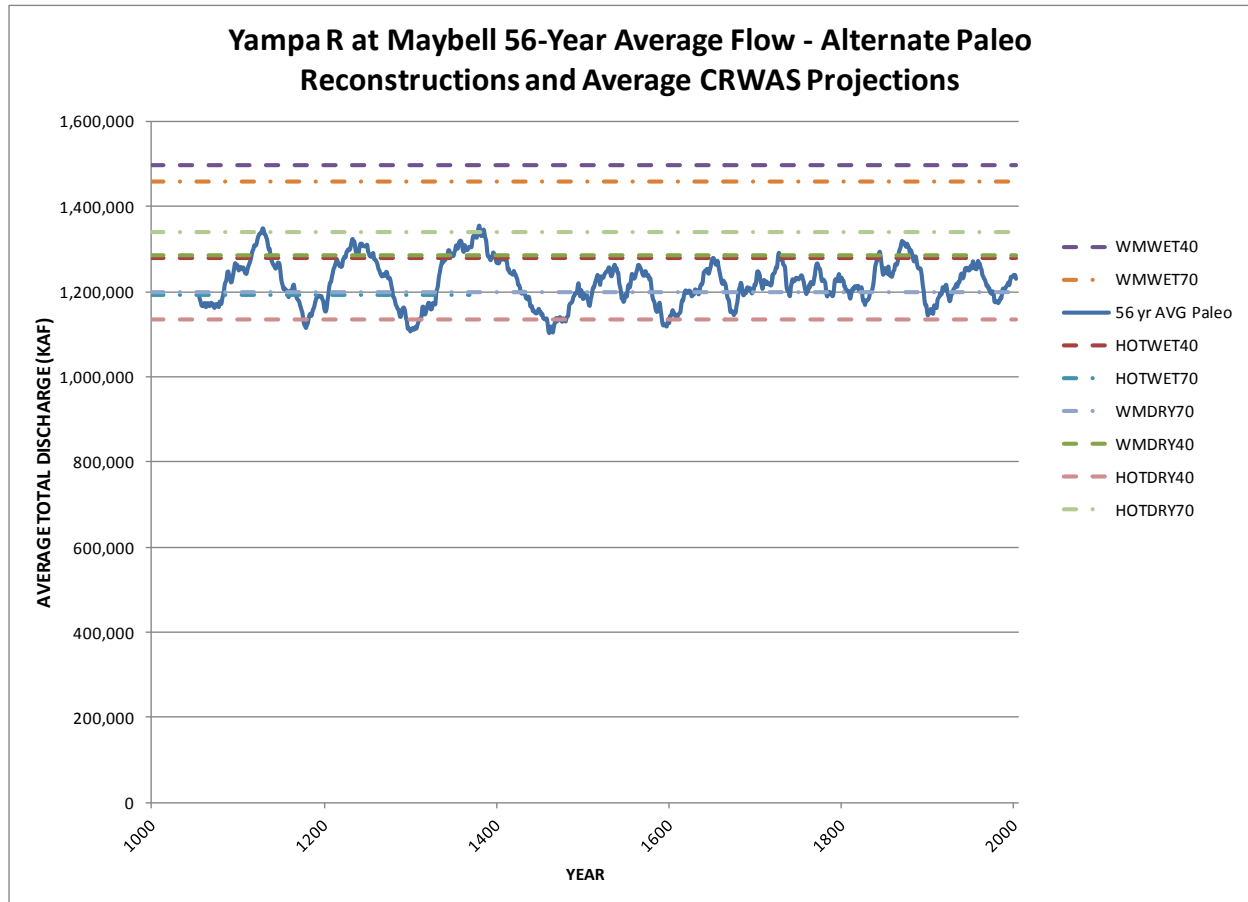
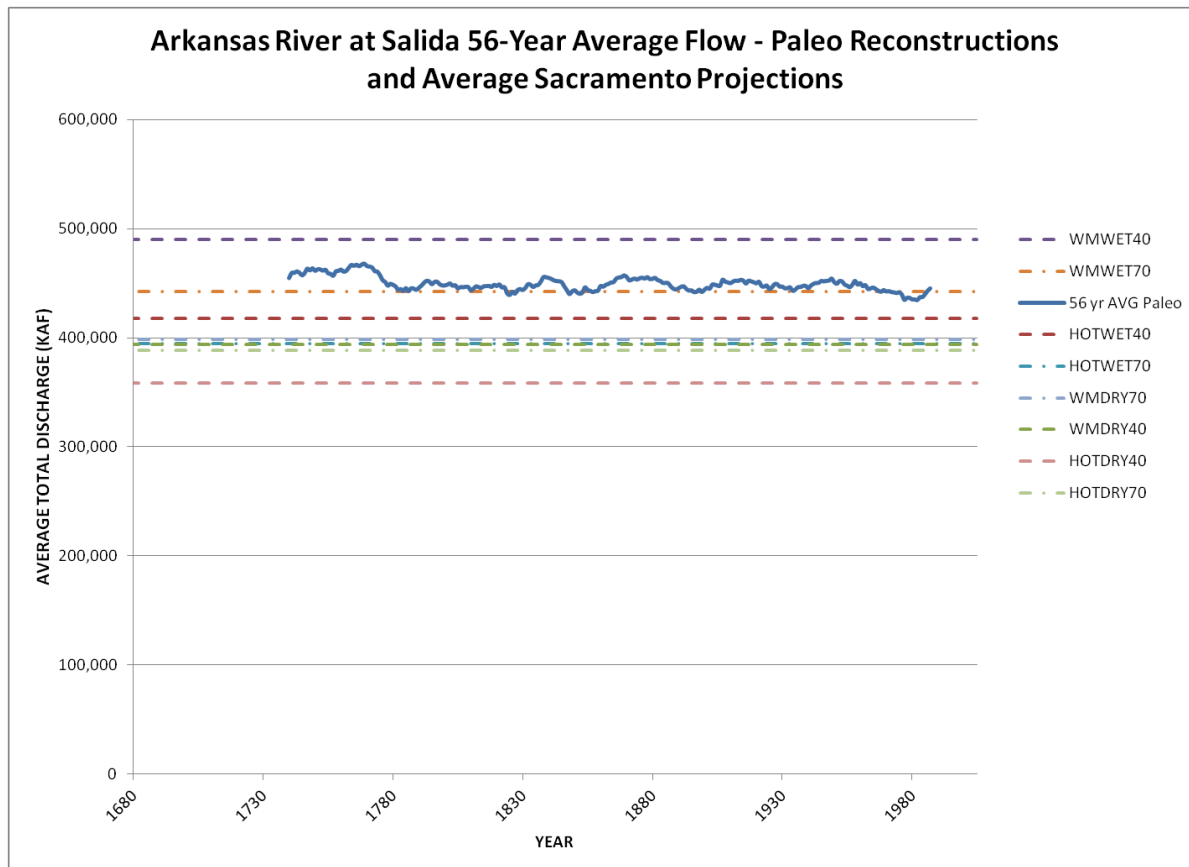


Figure 2.2 Flow Comparison, Arkansas River at Salida



Comparisons for all sixteen locations can be found in Appendix 1 to this Annex. The comparisons can be used to better understand the degree to which projected, climate-impacted streamflows differ from historical and prehistoric conditions. Because there is greater scientific confidence in the quantification of prehistoric flows than in the quantification of projected flows, there is a better scientific basis to support adaptation measures based on the variability of prehistoric flows. In the case of the Yampa, a system that performs acceptably over the range of prehistoric flows can be expected (within the limits of our current state of knowledge) to be reasonably well-adapted to future climate. In contrast, on the Arkansas, most of the projections fall outside the range of the prehistoric flows, and therefore decisions regarding adaptation must primarily consider the projections of future flow in order to develop management strategies that will meet future needs.

It is important to keep in mind that these comparisons use 56-year average flows. Annual droughts and multi-year dry spells will be superimposed on the average flows, so the curves and projections do not represent the most severe conditions that may face a system.

3 OTHER CLIMATE CHANGE FINDINGS IN COLORADO

3.1 Colorado River Water Availability Study Phase I

The Colorado River Water Availability Study (CRWAS Phase I), sponsored by the Colorado Water Conservation Board, investigated water availability on the Colorado River under a range of climate change scenarios. The Study Area for this work was the Colorado River Basin within the State of Colorado.¹ The methods are discussed in more detail in the following section. The discussion below outlines the primary findings of this study based on climate projections for 2040.

3.1.1 Colorado River Water Availability Study Findings

Compared to current conditions, CRWAS Phase I findings show that projected future climate conditions may lead to the following changes to hydrologic conditions in the Colorado River basin within western Colorado.

3.1.1.1 Temperature

- At northern climate stations (e.g., Grand Lake, Yampa, and Hayden), temperature increase is less than for the Study Area average.
- Every climate projection shows an increase in average annual and monthly temperature
- Study Area average annual increases range from 1.8°F to 5.2°F

3.1.1.2 Precipitation

- Generally increases in the winter months and decreases in the summer months
- Average winter increases are larger in the northern portion of the Study Area, and smaller in the southwestern portion of the Study Area
- Increase in temperatures causes a shift from snow to rain in the early and late winter months
- Study Area winter average changes by 102% to 116% of historical
- Study Area April through October average changes by 82% to 105% of historical

3.1.1.3 Crop Irrigation Requirement (based on acreage and crop types identified in a 1993 acreage inventory)

- Increases for each of the climate projections throughout the Study Area
- Increases are primarily due to higher temperature and lower irrigation-season precipitation, which increase:
 - the number of days in the growing season for perennial crops, and
 - the crop demand for irrigation water
- Peak CIR continues to occur in the same month as it has historically

¹ The CRWAS also evaluated the impact of climate change on streamflows at Lee's Ferry on the Colorado River.

-
- Study Area average annual CIR increases by 1.9 to 7.4 inches for individual climate scenarios
 - Study Area average annual growing season increases by 8 to 32 days

3.1.1.3.1 *Crop Irrigation Requirement for Study Basins*

- Every Study Basin shows an increase for all climate scenarios
- The White River basin shows the largest percentage increase
- The Yampa River basin shows the smallest percentage increase

3.1.1.4 Natural Flow

3.1.1.4.1 *Historical Hydrology*

- The longest (historical) wet spells range from 4 to 16 years in length, with only 4% longer than 7 years
- Historical dry spells range from 3 to 11 years in length with 95% being 5 or 6 years long
- Moving from north to south, historical dry spells generally become shorter and historical wet spells generally become longer
- The alternative historical flow analysis indicates that the return intervals for dry spells generally become shorter moving from north to south, meaning that droughts are more frequent in southern Colorado

3.1.1.4.2 *Extended Historical Hydrology*

- The return interval of historical wet and dry spells vary widely from location to location
- Return intervals are shorter for locations that have shorter historical spells and longer for locations that have longer historical spells
- At 90% of the sites, the return interval of the historical dry spell ranges from about 8 to about 200 years, and the return interval of the historical wet spell ranges from about 13 to about 100 years

3.1.1.4.3 *In very general terms, locations with shorter historical spells should expect longer spells and vice versa*

3.1.1.4.4 Climate-Adjusted Hydrology

- At over 80% of the sites, the majority of climate cases suggest a decrease in annual flow
- Annual flow is more likely to increase in parts of the Yampa River basin and in some higher elevation watersheds
- Annual flow is more likely to decrease in southwestern watersheds and at lower elevations
- At 75% of locations, all climate cases showed a shift toward earlier runoff, and at all locations, some climate cases showed a shift toward earlier runoff
- Higher peak flows may be beneficial for riparian health; however, lower flows in late summer and fall may impact other non-consumptive needs

-
- At three locations, all climate cases showed increases in average annual flows. At the remaining 224 locations, the climate cases contained the historical average annual flow
 - Runoff shifts earlier by an average of 8 days

3.1.1.4.5 Modeled Streamflow

- Flows are generally higher than historical in May and June and lower in July through March
- Flows are generally lower than historical in three of the five climate projections, but generally higher than historical in two projections
- The historical annual low-flow values generally fall within the range of projected low-flow values

3.1.1.4.6 Water Available to Meet Future Demands

- Upstream locations on main rivers and smaller tributaries generally have less flow available to meet future demands as a percent of modeled streamflow than gages farther downstream that include more tributary inflow
- Most locations show less water availability for three of the five climate projections. However, for one of the projections, the locations selected to display CRWAS Phase I results show more water available
- The climate projections generally indicate more water availability in April and May, corresponding to the shift in the natural flow hydrographs
- The historical annual minimum water availability values generally fall within the range of projected minimum water availability values for 2040 throughout the Study Area

3.1.1.4.7 Modeled Reservoir Storage

- Earlier peak runoff, reduced flows during the peak irrigation season, and increased crop demands result in more use of reservoirs (more reservoir fluctuation)
- Reservoirs are generally drawn down to lower levels, and generally fill to historical levels

3.1.1.4.8 Modeled Consumptive Use

- Average annual consumptive use in the Yampa, White, Upper Colorado, and Gunnison basins is greater for every climate projection. Average annual consumptive use in the San Juan basin is less for every climate projection
- Total consumptive use for the Study Area is greater than for historical climate conditions for most climate projections
- Although modeled consumptive use generally increases, not all crop demands are met in any basin. Similar to historical conditions, there continue to be water shortages on tributaries and in the late irrigation season for the projected conditions
- Projected consumptive use increases in most months in every basin except the San Juan. Projected consumptive use in the San Juan generally increases in spring months only

Phase I of the CRWAS considered five climate change scenarios, all treated as if they were equally probable. Temperature and precipitation changes from Global Climate Models (GCMs) were translated to natural flows using the Variable Infiltration Capacity (VIC) model. The historical hydrology used for comparison is the observed flow over the 56-year period from 1950-2005. Additionally, historical streamflow records were extended using previously published tree ring records dating back more than 1,200 years. The 56-year historical hydrology was re-sequenced into 100 equally likely 56-year traces based on the probabilities of transitioning between wet and dry years that were derived from the paleohydrology record. These traces are called the alternate historical hydrology traces in this report. The discussion in the following section outlines the technical approach of the CRWAS in more detail. The results of the CRWAS include information about how projected future climate might affect drought duration, drought intensity and drought frequency.

The CRWAS analyzed drought frequency and intensity compared to the longest drought observed throughout the 56-year period of record. Modeled natural flow results from each of the five equally likely climate change scenarios and the historical hydrology were each re-sequenced to produce a record 5,600 years long, equivalent to 100 equally likely 56-year hydrology traces. Drought durations and intensities (the degree to which flows are reduced during the drought) were calculated for each of the 100 traces. Drought conditions were defined as any time flow drops below the historical mean flow.

All of the droughts identified for each of the six scenarios (five climate change scenarios and the alternate historical hydrology) were used to calculate the return interval and the intensity of a dry or wet spell that has the same length as the longest spell experienced during the historical period. This approach answers the question: What is the likelihood that a spell of a particular length will begin next year (now, or in 2040 or 2070)?

3.1.1.5 Colorado River Water Availability Study Technical Approach Summary

- Historical Hydrology includes hydrology observed for period 1950-2005.
- Paleohydrology is based on an extended record dating to AD 762 (more than 1,200 years ago)
 - Provides estimated streamflow duration/frequency/intensity for years prior to gaged data.
 - Estimated using statistical models applied to tree ring data.
 - Paleohydrology flow magnitudes are derived from the historical flow record (1950-2005).
 - Flow sequences are derived from paleohydrology flow record to provide more robust variety of year to year flow sequences than historical record.
 - Re-sequencing – Future sequences of wet and dry years cannot be predicted; therefore, a 5,600-year hydrologic trace was developed.
 - This is statistically equivalent to the 100 56-year traces used for modeling in CRWAS.
 - Each 56-year period in the 5,600-year trace is equally probable.
- Climate-Adjusted Hydrology is based on five climate projections selected in consultation with the State's Climate Change Technical Advisory Group.

-
- Five climate projections were chosen for each of the 2040 and 2070 planning horizons.
 - Each of the selected climate projections is treated as being equally probable; but differs from the others.
 - Projections are “downscaled” to the Colorado River basin and temperature and precipitation changes were translated into effects on hydrology using the VIC hydrologic model. Flow sequences (dry/wet spells) were derived from those used in the paleohydrology flow record because it has been shown in the literature that GCM’s alone do not simulate flow sequences reliably.

Selected results from CRWAS are displayed in Table 3.1 through Table 3.4 and Figure 3.1 through Figure 3.6. Results for 42 sub-basins and selected weather stations and reservoirs may be found in Appendix C of the CRWAS final report (CWCB 2012a).

Table 3.1 through Table 3.4 present the characteristics of spells for the observed period, the Extended Historical Hydrology (EHH, labeled as Alternative Historical) and the Climate-Adjusted Hydrology (CAH) (CWCB, 2012a, Appendix C).

The observed spells are characterized in the top panel of the table. For example, for the Colorado River near Cameo (Table 3.1), the observed drought (during the period 1950 through 2005) was six years in length and, for those six years, the flow was, on average, 19 percent below the long-term mean flow. Similarly, the observed surplus was five years in length and flows were 46 percent greater than the mean during that period.

The statistics of the EHH (developed by re-sequencing) are shown in the first row of the bottom panel (Alternative Historical). The results in Table 3.1 show that droughts of six years in length returned every 31 years and surpluses of five years in length returned every 19 years. The average drought intensity for six-year droughts was -24 percent, somewhat greater than the historical intensity (-19 percent). The average intensity of surplus spells of five years in length was 27 percent, less than the historical intensity (46 percent).

The statistics for the CAH are in the ten rows below the statistics for the EHH in the lower panel. The first five rows are the results for the projections for 2040 while the next five rows are the results for the projections for 2070. Because the CAH and the EHH are based on the same year sequences, it is best to compare those two results rather than trying to compare the CAH to the historical observed event. On that basis, in Table 3.1, the 2040 time frame cases A, B and C show more frequent six-year droughts than is the case in the EHH; cases D and E show droughts that are less frequent. For 2070, cases F and G show six-year droughts that are substantially more frequent than the EHH, cases H and I show 6-year droughts that are approximately as frequent as in the EHH, and case J shows droughts that are substantially less frequent. For the 2040 time frame, cases A, B and C show five-year surpluses that are less frequent than was the case in the EHH, case D shows 5-year surpluses that are approximately as frequent as the EHH, and case E shows 5-year surpluses that are substantially more frequent than the EHH. For the 2070 time frame, cases F, G and H show five-year surpluses that are less frequent than was the case in the EHH, case I shows

5-year surpluses that are approximately the same frequency as in the EHH, and case J shows more frequent surpluses than in the EHH. Deficit intensities vary from case to case, but not by a large amount except for cases E and J; surplus intensities vary over a wider range.

When a spell of a length equal to or exceeding the historical spell is not encountered in a particular climate case, this is designated by a double dash in the return interval and intensity fields. For example, in Table 3.2, Yampa River near Maybell, a drought of six years in length was not encountered in climate case J for 2070.

Table 3.1 Colorado River near Cameo

	Observed Spells			
	Length of Spell (years)		Intensity of Spell (% of mean)	
	Drought	Surplus	Drought	Surplus
	6	5	-19%	46%

Alternative Hydrology Spells				
Case	Return Interval of historic spell length (years)		Average Annual Deficit/Surplus (% of mean)	
	Drought	Surplus	Drought	Surplus
Alternative Historical	31	19	-24%	27%
2040 Climate A	6	933	-30%	23%
2040 Climate B	27	47	-29%	19%
2040 Climate C	22	49	-28%	18%
2040 Climate D	53	20	-25%	29%
2040 Climate E	800	6	-19%	36%
2070 Climate F	6	5600	-31%	24%
2070 Climate G	12	267	-31%	18%
2070 Climate H	27	66	-32%	17%
2070 Climate I	30	22	-23%	27%
2070 Climate J	127	13	-19%	38%

Table 3.2 Yampa River near Maybell

	Observed Spells			
	Length of Spell (years)		Intensity of Spell (% of mean)	
	Drought	Surplus	Drought	Surplus
	6	5	-26%	48%

Alternative Hydrology Spells				
Case	Return Interval of historic spell length (years)		Average Annual Deficit/Surplus (% of mean)	
	Drought	Surplus	Drought	Surplus
Alternative Historical	31	14	-28%	31%
2040 Climate A	15	79	-30%	28%
2040 Climate B	56	21	-29%	34%
2040 Climate C	56	21	-28%	35%
2040 Climate D	--	6	--	51%
2040 Climate E	800	8	-21%	46%
2070 Climate F	24	51	-34%	29%
2070 Climate G	62	17	-29%	43%
2070 Climate H	66	15	-28%	41%
2070 Climate I	1120	8	-23%	44%
2070 Climate J	--	2	--	78%

Table 3.3 Gunnison River near Grand Junction

	Observed Spells			
	Length of Spell (years)		Intensity of Spell (% of mean)	
	Drought	Surplus	Drought	Surplus
	5	6	-33%	50%

Alternative Hydrology Spells				
Case	Return Interval of historic spell length (years)		Average Annual Deficit/Surplus (% of mean)	
	Drought	Surplus	Drought	Surplus
Alternative Historical	17	20	-30%	30%
2040 Climate A	5	2800	-40%	26%
2040 Climate B	13	187	-35%	32%
2040 Climate C	12	187	-36%	29%
2040 Climate D	18	35	-31%	36%
2040 Climate E	30	15	-22%	48%
2070 Climate F	4	--	-40%	--
2070 Climate G	8	311	-39%	15%
2070 Climate H	13	187	-38%	28%
2070 Climate I	13	187	-33%	37%
2070 Climate J	19	48	-28%	47%

Table 3.4 San Juan River near Carracas

	Observed Spells			
	Length of Spell (years)		Intensity of Spell (% of mean)	
	Drought	Surplus	Drought	Surplus
	4	6	-35%	47%

Alternative Hydrology Spells				
Case	Return Interval of historic spell length (years)		Average Annual Deficit/Surplus (% of mean)	
	Drought	Surplus	Drought	Surplus
Alternative Historical	17	34	-36%	35%
2040 Climate A	2	--	-40%	--
2040 Climate B	6	207	-38%	31%
2040 Climate C	11	86	-37%	45%
2040 Climate D	14	57	-33%	52%
2040 Climate E	61	16	-34%	54%
2070 Climate F	3	--	-44%	--
2070 Climate G	3	--	-46%	--
2070 Climate H	9	509	-44%	45%
2070 Climate I	6	200	-38%	33%
2070 Climate J	18	64	-39%	57%

The CRWAS also provided information that helps frame projected low-flow conditions in the context of conditions over the 56-year historical baseline. Figure 3.1 illustrates the effect of projected future climate conditions on mean flows and on low-flow events.

Figure 3.1 Low Flow Comparison Chart, Colorado River near Cameo

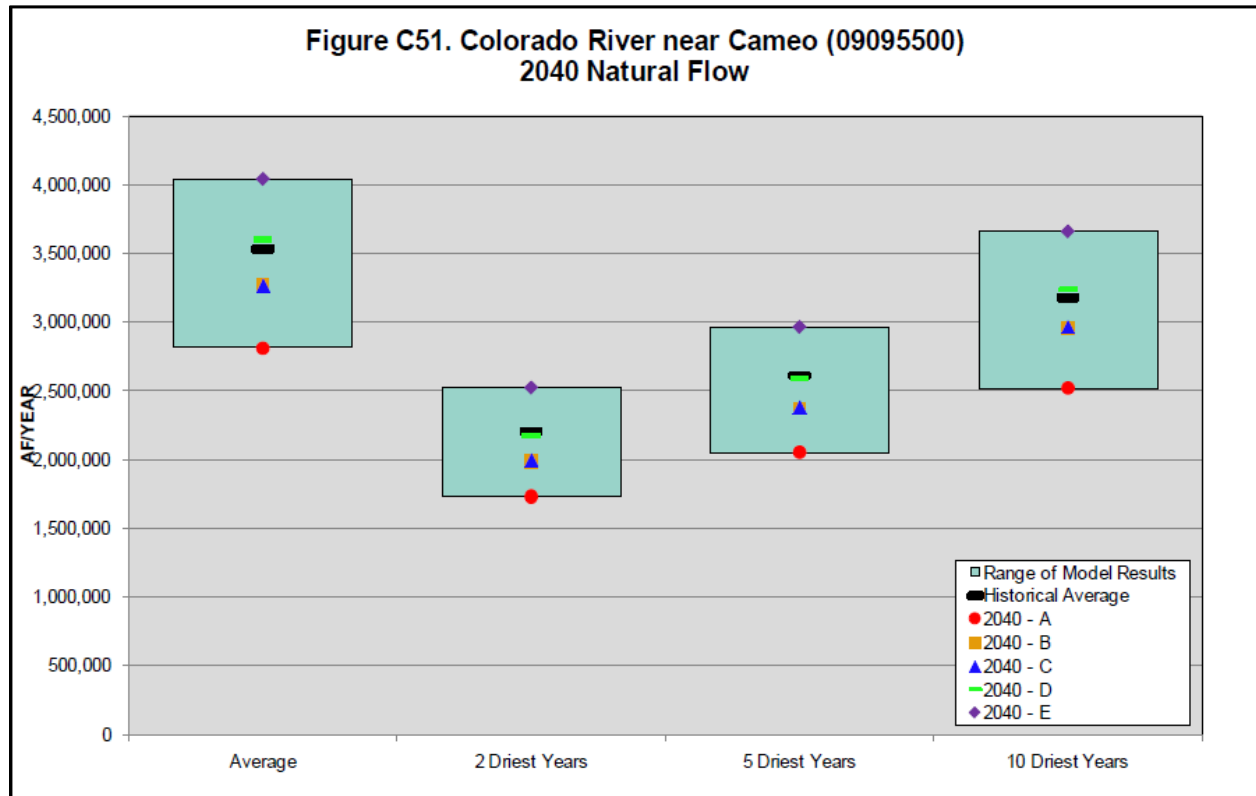


Figure 3.1 provides a direct comparison of projected conditions to conditions at Cameo during the 56-year historical baseline. From left to right, the chart represents four statistics of annual flow: average annual flow over the 56-year study period, the lowest consecutive 2-year average flow in the 56-year study period, the lowest consecutive 5-year average flow in the 56-year study period and the lowest consecutive 10-year average flow in the 56-year study period (CWCB 2012a). For each statistic, several pieces of information are shown. The red filled diamond represents the value of the statistic from the historical record during the study period. The estimated values of the statistics for the five different projections of future climate are represented by dashes. The wide cyan-colored bars show the overall range of the projected future values of the statistic.

Depending on the selected projections, average flows and low flows for durations of 2, 5, and 10 years may be greater or lesser than the corresponding condition during the 56-year historical baseline. As noted above, wetter scenarios will tend to exhibit droughts that are shorter and less intense than those experienced during the 56-year baseline period. Conversely, drier scenarios will tend to exhibit droughts that are longer and more intense than those experienced during the 56-year baseline period. Figure 3.2 through Figure 3.4 show the same information for the Yampa River near Maybell, the Gunnison River near Grand Junction, and the San Juan River near Carracas.

Figure 3.2 Low Flow Comparison Chart, Yampa River near Maybell

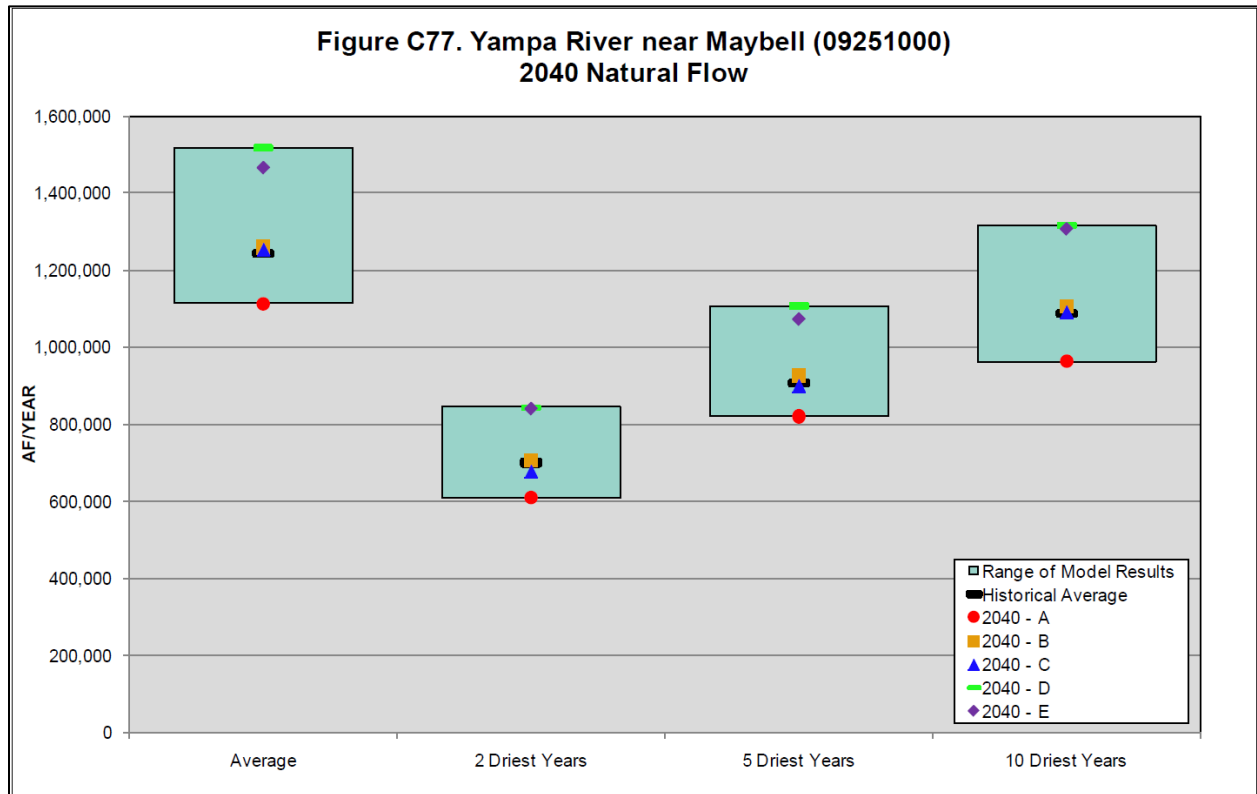


Figure 3.3 Low Flow Comparison Chart, Gunnison River near Grand Junction

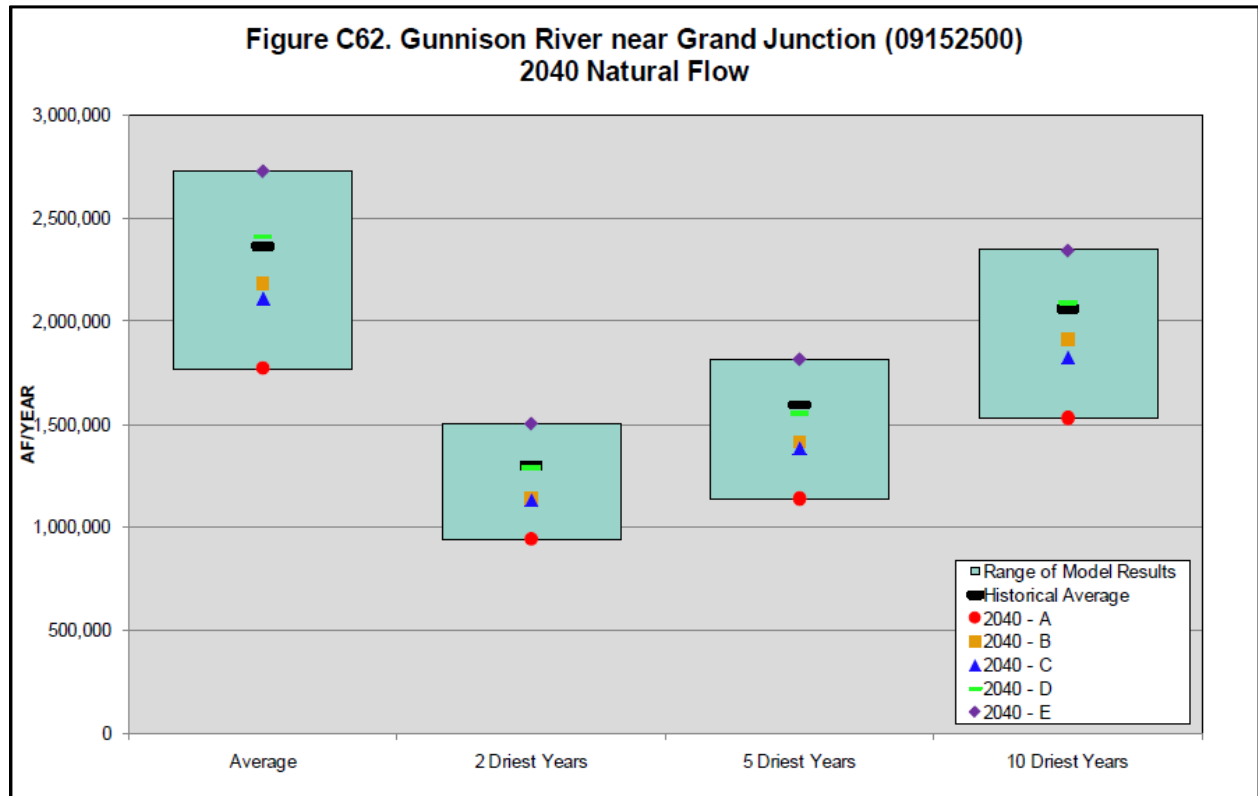


Figure 3.4 Low Flow Comparison Chart, San Juan River near Carracas

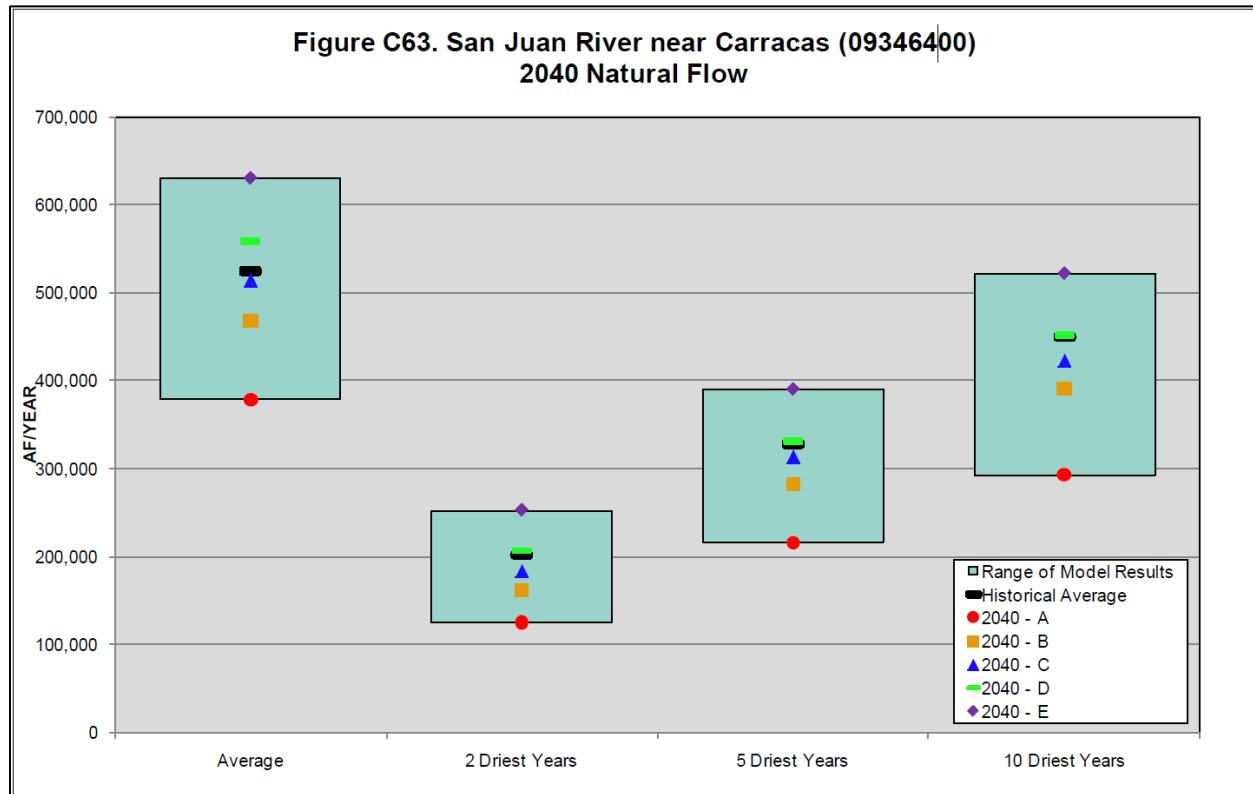


Figure 3.1 through Figure 3.4 reflect the spatial pattern of the impact of projected climate on streamflow in Colorado: in the selected projections, natural flow increases (or decreases less) more often in more northerly parts of the state (and at higher elevations) while the converse is true in more southerly areas (and at lower elevations).

Figure 3.5 illustrates the impact of projected climate conditions on crop irrigation requirement or consumptive irrigation requirement (CIR), the amount of water (expressed as depth, in inches) necessary to supplement precipitation in order to fully supply a crop's water needs. This is also commonly referred to as the irrigation water requirement (IWR). Figure 3.5 shows that because temperature increases in all projections, CIR increases even if the projections indicate an increase in precipitation.

Figure 3.5 Average Monthly CIR Comparison

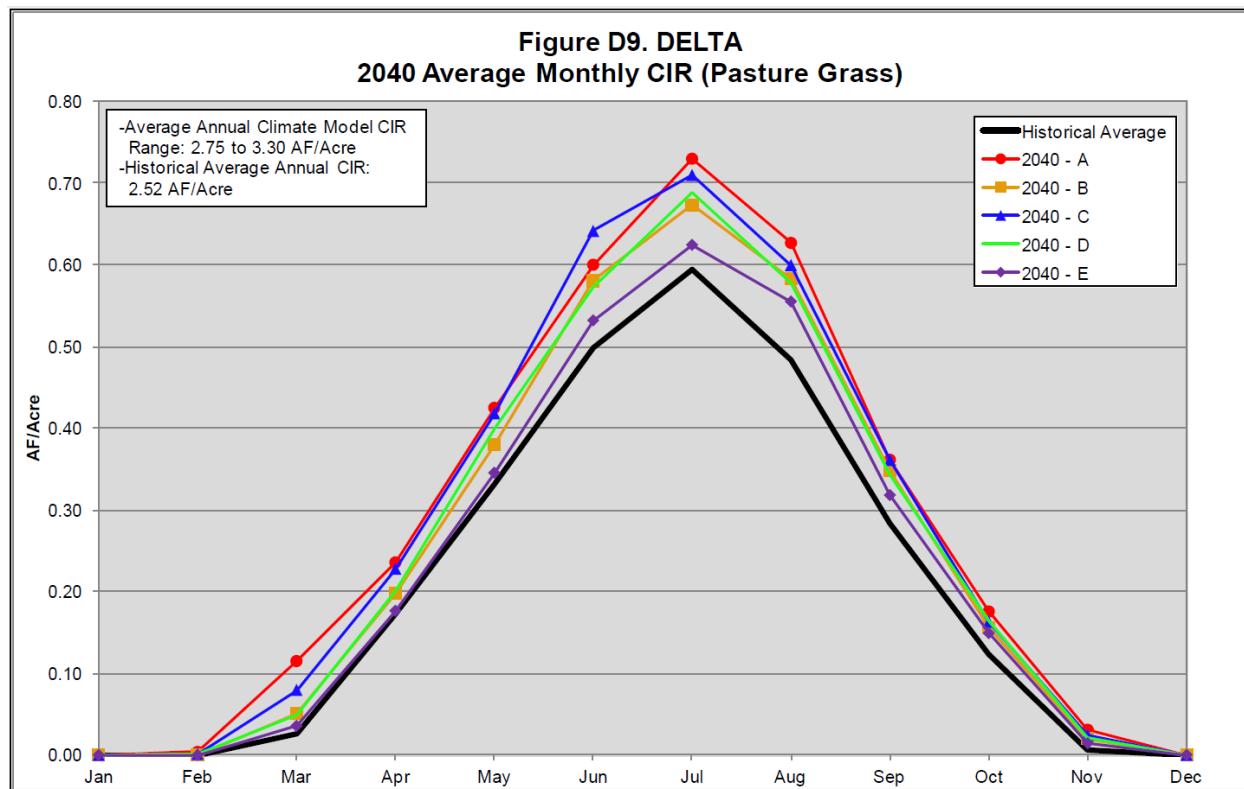
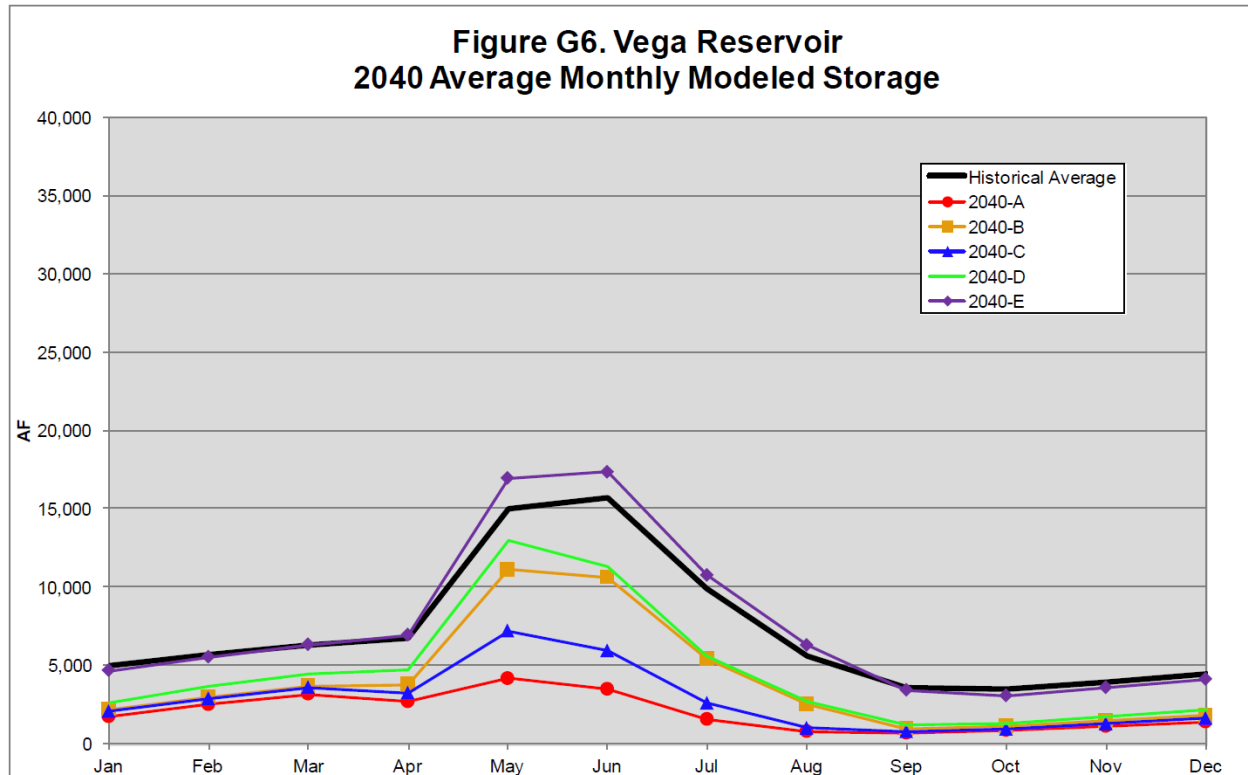


Figure 3.6 brings together the effects of climate on natural flow and agricultural water demand. It shows average monthly modeled Vega Reservoir content over the 1950 through 2005 study period for historical climate conditions, and for each of the 2040 climate projections. These results, which are from StateMod modeling done as part of the CRWAS, reflect the operation of Vega reservoir in the context of the climate-impacted natural flows, climate-impacted water demands, and the water rights and operating rules in the basin. Figure 3.6 illustrates the significance of changes in the monthly pattern of precipitation and increasing temperature – even the climate projections that result in natural flows similar to or greater than historical conditions show increased impacts on reservoir storage. This is due to increased agricultural water demand as is illustrated in Figure 3.5. Because average end-of-water-year storage is reduced in all climate projections, the amount of water available for year-to-year carryover storage is reduced, which will increase vulnerability to drought.

Figure 3.6 Vega Reservoir - 2040 Average Monthly Modeled Storage Contents



The CRWAS provides excellent information for the Colorado River. However, given the diversity of Colorado’s river basins and the spatial differences noted just within the Colorado River, it is not appropriate to translate the results of the CRWAS to other basins.

3.2 Colorado River Water Availability Study Phase II

The CRWAS project was completed in 2012 and was later continued as CRWAS Phase II (CRWAS-II), to achieve the following climate and hydrology objectives:

- Update Phase I (CRWAS-I) to include projections in the Coupled Model Intercomparison Project Phase 5 (CMIP5) archive;
- Develop an improved method for creating climate scenarios;
- Extend the historical hydrology through 2012;
- Provide climate adjustments to natural flow and CIR for the entire state (not just the Colorado River Basin).

The CRWAS-II extension was completed in 2015, and the data was used to update the low flow comparison charts included in the 2013 Drought Mitigation and Response Plan (Annex C). This 2018 update to the Drought Mitigation and Response Plan includes low flow analysis charts for the major rivers throughout Colorado, including the Colorado River, Dolores River, Gunnison

River, Los Pinos River, San Juan River, White River, Yampa River, Arkansas River, North Platte River, South Platte River, and Rio Grande.

3.2.1 Climate Model Background

The CRWAS-I project was based on the latest climate data available at the time, the Coupled Model Intercomparison Project Phase 3 (CMIP3) archive, which aligned with the IPCC Assessment Report 4 (AR4) (CWCB, 2012). When CRWAS was updated as a part of Phase II, the CMIP5 dataset was the latest available data, therefore CRWAS Phase II (CRWAS-II) incorporated model projections from both the CMIP3 and CMIP5 archives to draw the most robust understanding of future climate conditions. The following paragraphs present a brief introduction into high level differences between the CMIP3 and CMIP5 datasets.

The CMIP3 archive of twenty-first century projections contains 112 projections from 16 GCMs forced with three Special Report on Emission Scenarios (SRES) emissions pathways (A1B, A2, and B1). Each projection consists of a twentieth century simulation running through 1999 and a twenty-first century projection running from 2000 through 2099 (CWCB, 2015a). Additional information regarding the SRES emissions pathways can be found online at the IPCC website (<http://sedac.ipcc-data.org/ddc/sres/index.html>).

The CMIP5 archive consists of a number of model experiments involving more than 20 modeling groups and more than 50 models (Taylor et al., 2012). Long term simulations within the CMIP5 archive consist of a historical period from the mid-nineteenth century to 2005, and a simulation of future climate from 2006 to the end of the twenty-first century. The CMIP5 long-term projection ensemble consists of 234 runs of 37 climate models (CWCB, 2015a). The CMIP5 model runs are forced by representative concentration pathways (RCPs), which are used to represent different assumptions about the effect of past and future greenhouse gas emissions. There are four different RCPs used for the CMIP5 experiment: 2.6, 4.5, 6.0, and 8.5. Research currently makes no distinction between the CMIP3 and CMIP5 projections with respect to reliability or accuracy (Rupp et al., 2013).

3.2.1.1 Climate Scenarios

Due to the large size of climate datasets (period of record, model runs, scenarios, future periods), climate change studies necessarily must consolidate results from hundreds of projections into a few meaningful scenarios that will be used for planning purposes. The CRWAS-I study approach selected individual climate projections that would capture most of the variability of future climate according to temperature and precipitation for two time periods (2040 and 2070). The five CRWAS planning scenarios are described in Table 3.5 below:

Table 3.5 Characteristics for CRWAS-I Future Climate Scenarios

Qualitative Scenario	Characteristic Temperature	Characteristic Precipitation
Hot and Dry	90 th percentile	10 th percentile
Hot and Wet	70 th percentile	70 th percentile
Warm and Dry	30 th percentile	30 th percentile
Warm and Wet	10 th percentile	90 th percentile
Median	50 th percentile	50 th percentile

In CRWAS-II, the methods for scenario selection were refined by selecting the future climate impacts from runoff and CIR, rather than temperature and precipitation. While changes in temperature and precipitation are a good representation of the environment, the more important element is how they affect water systems. Thus the change in supply (runoff) and demand (CIR) were used to determine future climate change impacts. Additional information regarding the change in methods can be found in the CRWAS Phase II Climate, Task 1 technical memorandum, *Approach for constructing climate scenarios* (CWCB, 2015b). For the CRWAS-II study, seven aggregated climate scenarios were selected from pooled model projections (Table 3.6), listed in ascending order of severity of impact on water supply systems. These seven climate scenarios each were comprised of a pool of ten projections taken from the combined ensemble of CMIP3 and CMIP5 climate projections for the 2050 time period. These scenarios did not distinguish between CMIP3 SRES scenarios or CMIP5 RCPs; instead, all model projections were included within the same sample space for aggregation into the seven climate scenarios. The designation “9010” is pronounced “ninety-ten” and represents the 90th percentile CIR and 10th percentile runoff. Other designations follow this convention.

Table 3.6 Characteristics for CRWAS-II Future Climate Scenarios

Designation	CIR Percentile	Runoff Percentile
Lower Left	100%	0%
9010	90%	10%
7525	75%	25%
Center	50%	50%
2575	25%	75%
1090	10%	90%
Upper Right	0%	100%

3.2.1.2 Change Factors

The CRWAS-I project was assessed using a baseline historical dataset (natural flow and CIR) from water years 1950 to 2005, which was extended through water year 2013 as a part of CRWAS-II. The CRWAS method for assessing future climate change impacts involves the use of change factors or ratios to determine adjustments to runoff and CIR. For instance, the annual average runoff change factor would be calculated as the annual average simulated future runoff divided by the annual average simulated historical runoff (Equation 1).

Equation 1:

$$\text{Runoff change factor} = \frac{\text{annual average future runoff}}{\text{annual average historical runoff}}$$

The change factors were calculated by month (one set of 12 change factors) using a 30-year window around the target future date. Thus the 2050 analysis used the average change factor for years 2035 to 2064, the 2040 analysis used the average change from 2025 to 2054, and the 2070 analysis used the average change factors from 2055 to 2084. These change factors were then applied back to the original historical dataset, to provide climate-adjusted hydrology (runoff and CIR) that could be used for a climate change impact analysis.

3.2.1.3 Historical Flows

Utilizing the change factor method is a fairly simple approach that minimizes model bias when completing a climate change impact analysis. However, it requires natural flow data, also referred to as unimpaired flow or full natural flow. Simply stated, this is the flow that would exist in the river without human impact. Natural flow is calculated by removing the unnatural, human-caused impacts to rivers such as reservoirs, diversions, augmentations, evaporation, etc. In Colorado, the stream simulation model StateMod has been developed to model historical and future river flows. The historical flows referred to within this analysis are natural flows calculated by StateMod modeling. This modeling has been completed for the Colorado River, South Platte River and North Platte River, but not for the Arkansas River and Rio Grande.

The natural flow records at the Colorado River sites were extended through 2014 as part of the CRWAS-II work, so the statistics of those flow records are slightly different than those of the CRWAS-I records.

In the place of natural flow for the Rio Grande, measured historical gage flows have been used from a site located near the headwaters of the watershed, where there is less human influence. The measured flow is assumed to be similar enough to the natural flow that it provides output which is useful for the purposes of this drought analysis.

The Arkansas River was analyzed in a unique manner, because none of the climate-adjusted gage (flow) stations closely reflected the natural flow of the river. In this instance, nine flow gages on the Arkansas River and tributaries to the Arkansas River were used to calculate flow-weighted adjustment factors for the Arkansas River. The nine gage stations used for the Arkansas River are provided in Table 3.7.

Since the sum of these nine Arkansas River stations did not reflect the total natural flow of the Arkansas River, the low flow statistics were analyzed using the climate-adjusted change factors for flow rather than the flow itself. A flow (runoff) change factor (see Equation 1) with a value

less than 1 indicates a reduction in flow for the future (2050), while a change factor greater than 1 indicates an increase in flow for the future. The change factor for the Arkansas River analysis is a flow-weighted average, divided by the aggregate natural flow of the nine sites, thereby reflecting the future climate condition of the Arkansas River Basin.

Table 3.7 Arkansas River Gages

Station Name	StationID	River Basin	Historical Flow Period of Record
Arkansas River near Leadville	USGS 07081200	Arkansas	1/1950 –12/2013
Clear Creek above Clear Creek Reservoir	USGS 07086500	Arkansas	1/1950 –12/2013
Grape Creek near Westcliffe	USGS 07095000	Arkansas	1/1950 –12/2013
Fountain Creek near Fountain.	USGS 07106000	Arkansas	1/1950 –12/2013
St. Charles River at Vineland	USGS 07108900	Arkansas	1/1950 –12/2013
Huerfano River at Manzanares Xing near Redwing	USGS 07111000	Arkansas	1/1950 –12/2013
Cucharas River at Boyd Ranch near La Veta	USGS 07114000	Arkansas	1/1950 –12/2013
Apishapa River near Fowler	USGS 07119500	Arkansas	1/1950 –12/2013
Purgatoire River at Madrid	USGS 07124200	Arkansas	1/1950 –12/2013

3.2.1.4 Drought Analysis Results

The low flow analysis completed for the CRWAS-I study was updated using results from CRWAS-II. The analysis shows the climate-adjusted low flow conditions during the future period of 2050 (from CRWAS-II), combined with the climate-adjusted low flow conditions during the future periods of 2040 and 2070 (from CRWAS-I, if available), compared to the historical natural flow. Note that CRWAS-I results were not available for the rivers outside of the Colorado River Basin, including the North Platte River, South Platte River, Arkansas River and Rio Grande. Additionally, the historical flows for the Arkansas River and the Rio Grande represent measured gage flow rather than natural flow. A map of the stations is provided in Figure 3.7 and the station names and ID numbers are listed in Table 3.8.

Figure 3.7 Map of Low Flow Stations



Table 3.8 CRWAS-II Stations

Station Name	StationID	River Basin	Historical Flow Period of Record
Colorado River near Cameo	USGS 09095500	Colorado	10/1949 – 9/2013
Colorado River near Colorado-Utah State Line	USGS 09163500	Colorado	10/1949 – 9/2013
Dolores River at Bedrock	USGS 09169500	Colorado	10/1949 – 9/2013
Gunnison River near Grand Junction	USGS 09152500	Colorado	10/1949 – 9/2013
Los Pinos River at La Boca	USGS 09354500	Colorado	10/1949 – 9/2013
San Juan River near Carracas	USGS 09346400	Colorado	10/1949 – 9/2013
White River near Meeker	USGS 09304500	Colorado	10/1949 – 9/2013
Yampa River near Maybell	USGS 09251000	Colorado	10/1949 – 9/2013
Arkansas River at La Junta	USGS 07123000	Arkansas	1/19450 – 9/2013
North Platte River near Northgate	USGS 06620000	North Platte	10/1956 – 9/2007
Rio Grande at Wagon Wheel Gap	USGS 08217500	Rio Grande	10/1950 – 9/2013
South Platte River at Julesburg	USGS 06764000	South Platte	10/1950 – 9/2012

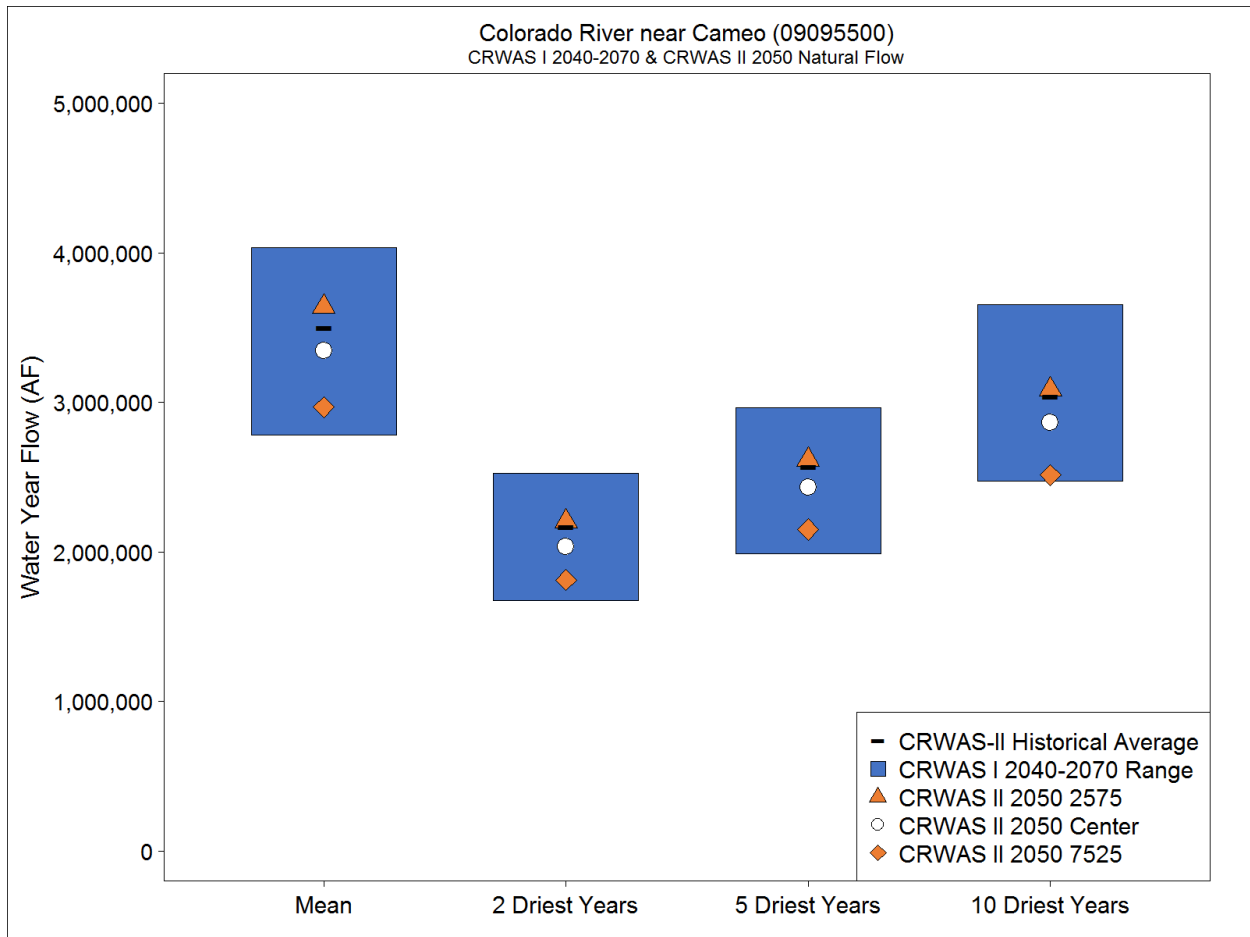
Each chart (Figure 3.8 to Figure 3.19) presents four statistics of annual flow, from left to right: average annual flow over the study period, the lowest consecutive 2-year average flow over the study period, the lowest consecutive 5-year average flow over the study period, and the lowest consecutive 10-year average flow over the study period. Due to the different data availability at the time of completion, the CRWAS-I analysis (2040 and 2070) uses a study period from 1950 to 2005, while the CRWAS II analysis (2050) uses a study period from 1950 to 2014. For each graph presented, several pieces of information are shown:

- The blue box represents the range of values from the CRWAS-I results for both the 2040 and 2070 analyses. The top of the box represents the maximum annual flow (in acre feet [AF]) and the bottom of the box represents the minimum annual flow (in AF).
- The orange-filled diamond represents the CRWAS-II year 2050, 7525 value (75th percentile CIR, 25th percentile runoff).
- The white-filled circle represents the CRWAS-II year 2050, 5050 or center value (50th percentile CIR, 50th percentile runoff).
- The orange-filled triangle represents the CRWAS-II year 2050, 2575 value (25th percentile CIR, 75th percentile runoff).
- The black horizontal line represents the average historical natural flow for the CRWAS-II record.

On average, the CRWAS-II results are slightly drier than the CRWAS-I results; the CRWAS-II results are skewed slightly to the bottom of the box representing the CRWAS-I results. The results for the Yampa River near Maybell (Figure 3.15) show that CRWAS-II flows are noticeably drier than CRWAS-I flows. The CRWAS-II model results follow the same relative order, where the 2575 scenario (25th percentile CIR, 75th percentile runoff) is the wettest, the Center scenario (50th percentile CIR, 50th percentile runoff) is in the middle and the 7525 scenario (75th percentile CIR, 25th percentile runoff) is the driest of the three aggregated scenarios. The historical flows are typically closest to the CRWAS-II 2575 scenario (orange triangle); however, this varies from site to site.

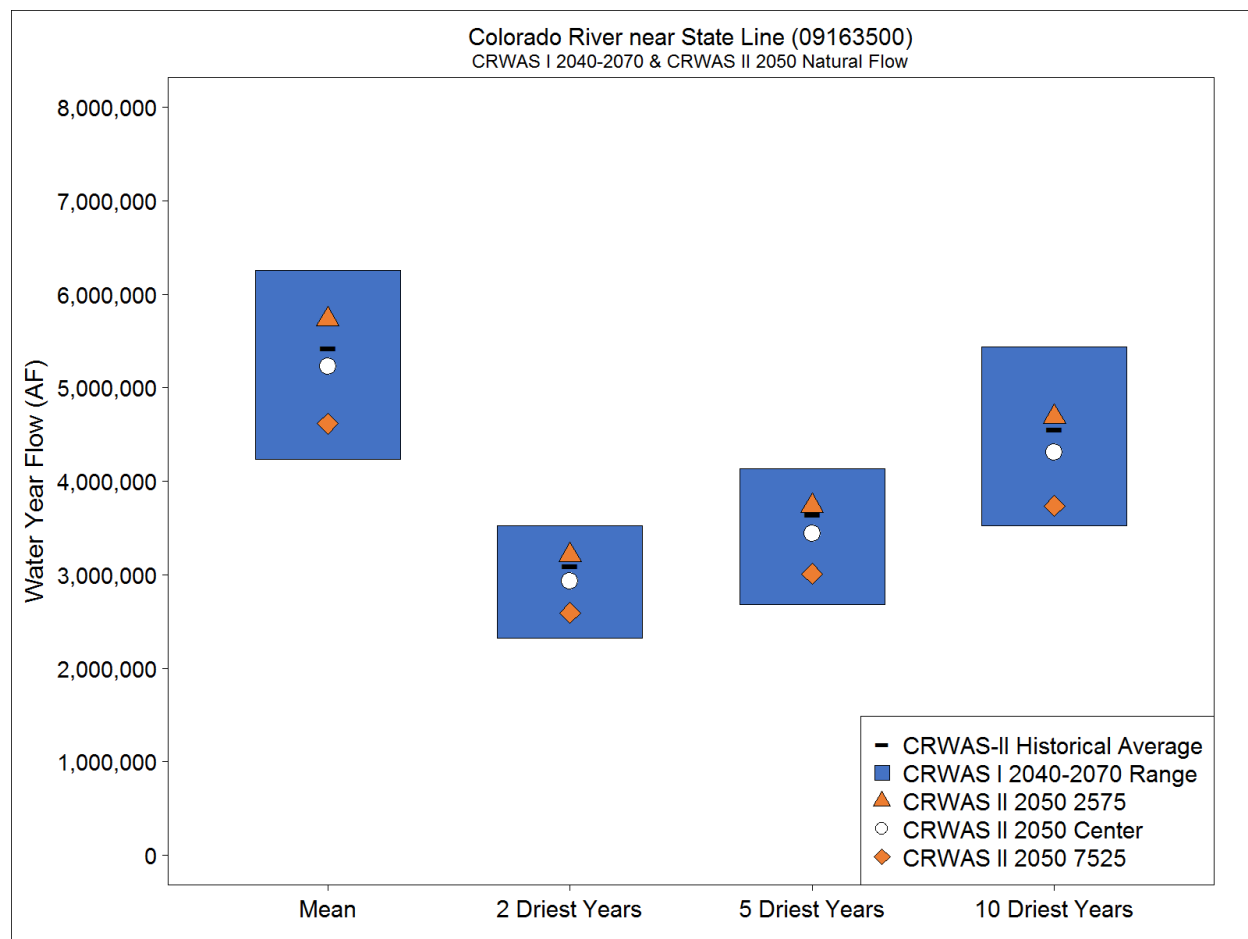
The future climate scenarios for the Colorado River near Cameo shows that the driest 2-year flow represents a 39% reduction from the average annual flow of approximately 3.3 million AF when comparing the CRWAS-II Center (2050) scenarios. The CRWAS-II Center scenario is within 5% of the historical average flow. The results are shown in Figure 3.8.

Figure 3.8 Low Flow Comparison Chart, Colorado River near Cameo



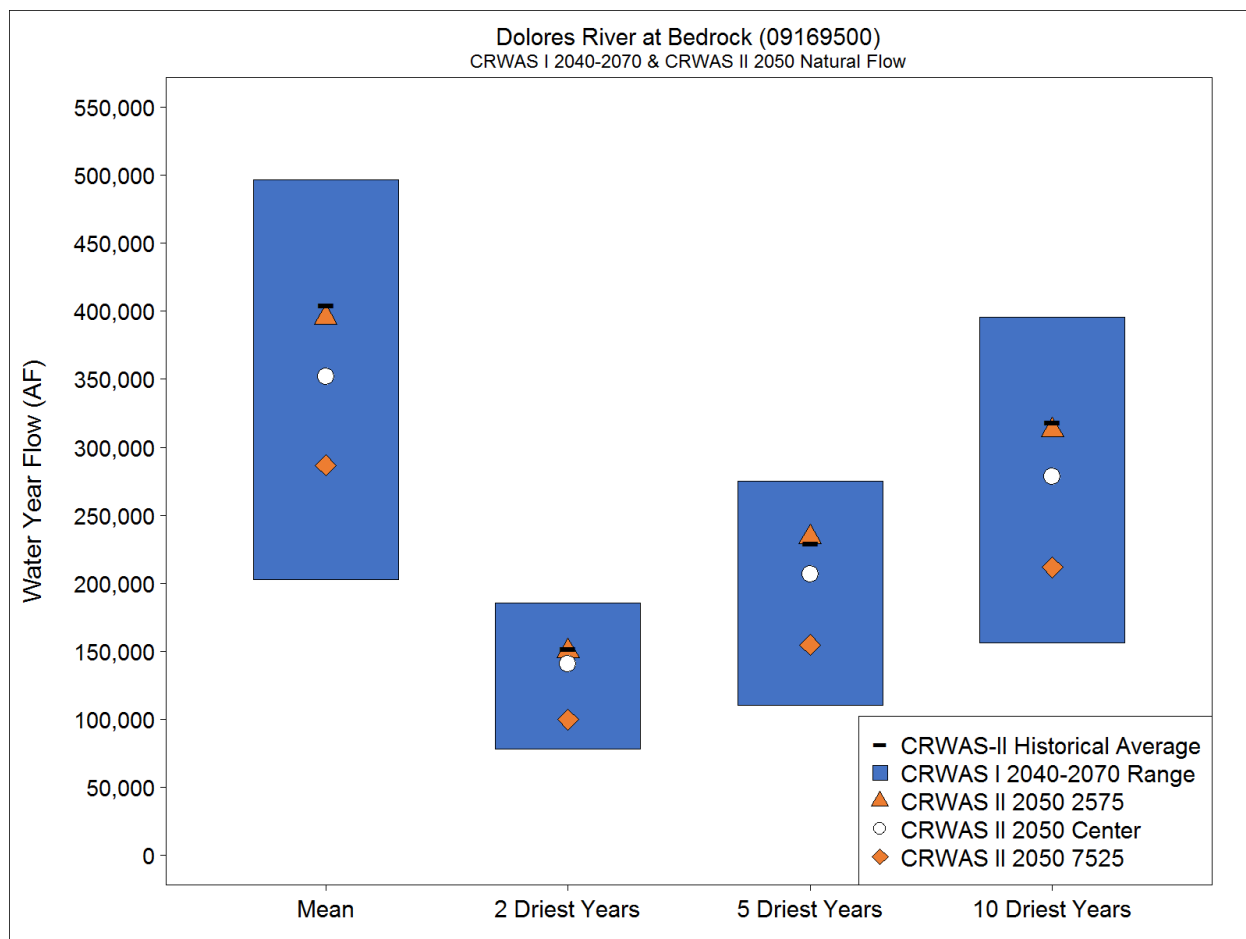
The future climate scenarios for the Colorado River near the Utah state line shows that the driest 2-year flow represents a 44% reduction from the average annual flow of approximately 5.2 million AF when comparing the CRWAS-II Center scenarios. The CRWAS-II Center scenario is within 5% of the historical average flow. The results are shown in Figure 3.9.

Figure 3.9 Low Flow Comparison Chart, Colorado River near State Line



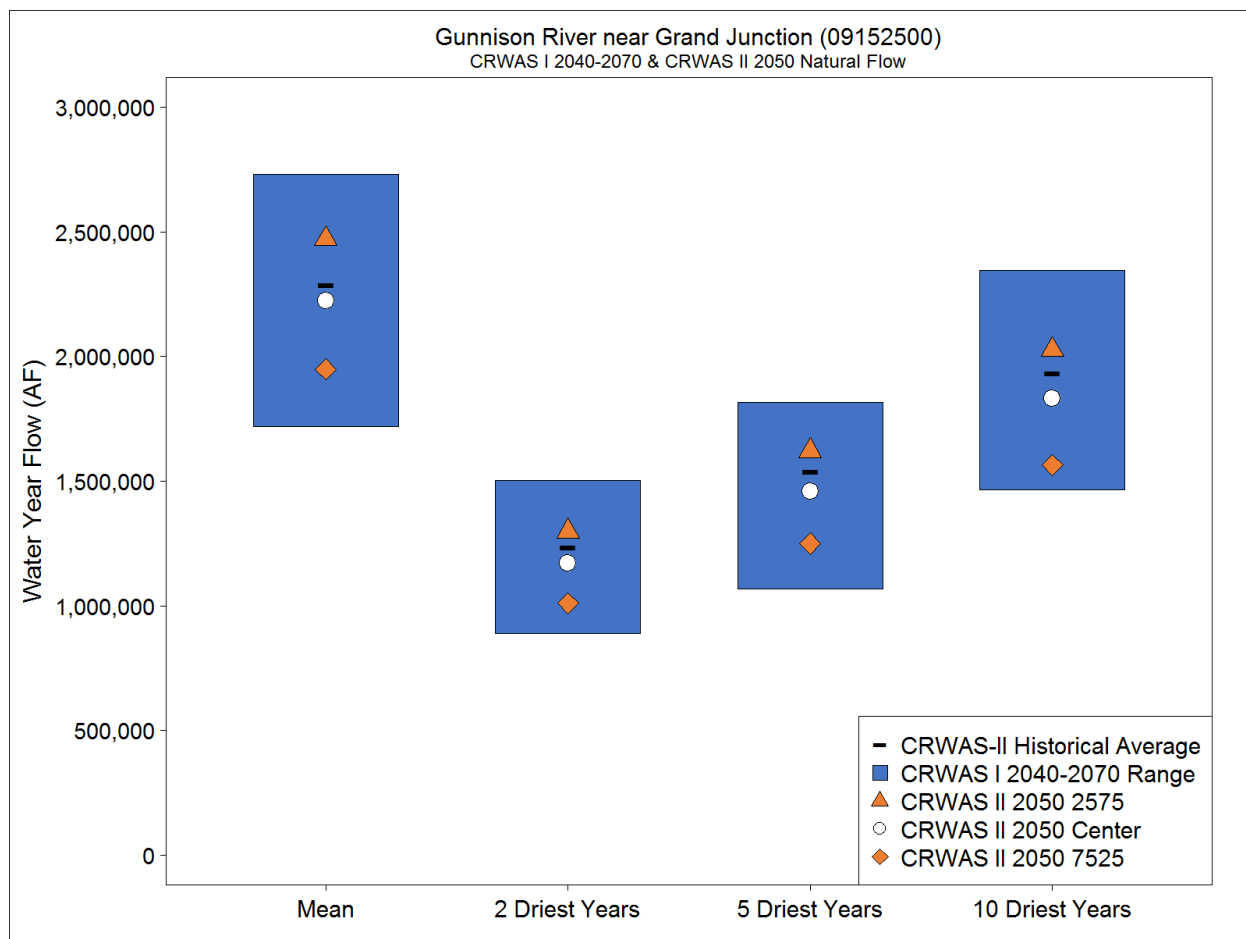
The future climate scenarios for the Dolores River at Bedrock show that the driest 2-year flow represents a 60% reduction from the average annual flow of approximately 350,000 AF, for the CRWAS-II Center scenario. The CRWAS-II Center scenario is 13% drier than the average annual historical flow. The results are shown in Figure 3.10.

Figure 3.10 Low Flow Comparison Chart, Dolores River at Bedrock



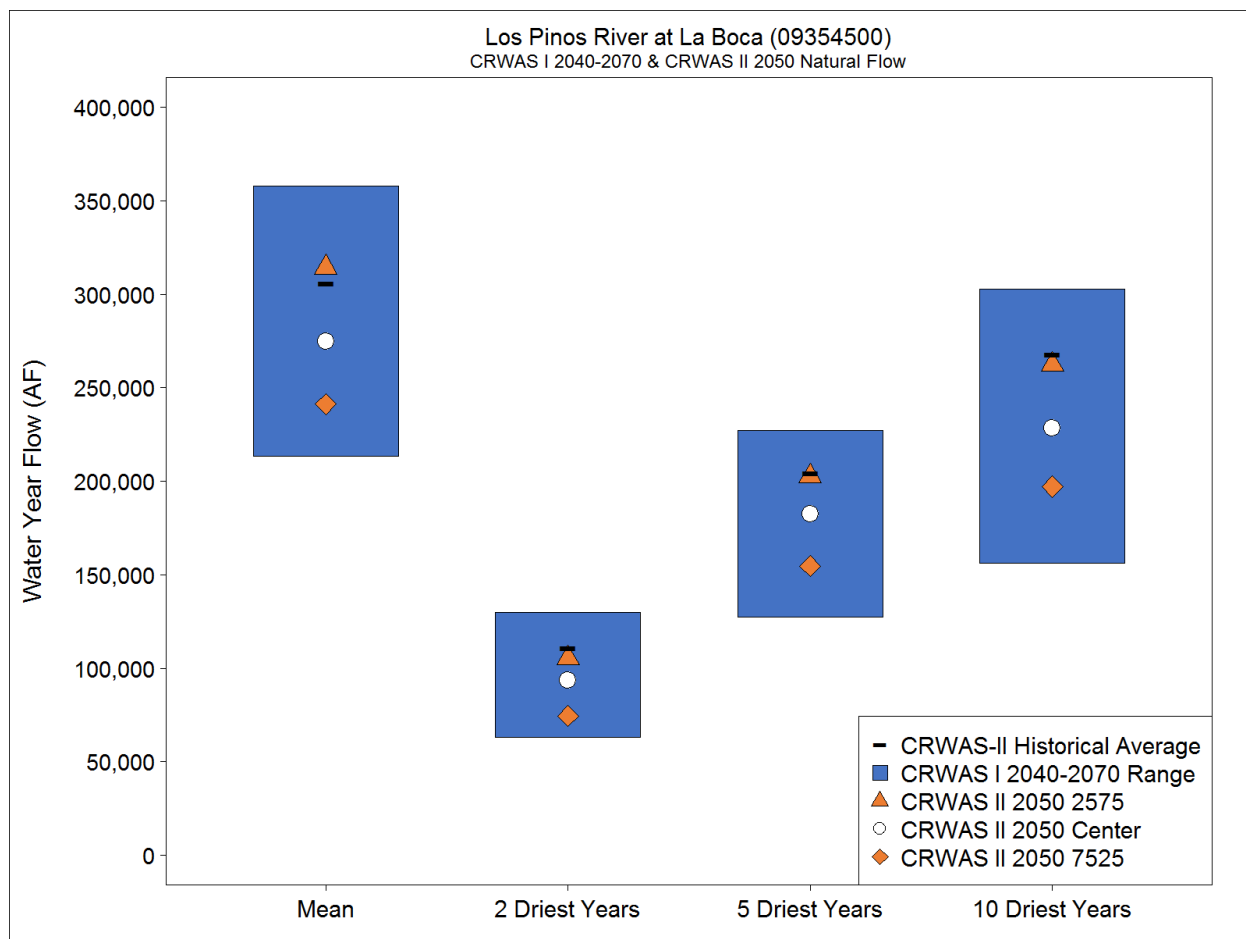
The future climate scenarios for the Gunnison River near Grand Junction show that the driest 2-year flow represents a 47% reduction from the average annual flow of approximately 2.2 million AF, for the CRWAS-II Center scenario. The CRWAS-II Center scenario is within 5% of the average annual historical flow. The results are shown in Figure 3.11.

Figure 3.11 Low Flow Comparison Chart, Gunnison River near Grand Junction



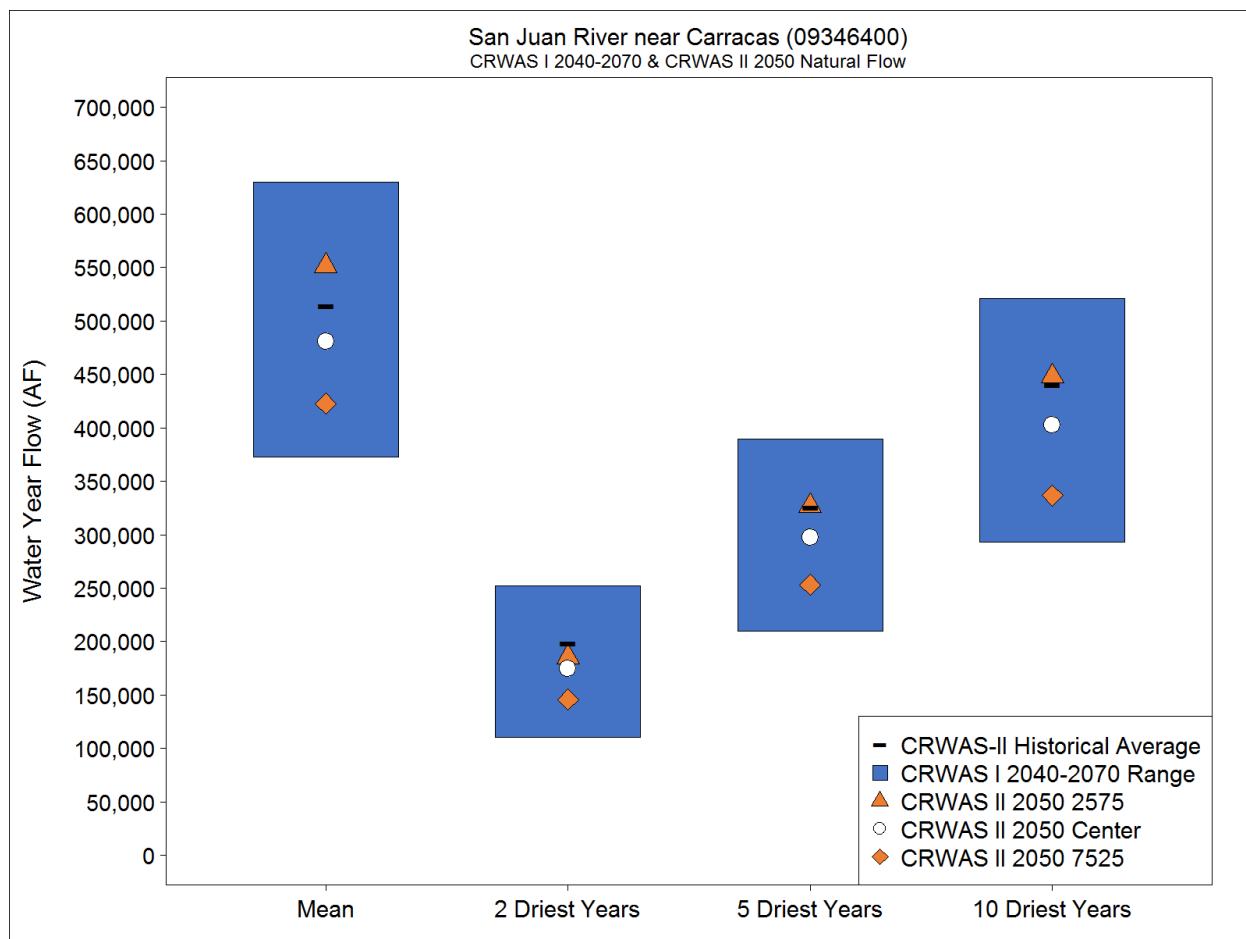
The future climate scenarios for the Los Pinos River at La Boca show that the driest 2-year flow represents a 66% reduction from the average annual flow of approximately 270,000 AF, for the CRWAS-II Center scenario. The CRWAS-II Center scenario is 10% drier than the average annual historical flow. The results are shown in Figure 3.12.

Figure 3.12 Low Flow Comparison Chart, Los Pinos River at La Boca



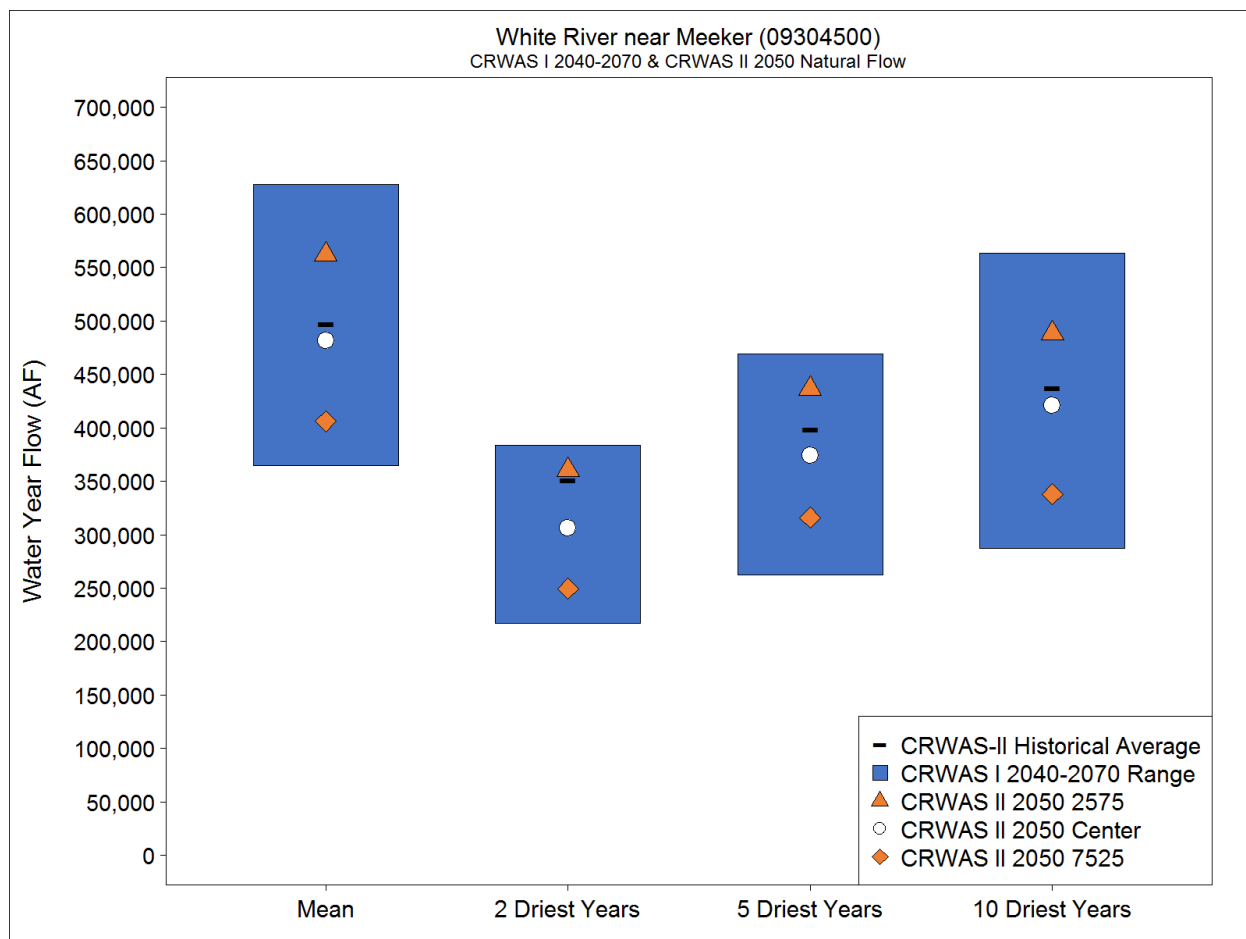
The future climate scenarios for the San Juan River near Carracas show that the driest 2-year flow represents an 64% reduction from the average annual flow of approximately 480,000 AF, for the CRWAS-II Center scenario. The CRWAS-II Center scenario is 6% drier than the average annual historical flow. The results are shown in Figure 3.13.

Figure 3.13 Low Flow Comparison Chart, San Juan River near Carracas



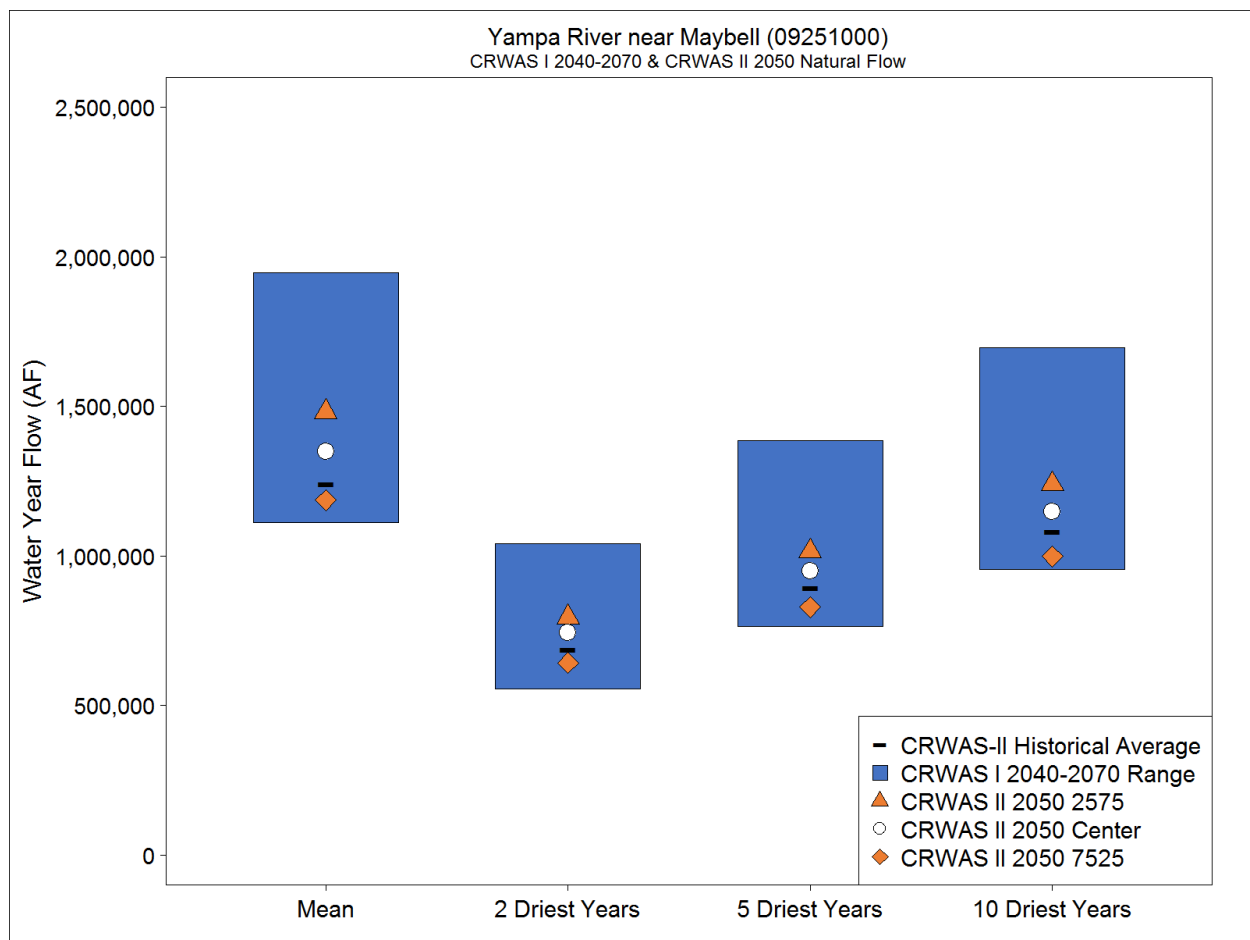
The future climate scenarios for the White River near Meeker show that the driest 2-year flow represents a 36% reduction from the average annual flow of approximately 480,000 AF, for the CRWAS-II Center scenario. The CRWAS-II Center scenario is within 5% of the average annual historical flow. The results are shown in Figure 3.14.

Figure 3.14 Low Flow Comparison Chart, White River near Meeker



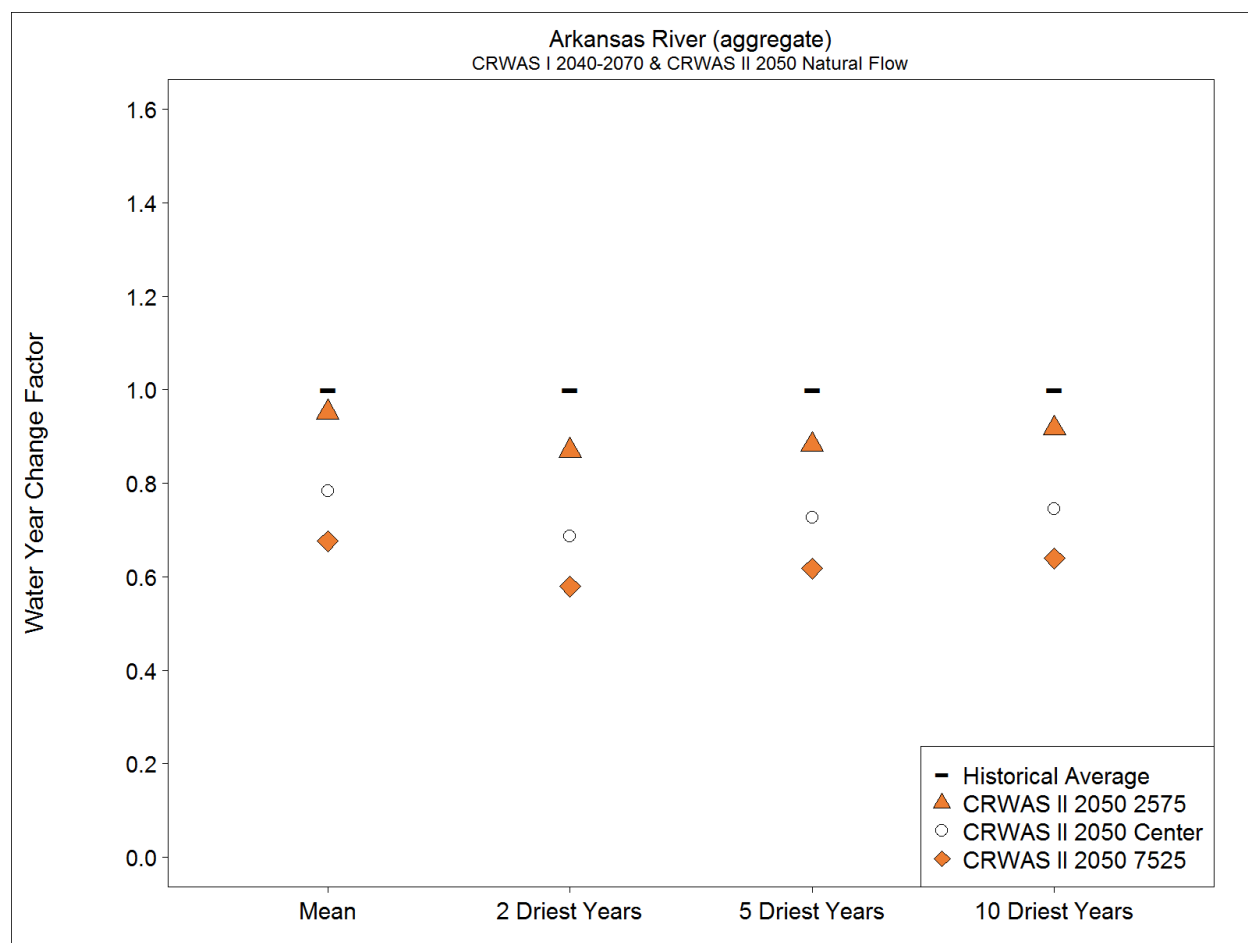
The future climate scenarios for the Yampa River near Maybell show that the driest 2-year flow represents a 45% reduction from the average annual flow of approximately 1.35 million AF, for the CRWAS-II Center scenario. The CRWAS-II Center scenario is 9% wetter than the average annual historical flow, reflecting the trend for northern Colorado that indicates there is a higher probability of increased precipitation in the future. The results are shown in Figure 3.15.

Figure 3.15 Low Flow Comparison Chart, Yampa River near Maybell



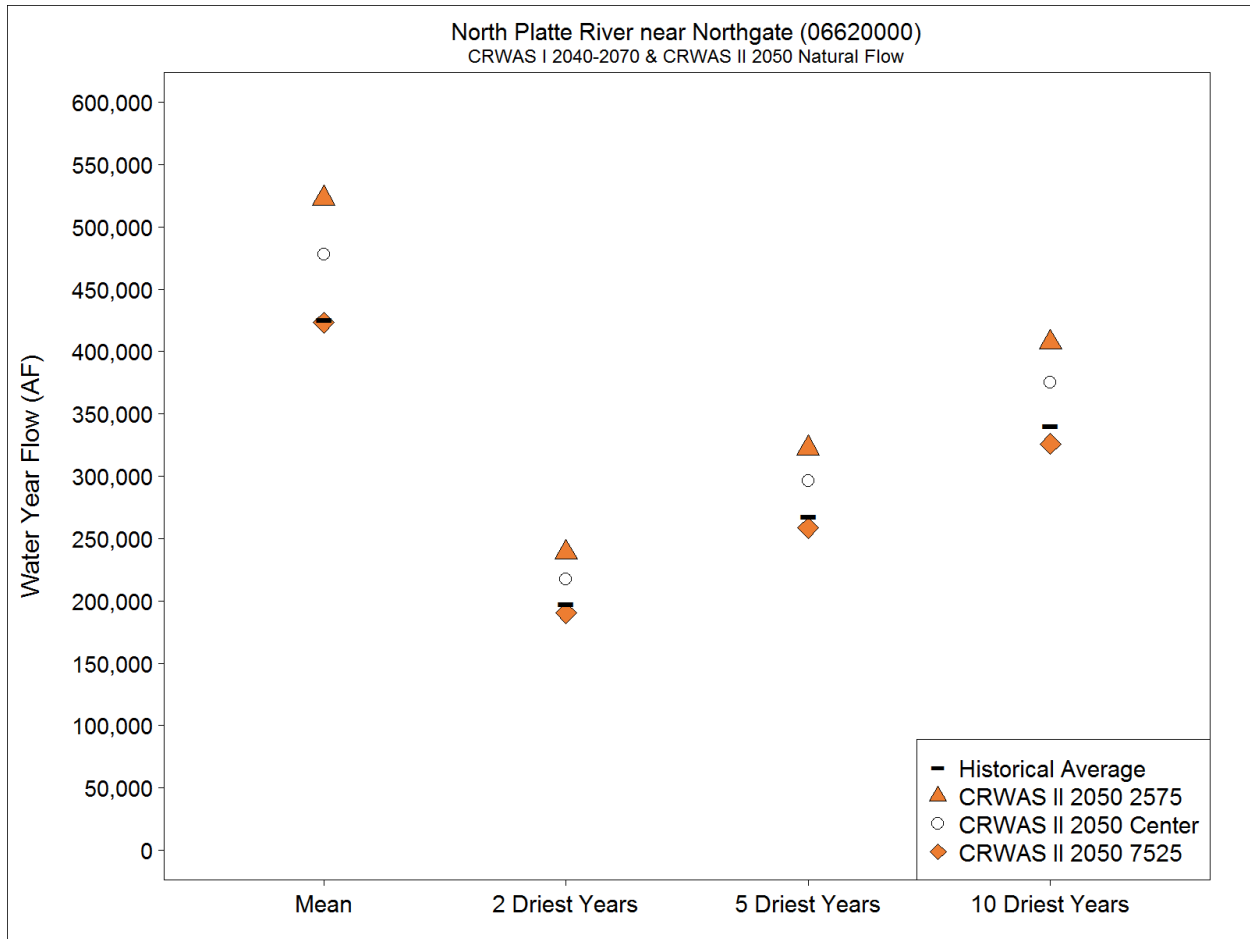
As discussed in Section 3.2, Historical Flow, there was no single gage station that represented the full natural flow of the Arkansas River. Thus, the low flow analysis was completed using an aggregate of nine Arkansas River gages. Figure 3.16 is unique in this way because it presents results using change factors (indicating future increases or decreases in flow) rather than the flow itself. The future climate scenarios for the Arkansas River at La Junta show that the change factors for the driest 2-year flow represents a 12% reduction from the change factor for average annual flow of approximately 0.78, for the CRWAS-II Center scenario. The change factor for the CRWAS-II Center scenario is 22% drier than the change factor for the average annual historical flow. The results are shown in Figure 3.16.

Figure 3.16 Low Flow Comparison Chart, Arkansas River at La Junta



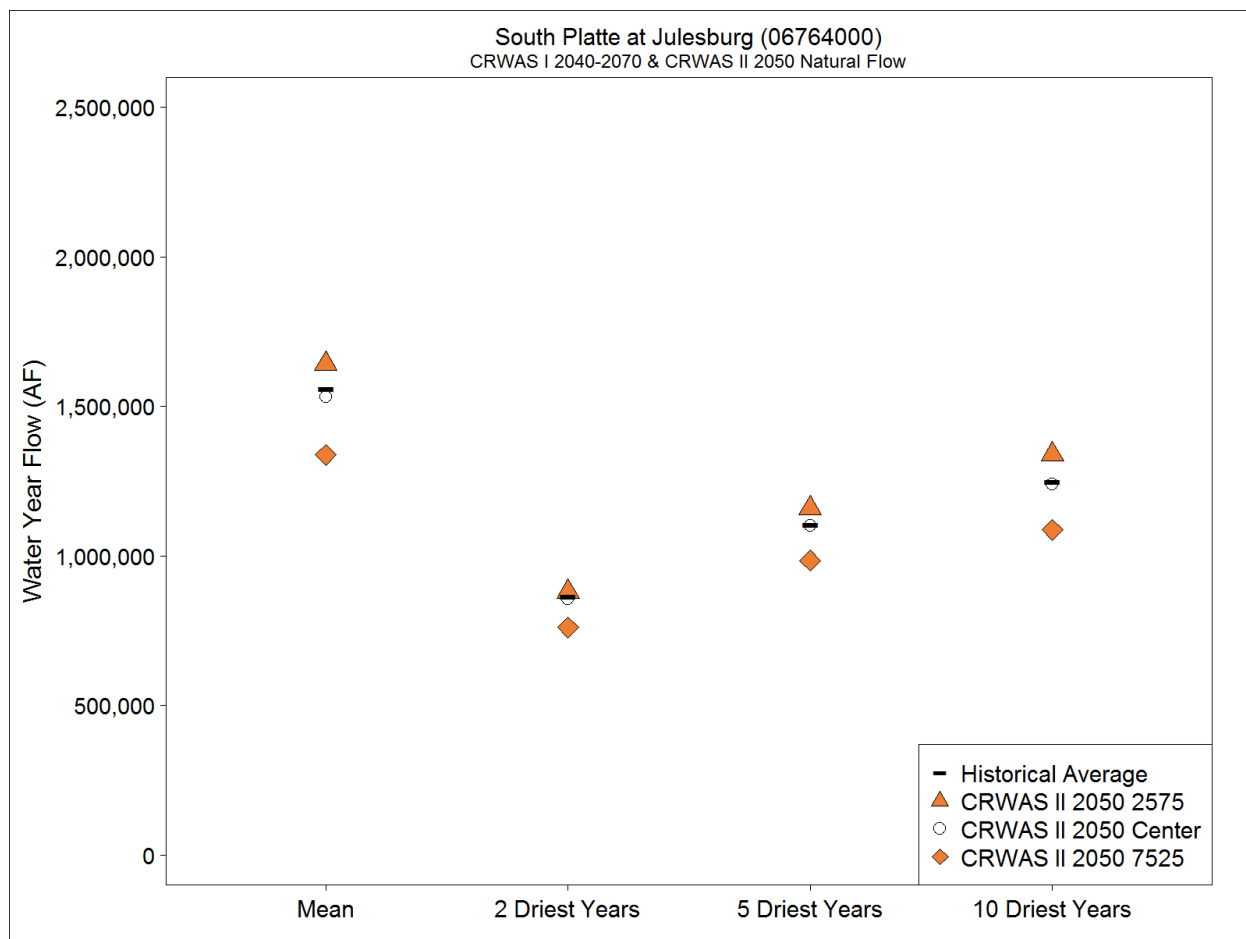
The future climate scenarios for the North Platte River near Northgate show that the driest 2-year flow represents a 54% reduction from the average annual flow of approximately 480,000 AF, for the CRWAS-II Center scenario. The CRWAS-II Center scenario is 12% wetter than the average annual historical flow, reflecting the trend for northern Colorado that indicates there is a higher probability of increased precipitation in the future. The results are shown in Figure 3.17.

Figure 3.17 Low Flow Comparison Chart, North Platte River near Northgate



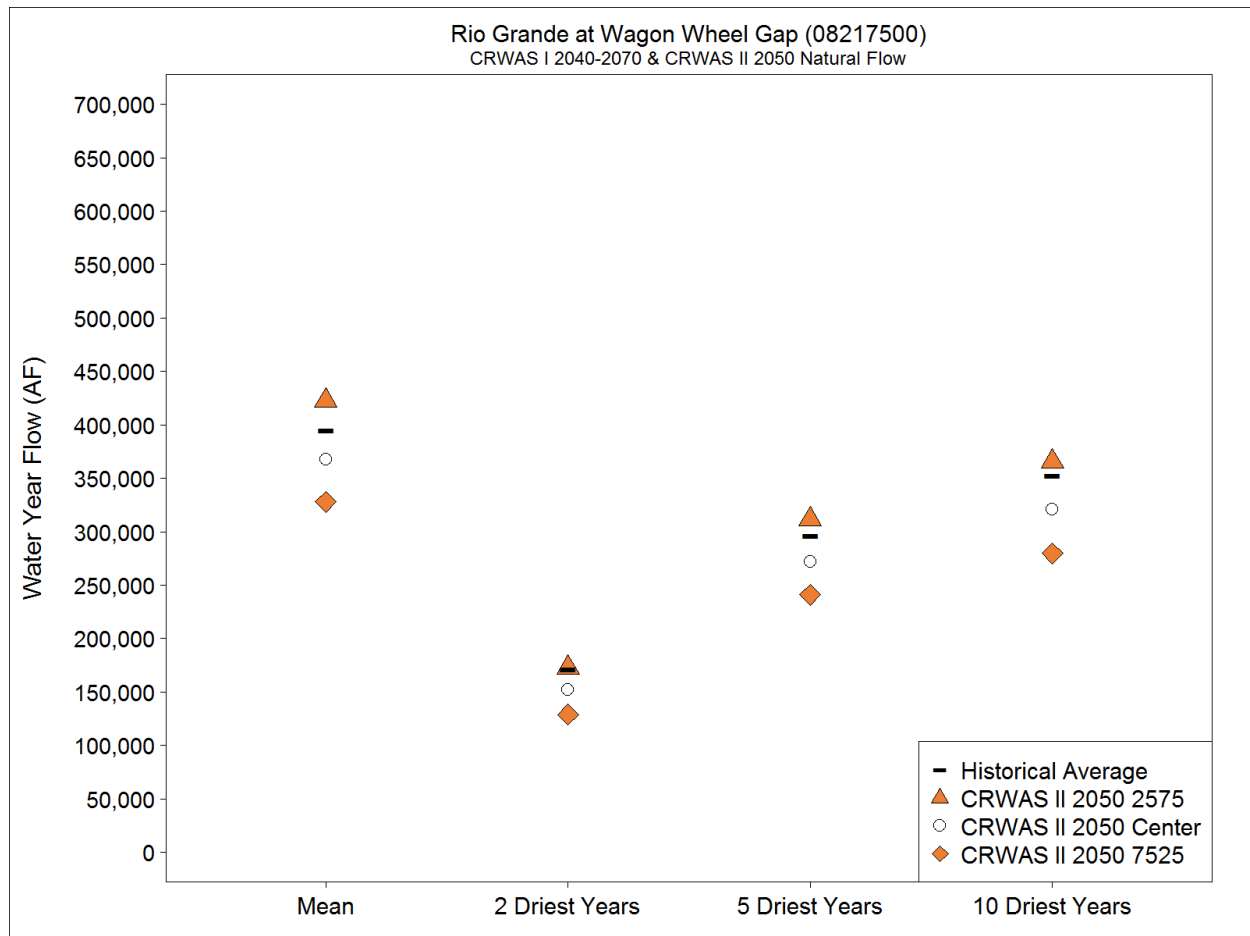
The future climate scenarios for the South Platte River at Julesburg show that the driest 2-year flow represents a 44% reduction from the average annual flow of approximately 1.5 million AF, for the CRWAS-II Center scenario. The CRWAS-II Center scenario is within 5% of the annual historical flow. The results are shown in Figure 3.18.

Figure 3.18 Low Flow Comparison Chart, South Platte River at Julesburg



The future climate scenarios for the Rio Grande at Wagon Wheel Gap show that the driest 2-year flow represents a 59% reduction from the average annual flow of approximately 370,000 AF, for the CRWAS-II Center scenario. The CRWAS-II Center scenario is 7% drier than the average annual historical flow. The results are shown in Figure 3.19.

Figure 3.19 Low Flow Comparison Chart, Rio Grande at Wagon Wheel Gap



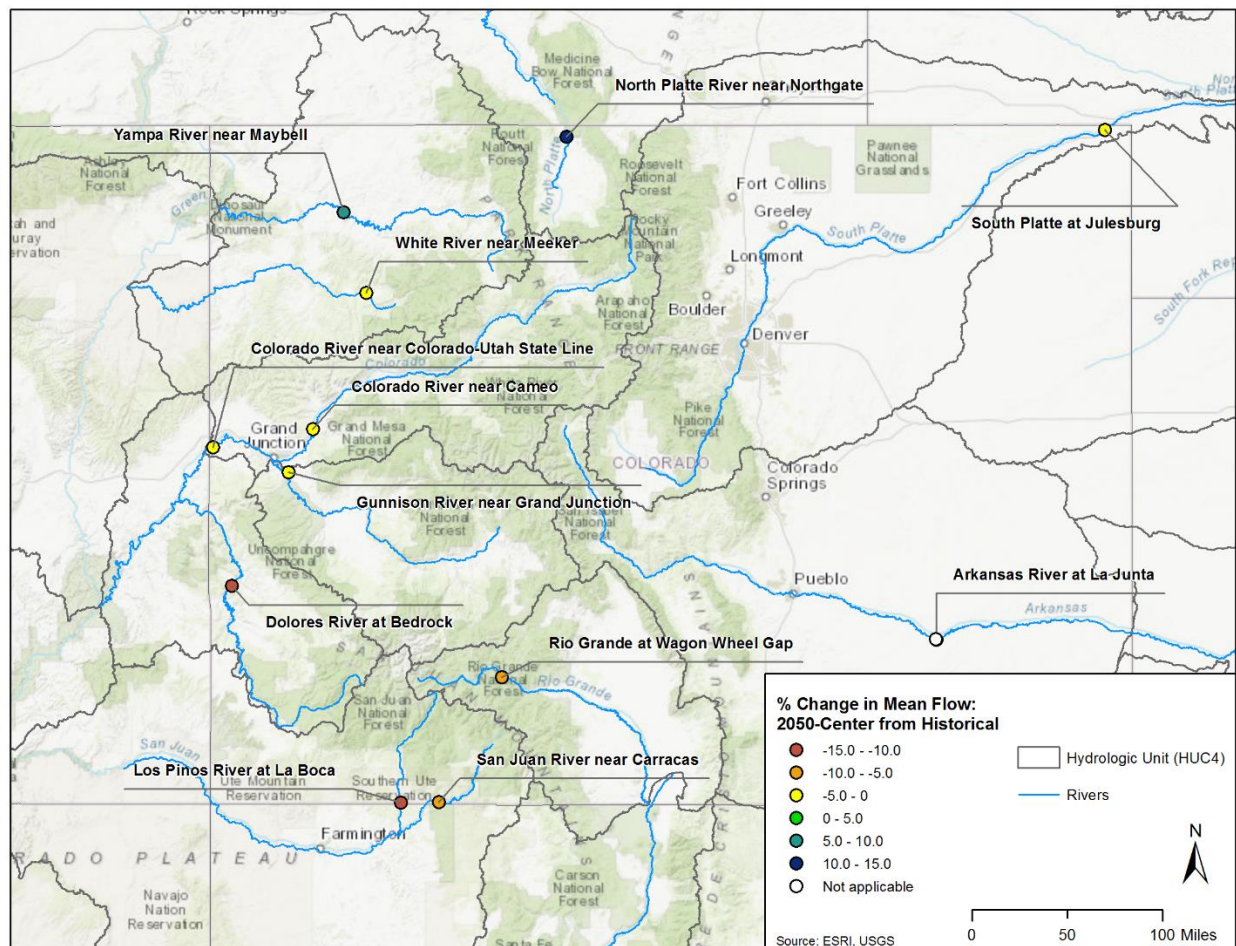
3.2.1.5 Summary of Results

The results of the CRWAS-II climate change study were used to compare future projected flow to historical natural flows for 12 river locations throughout Colorado. The historical flows are typically closest to the CRWAS-II 2575 scenario (25th percentile CIR and 75th percentile runoff), which represents more favorable or wetter future conditions. However, the central tendency of future climate projections, represented by the Center scenario, indicate decreases in flow, on average for Colorado.

The CRWAS-II results show future (2050) projected flows throughout Colorado have a range of uncertainty, with the possibility of both increased and decreased future flows for any given river. However, the average trend of future climate projections (Center scenario, using the 50th

percentile CIR and 50th percentile runoff) indicates a decrease in future average flows compared to historical average flows over the period of record. More specifically, rivers in southern Colorado show the largest decreases in flow, while rivers in northern Colorado show an increase in flow. Of the rivers analyzed for this study, the Dolores River, Los Pinos River, Rio Grande, and San Juan River are projected to have the largest decreases in flow, with changes of -13%, -10%, -6.8% and -6.4%, respectively. The North Platte River and the Yampa River are projected to have the largest increases in flow, with changes of 12.2% and 8.9%, respectively. The projected changes in average annual flow for the 12 river stations are shown in Figure 3.20.

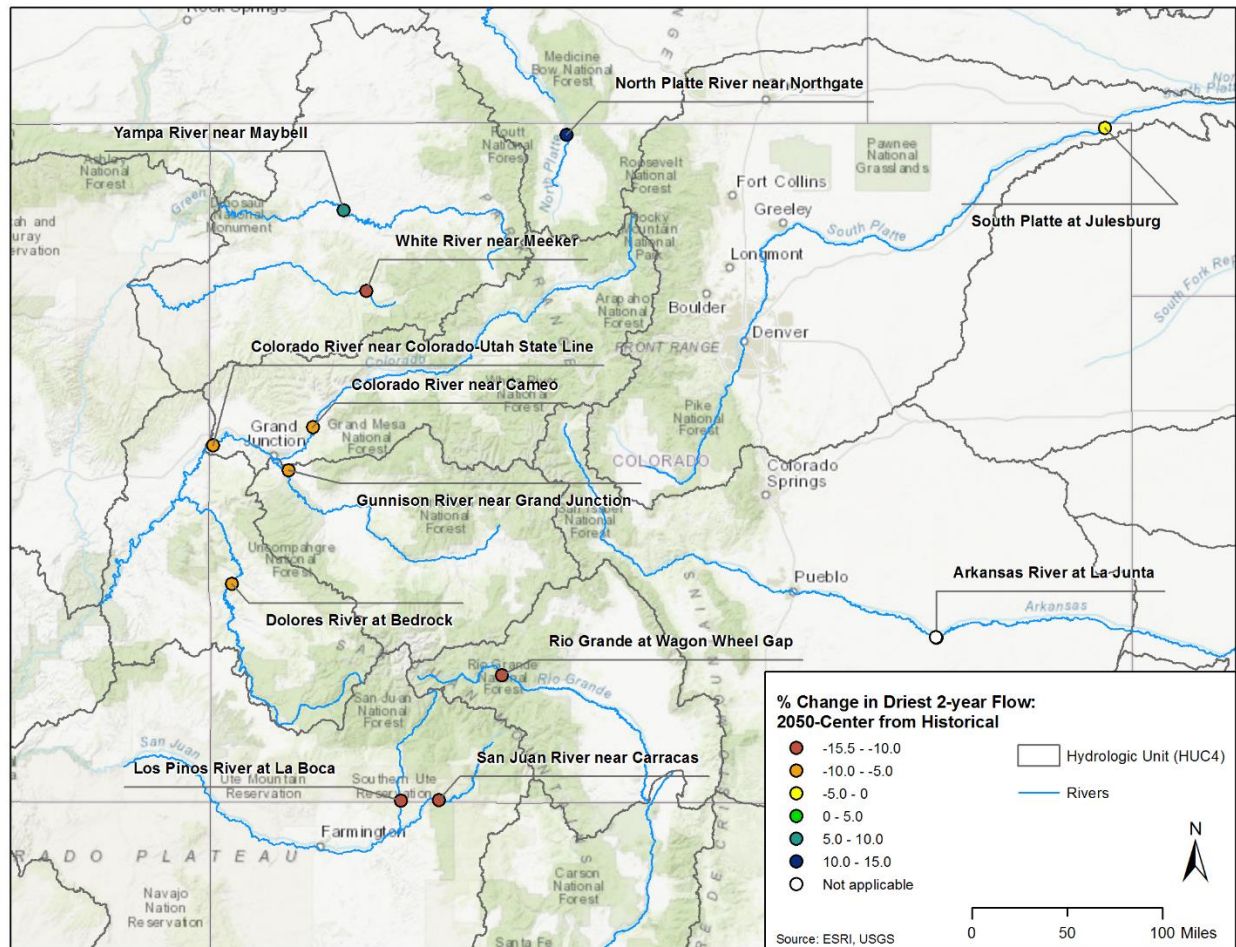
Figure 3.20 Summary of CRWAS-II Average Center (2050) Results



The low flow analysis completed using the CRWAS-II data helps to illuminate how droughts may change in the future. The historical and future (2050) projected lowest consecutive 2-year average flows were calculated for each of the 12 river locations. Most of the stations had a decrease of 5% or more in 2-year low flow indicating that drought conditions will be worse in the future. The Los Pinos River, White River, San Juan River, and Rio Grande show the largest decreases in 2-year low flow, with changes of -15.5%, -12.7%, -11.8%, and -11.2%, respectively. The North Platte River and the Yampa River are projected to have the largest

increases in 2-year low flow, with changes of 10.1% and 7.9%, respectively. The projected changes in the driest 2-year flow for the 12 stations are shown in Figure 3.21.

Figure 3.21 Summary of CRWAS-II Driest 2-year Center (2050) Results



3.3 The Boulder Climate Change Study

The potential impacts of climate change on a Front Range municipal water supply system was the subject of a NOAA-sponsored study entitled “Potential Consequences of Climate Change for the City Boulder, Colorado’s Water Supplies” (the Boulder Climate Change Study). This study combined the potential impacts of climate change with long-term climate variability to examine their effects on the City of Boulder’s water supply system. For this project, output from the Boulder Climate Change Study was evaluated to examine the effects of climate change on droughts on Boulder Creek. The hydrology of Boulder Creek is generally representative of the major mountain tributaries of the South Platte River.

The study examined outputs from 21 GCMs for the area covering the Boulder Creek basin and the Colorado-Big Thompson and Windy Gap projects. All of the models project higher temperatures

for this area. Roughly half of the models project decreased precipitation, and half project increased precipitation. While there is significant variation from model to model, in general the models tend to project wetter winters and drier summers. Four GCMs were selected to reflect a range of potential changes in precipitation. Outputs from the selected models reflecting three greenhouse gas emission scenarios (B1, A1-B and A2) were evaluated. Estimates of climate change for 20-year periods centering on 2030 and 2070 were used.

The study incorporated long-term climate variability exhibited by 437-year (1566-2002) tree ring-based streamflow reconstructions for Boulder Creek, South Boulder Creek, and the Colorado River (Woodhouse and Lukas 2006). A “nearest neighbor” approach was used to match natural streamflows and observed temperature and precipitation for 1953 through 2004 (for which climate records are available for the mountains above Boulder) with tree ring-derived annual streamflows. Years from 1953 through 2004 were used as proxies for pre-1953 years. A non-parametric re-sampling method was used to generate a 1,000 member ensemble of climate change scenarios (and a base case “no-climate-change” scenario), each comprised of 437 “years” selected from the 1953-2004 population that reflects the statistical properties of the 437-year long paleo-streamflow reconstruction.

A runoff model was calibrated using historical (1953-2004) weather data from the Niwot Ridge C1 station located west of Boulder and monthly natural streamflows for Boulder Creek at Orodell, South Boulder Creek near Eldorado Springs, and the Colorado River at Hot Sulphur Springs. Temperature and precipitation changes from the GCMs were applied to the runoff model to generate altered monthly flows that were reflected in the ensembles. Temperature and precipitation changes from the GCMs were also used to adjust Boulder Creek basin irrigation demands and South Platte River calls.

The effects of altered streamflows, precipitation and temperature upon Boulder’s water supply system were evaluated using the Boulder Creek Model, developed by the City of Boulder to analyze water supply reliability. The Boulder Creek Model simulates the operation of Boulder’s water supply system given natural streamflows, water rights, water demands and return flows, and diversion and storage facilities in the Boulder Creek basin and calls from downstream South Platte rights.

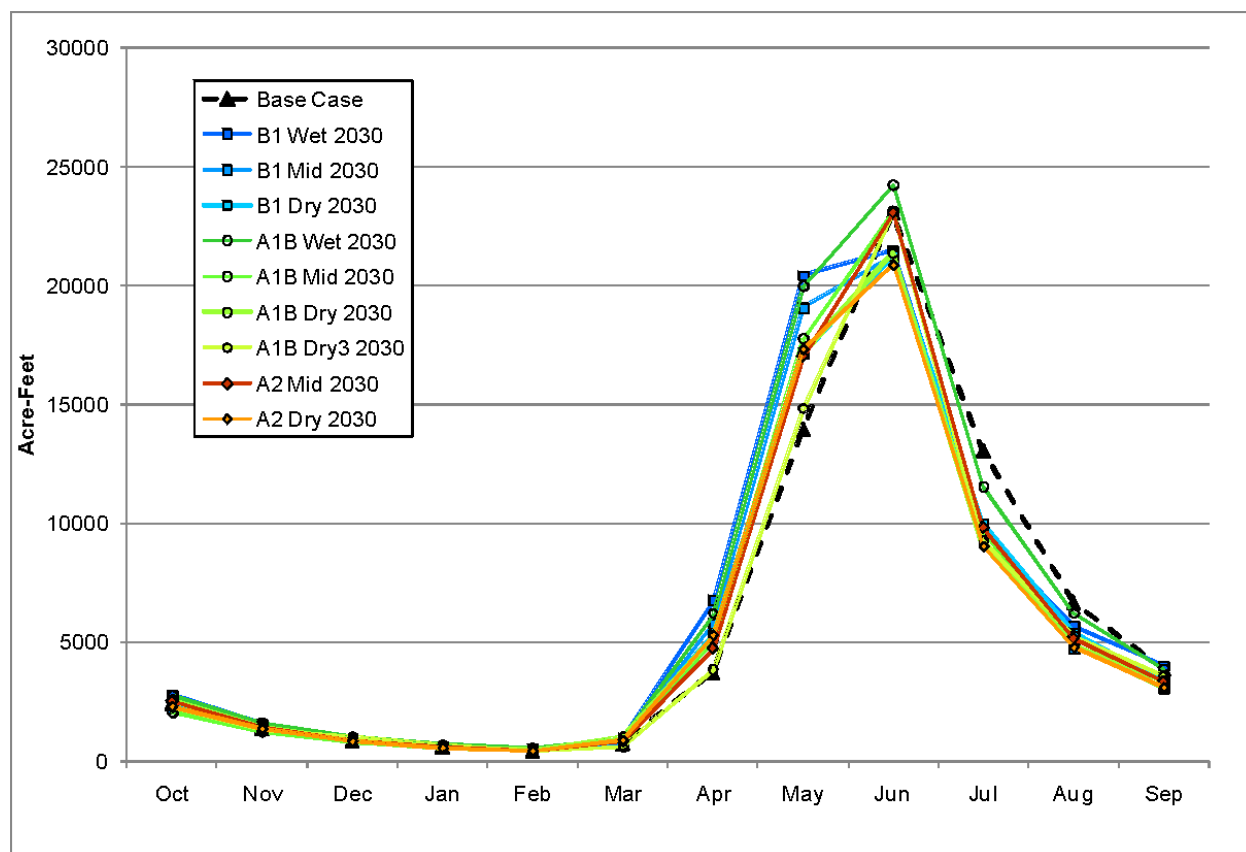
Results from the Boulder Climate Change Study (shown in Table 3.9) indicate that, in seven out of the nine climate change scenarios evaluated, droughts on Boulder Creek are likely to be longer than those simulated in the base-case.

Table 3.9 Drought Lengths, Boulder Creek Near Orodell (2030 Conditions)

Average Length of Maximum Drought (years)	Maximum Drought Length (years)
Base Case Hydrology	
10.6	13
Projected Climate Scenarios	
7.6	11
12.5	20
12.6	20
4.4	5
13.4	21
14.1	20
24.0	24
12.5	20
22.9	24

Increase in temperature alone was estimated to have little effect on the total annual volume of runoff, but by 2030 would result in increases in runoff in April and May and decreases in runoff in July and August, as shown in Figure 3.20. These seasonal changes (e.g., higher spring flows, lower summer flows) were estimated with increased or decreased precipitation. Annual runoff is quite sensitive to change in precipitation, with runoff decreasing with reduced precipitation and increasing with higher precipitation.

Figure 3.22 Mean Monthly Flows for Base Case and Climate Change Scenarios, Boulder Creek Near Orodell



4 INCORPORATING CLIMATE CHANGE INTO PLANNING

The results discussed above highlight possible changes to drought risk in a future climate. While there is no way to be certain what future hydrology may look like, it is important for planners to be aware that the future is unlikely to repeat the observed hydrology, and it is likely that Colorado will experience more severe and sustained droughts than seen in the last 56 years.

There are two main pathways for integrating climate information in water resources management. The first is a top-down perspective, in which projections are used to drive resource models and project future impacts. Conversely, a bottom-up approach starts with knowledge of specific system and analyzes the potential climate changes that would be most threatening to long-range plans or operations (CWCB 2008). No matter the approach, water resources managers and planners must make decisions based on a range of possible future scenarios. Scenario Planning is a widely used long-term planning approach to help managers keep open a wide range of options and maintain flexibility in the face of uncertainty (Water Plan 2015).

The CWCB has adopted scenario planning as an approach to plan for the uncertainties of future water supply and demand. Scenario planning assumes the future is unknown, providing flexibility in responding to future conditions. The use of scenario planning allows for conversations with stakeholders about water resource challenges and helps to answer questions on the future of water in Colorado (Water Plan 2015). Scenario planning has been used by the IBCC and basin roundtables in partnership with CWCB to explore unpredictable factors that will impact Colorado's future such as, climate change and economic and population growth and identify projects and policies that may be needed across various scenarios.

In recent years, the State has been paying increased attention to climate change projections from the IPCC. In 2014 Governor Hickenlooper released the Colorado Climate Plan (CCP) that defined policy recommendations and actions to improve Colorado's ability to mitigate and adapt to climate change, and in July of 2017, Governor Hickenlooper signed an executive order committing the state to additional climate action and specifying greenhouse gas emission reduction goals. An update to the CCP was issued in 2018 and included public input from the water sector.

Future climate change analysis should be used in conjunction with the vulnerability assessment completed here to inform the hazard profile and to support a drought risk assessment that incorporates vulnerability to possible future droughts.

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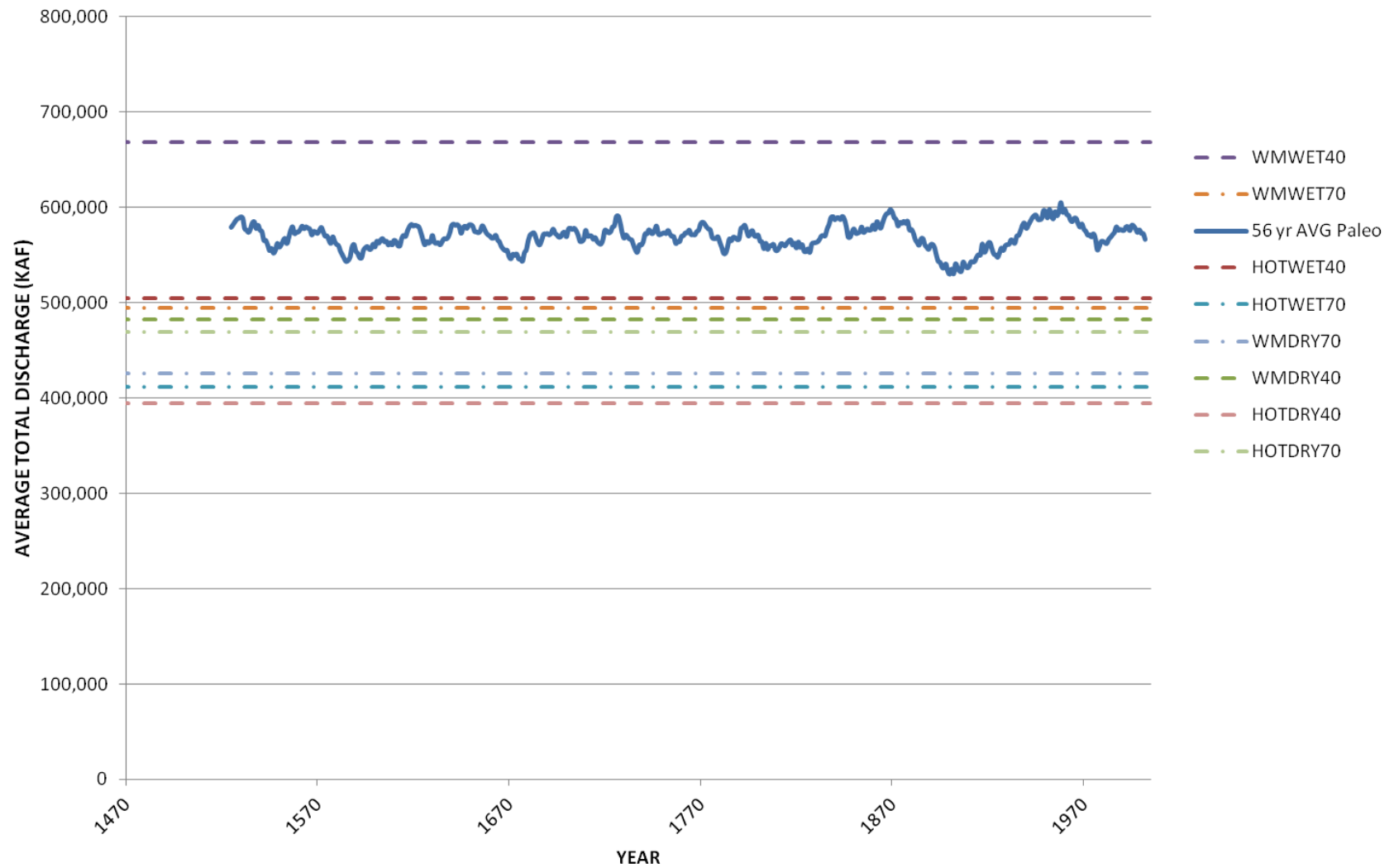
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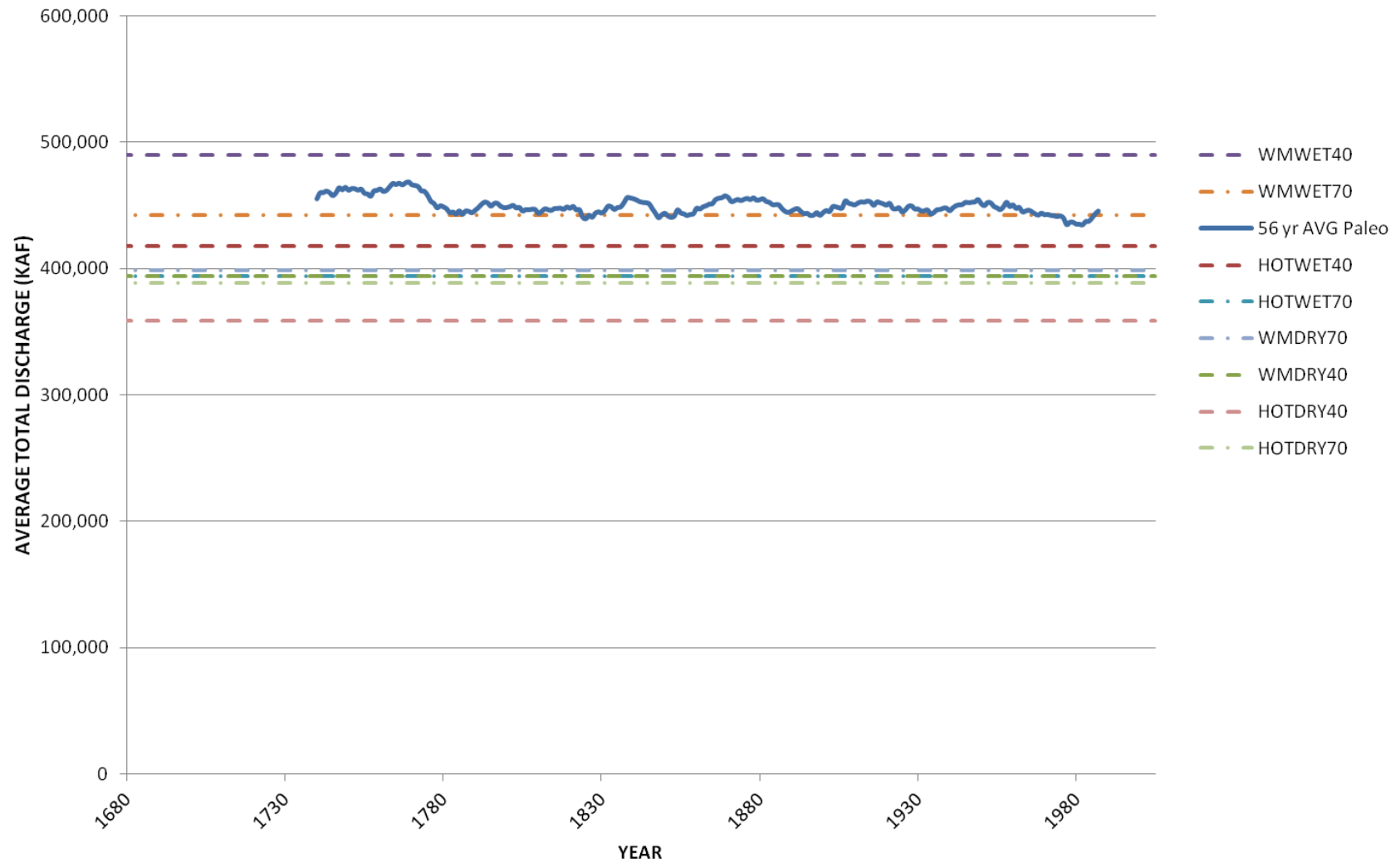
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6 APPENDIX 1: FLOW COMPARISON CHARTS

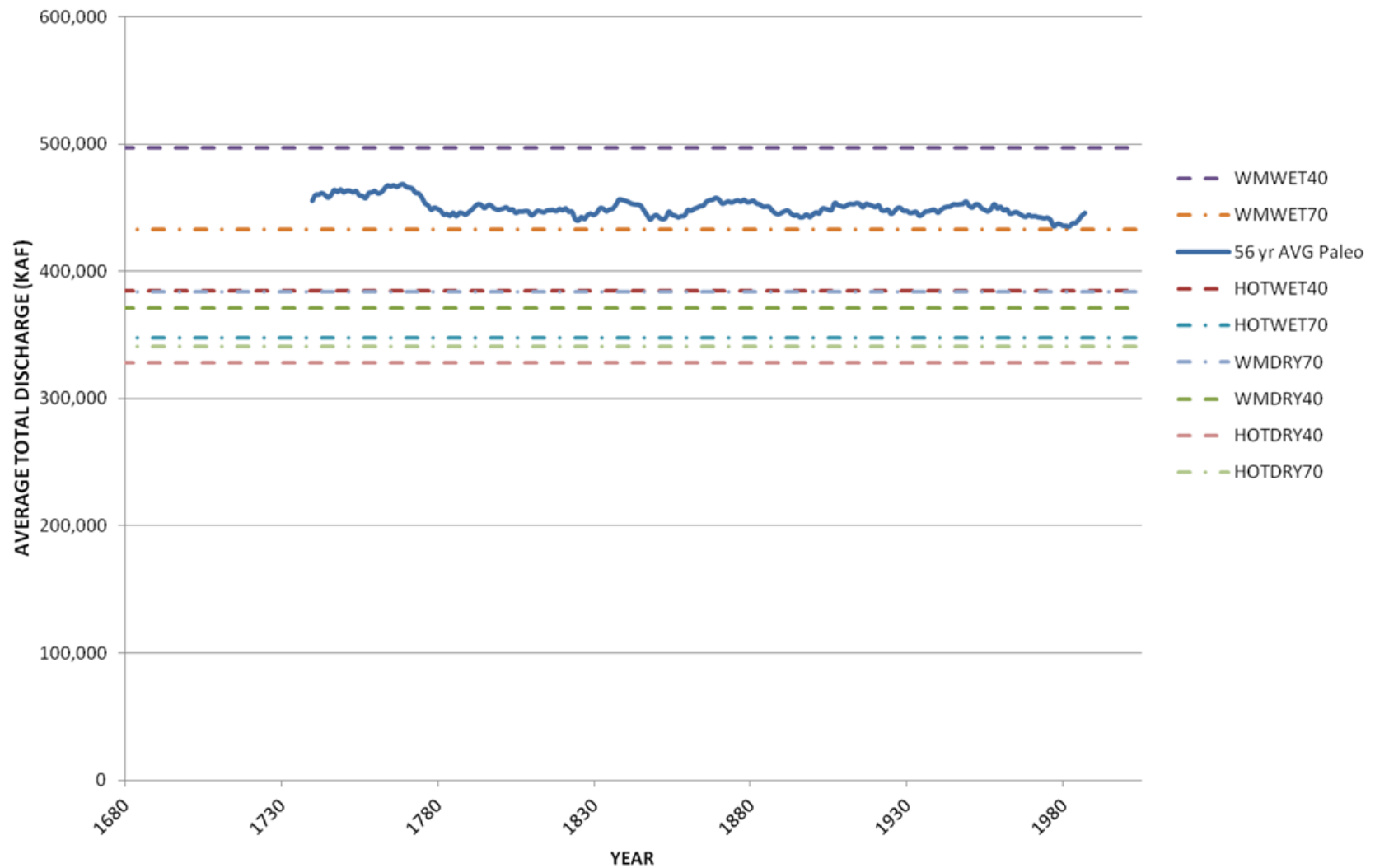
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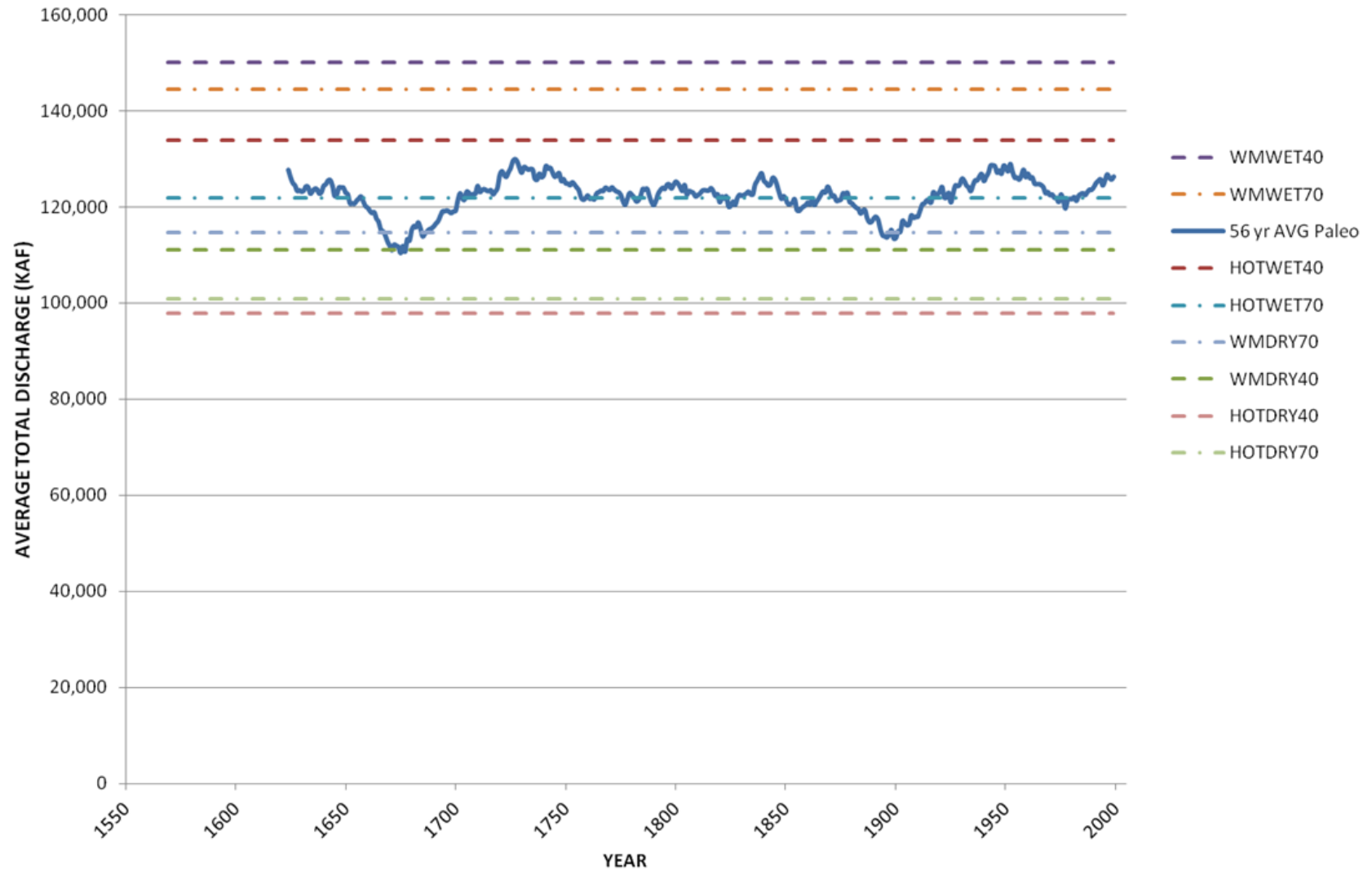
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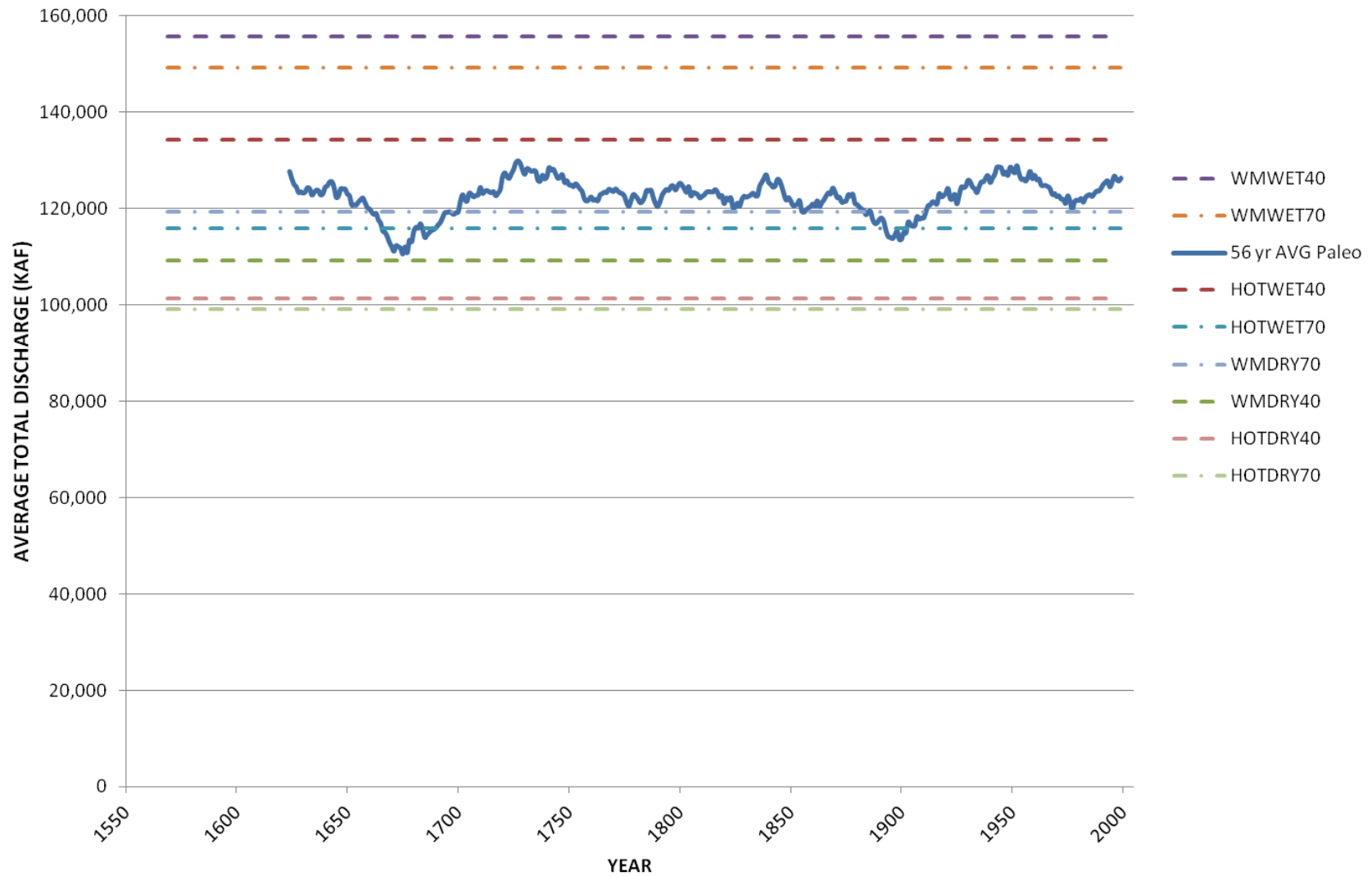
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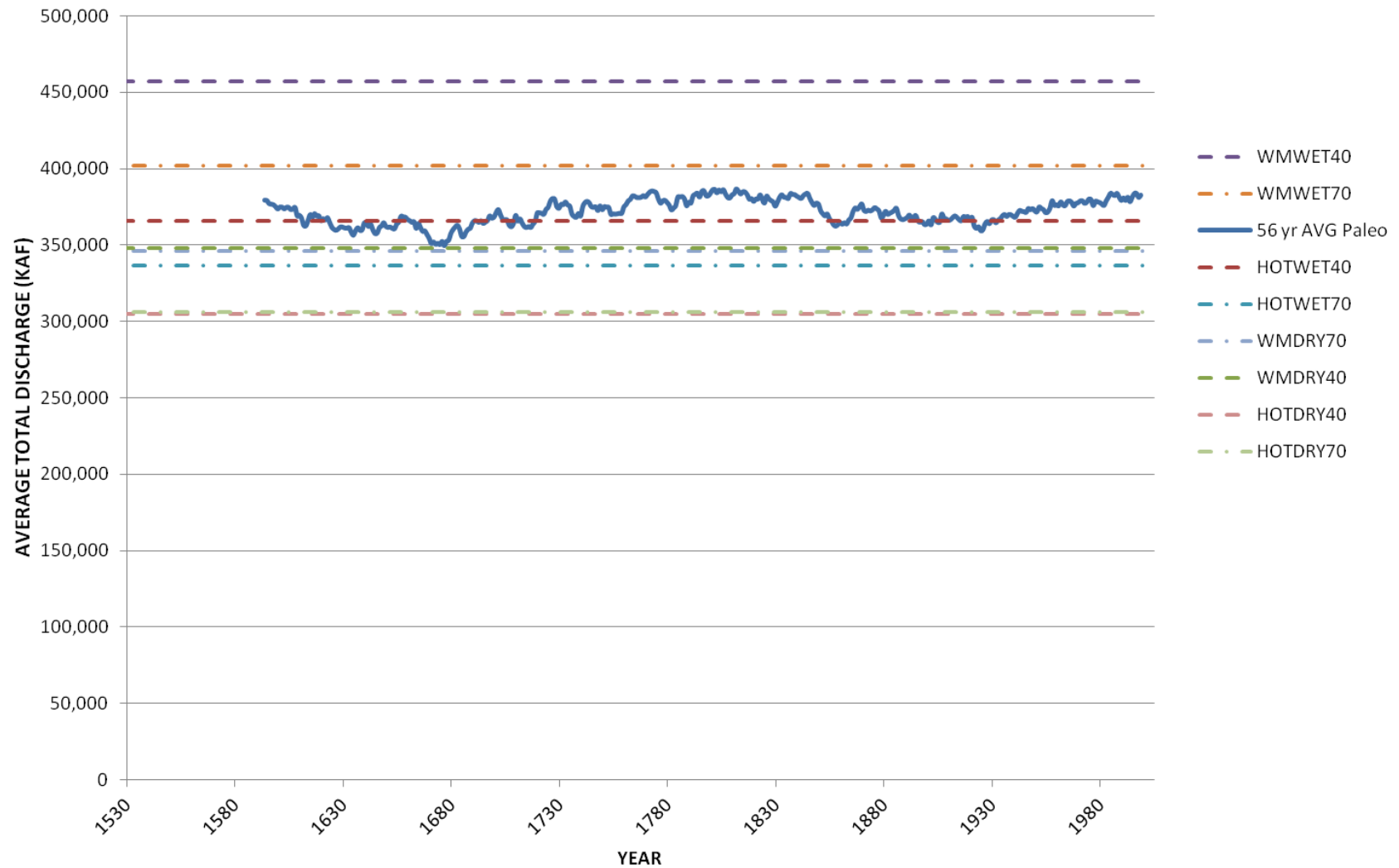
Big Thompson R 56-Year Average Flow - Paleo Reconstructions and Average Sacramento Projections



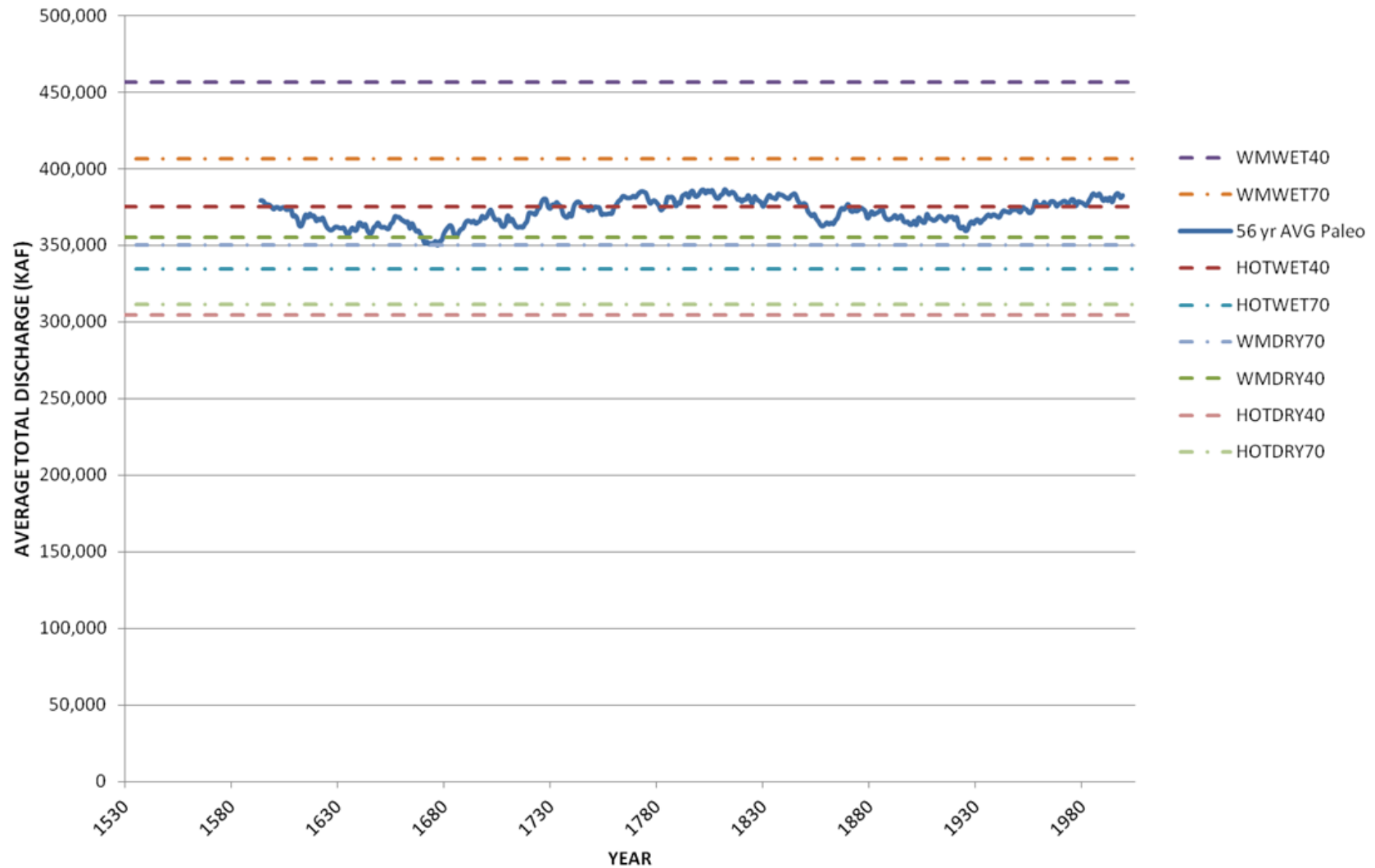
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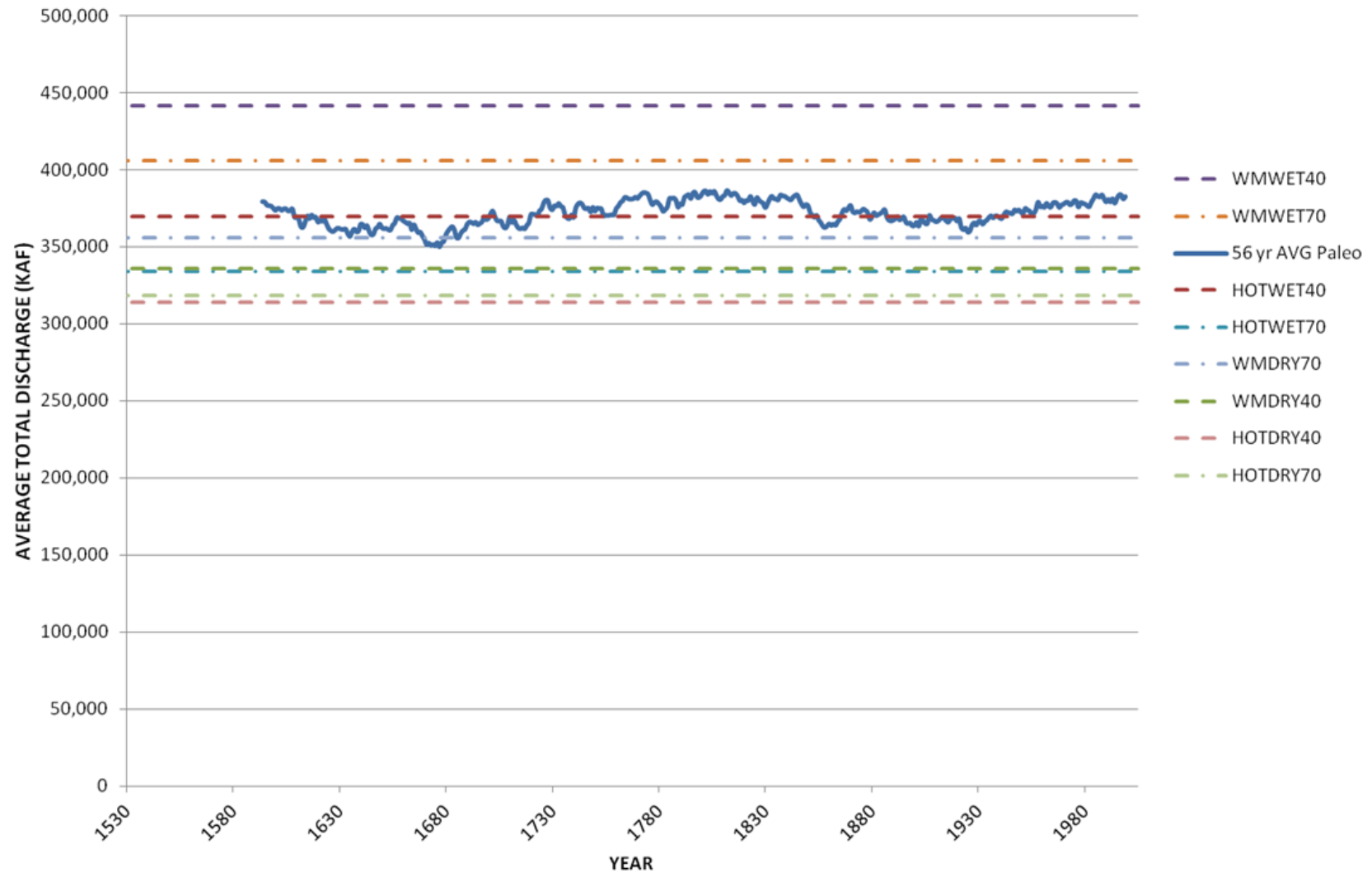
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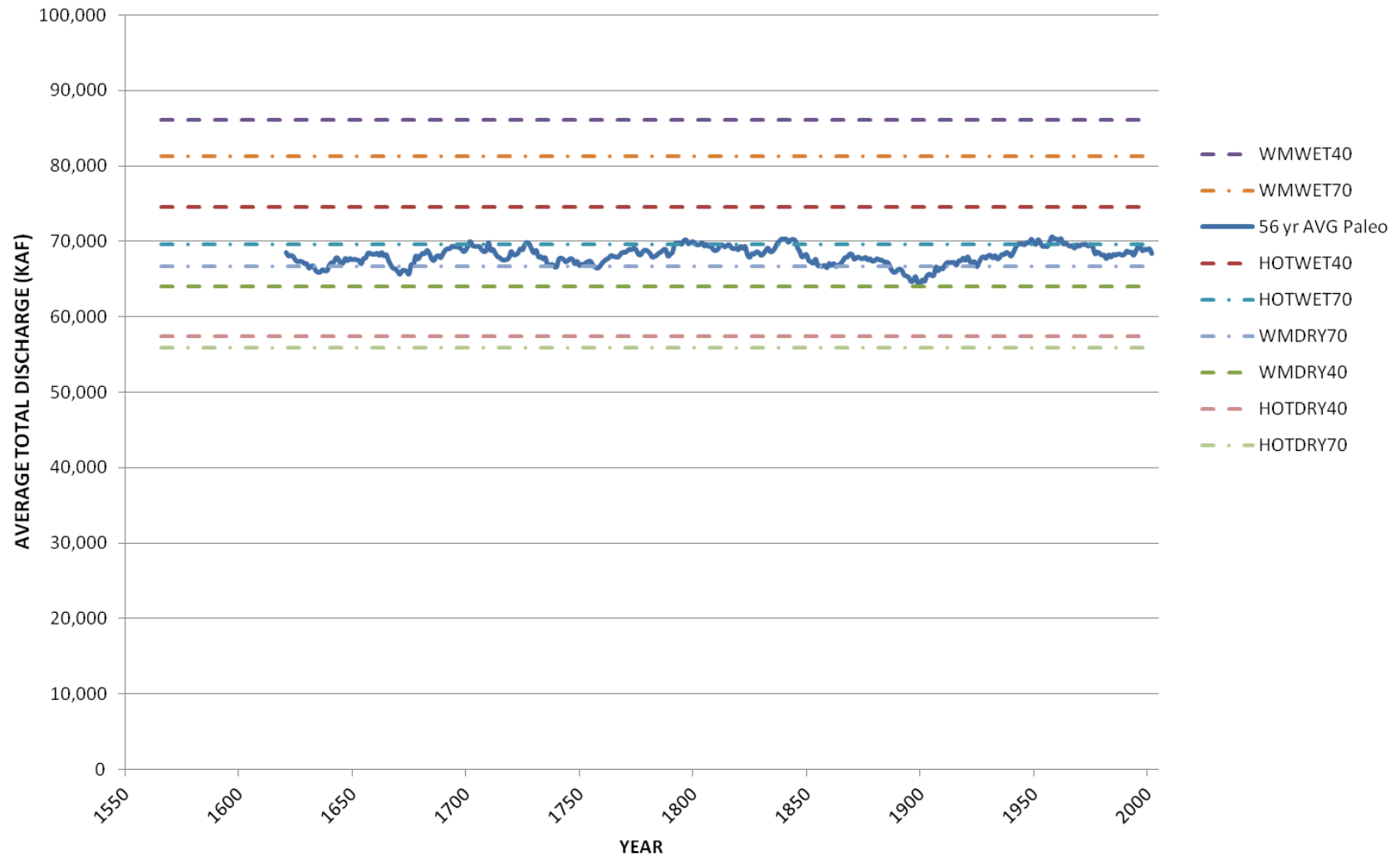
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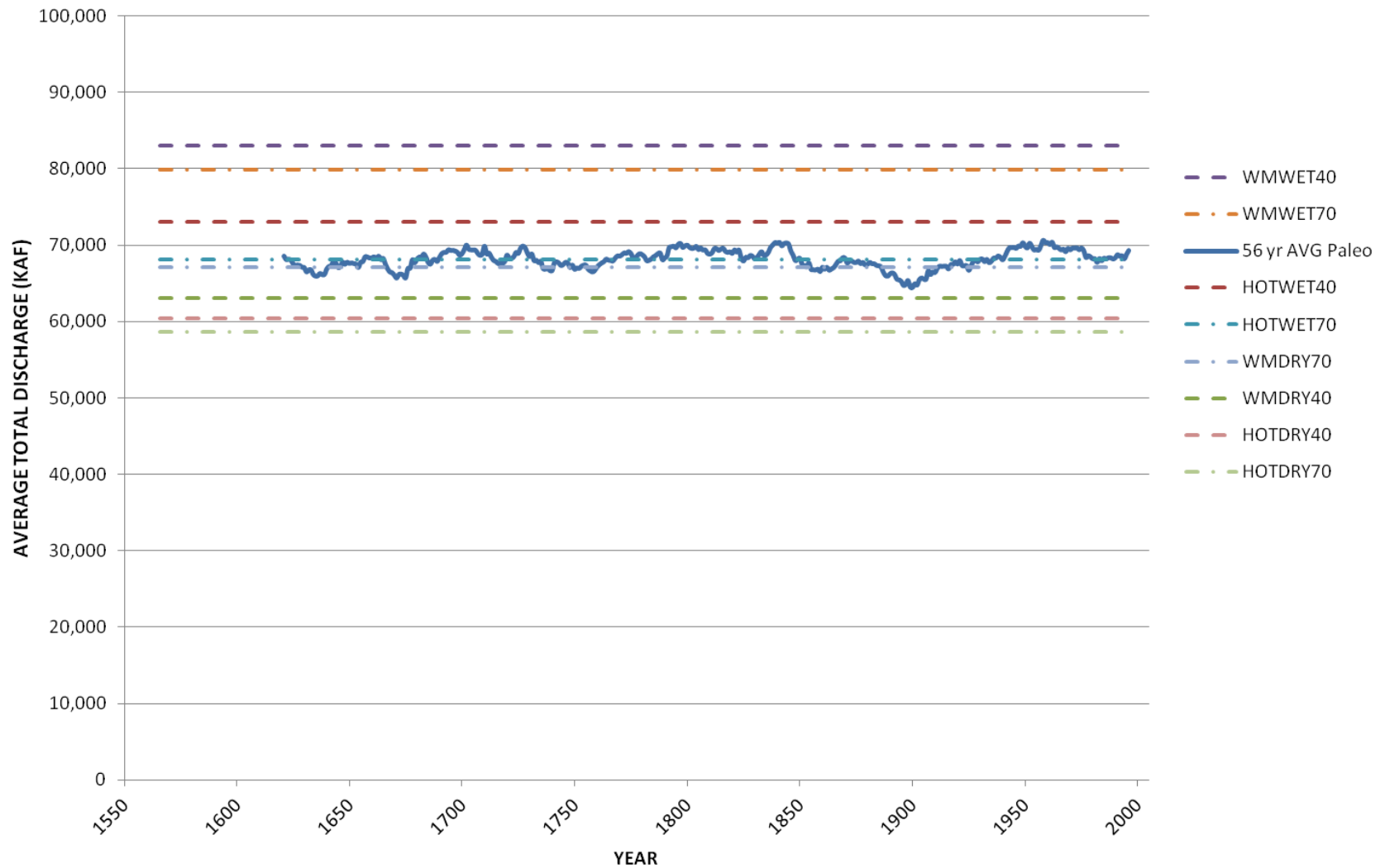
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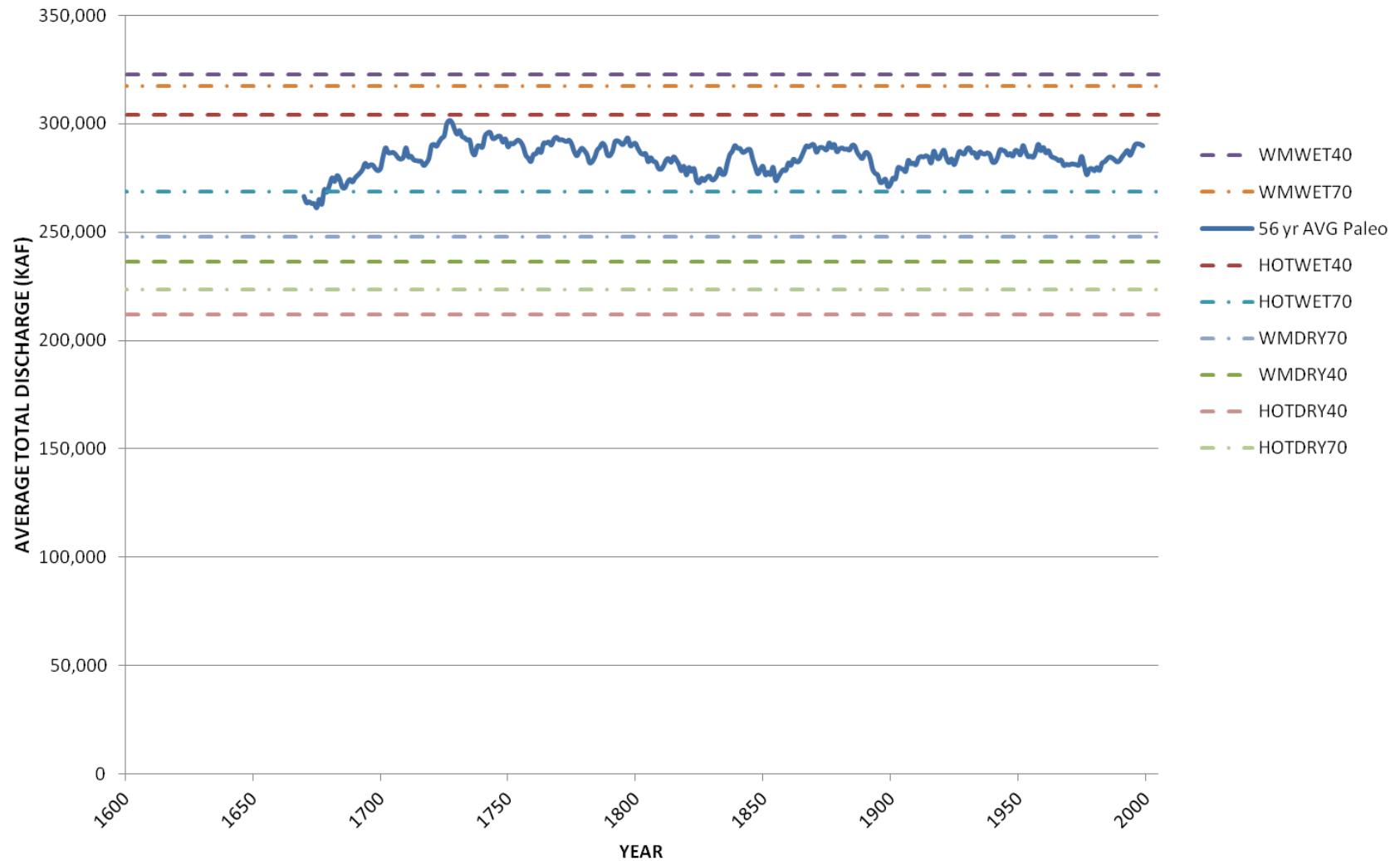
Boulder Ck at Orodell 56-Year Average Flow - Paleo Reconstructions and Average Sacramento Projections



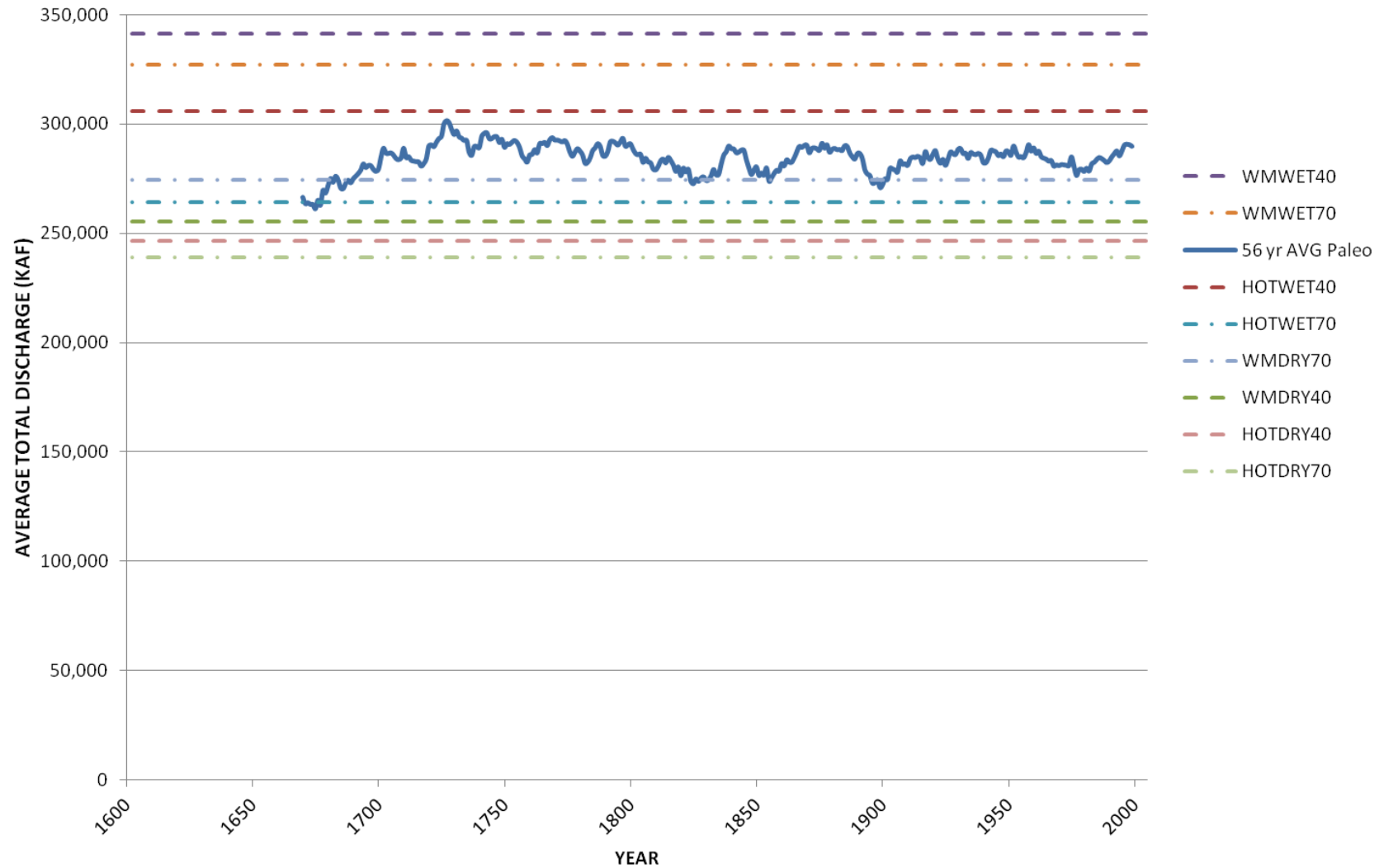
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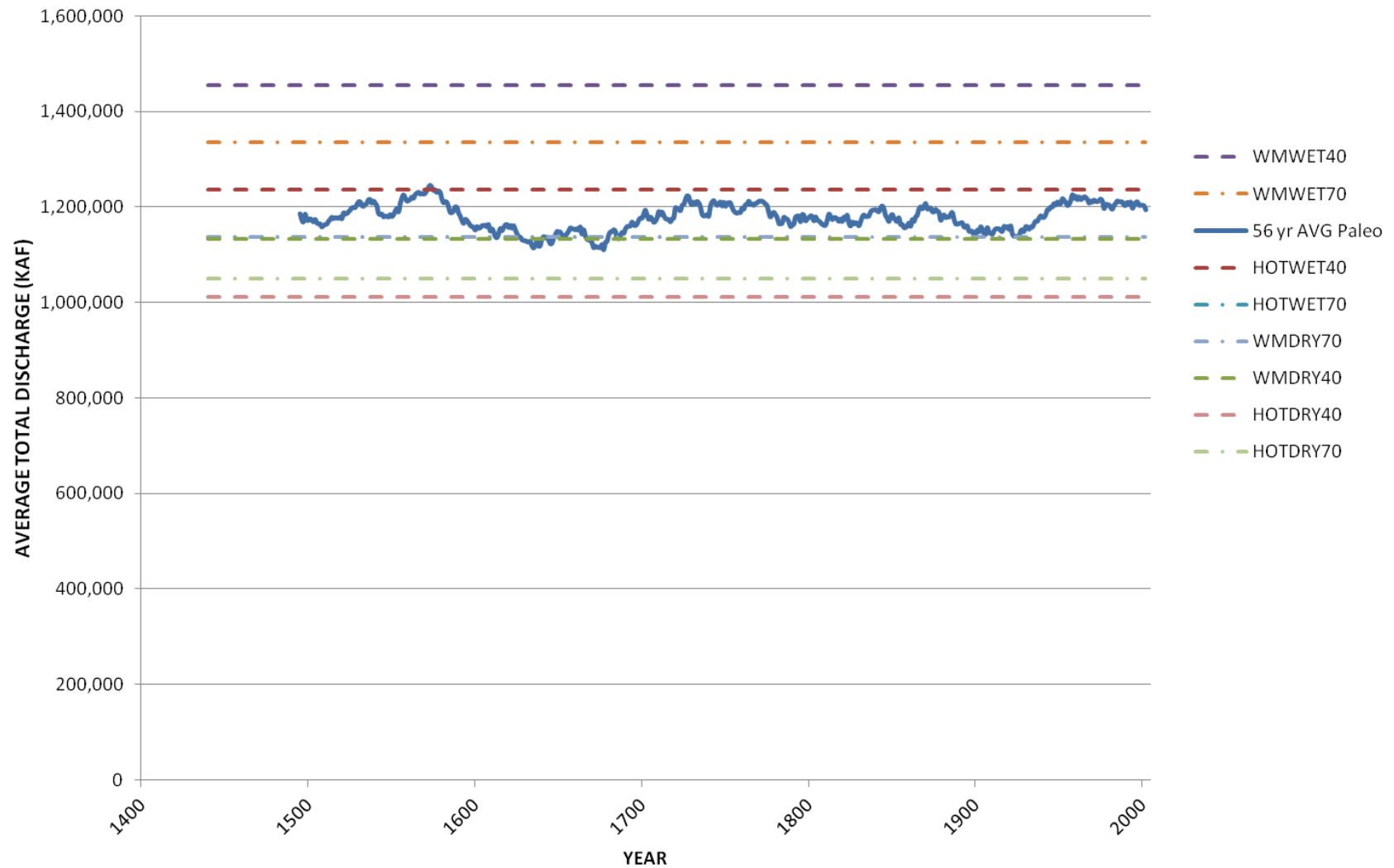
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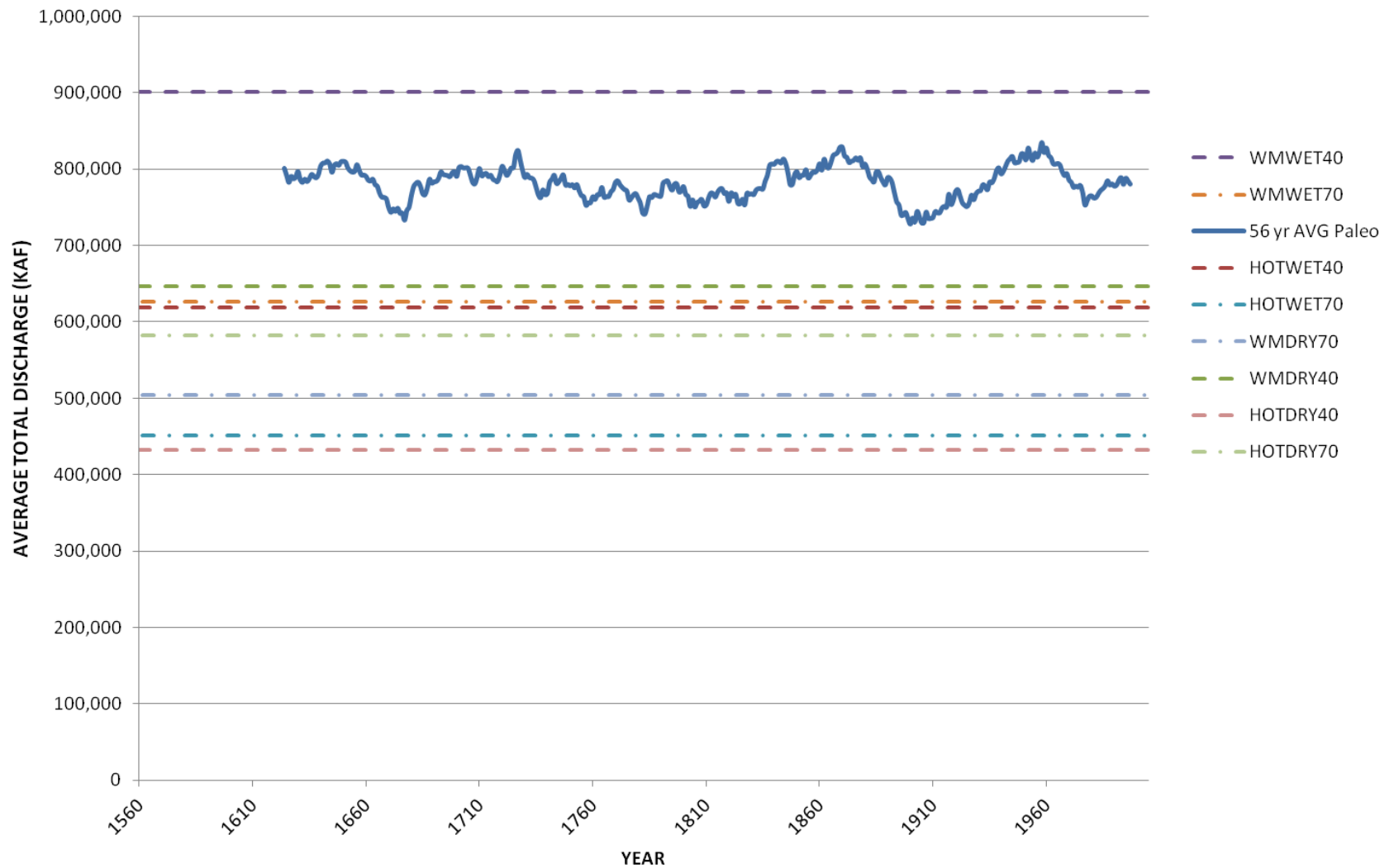
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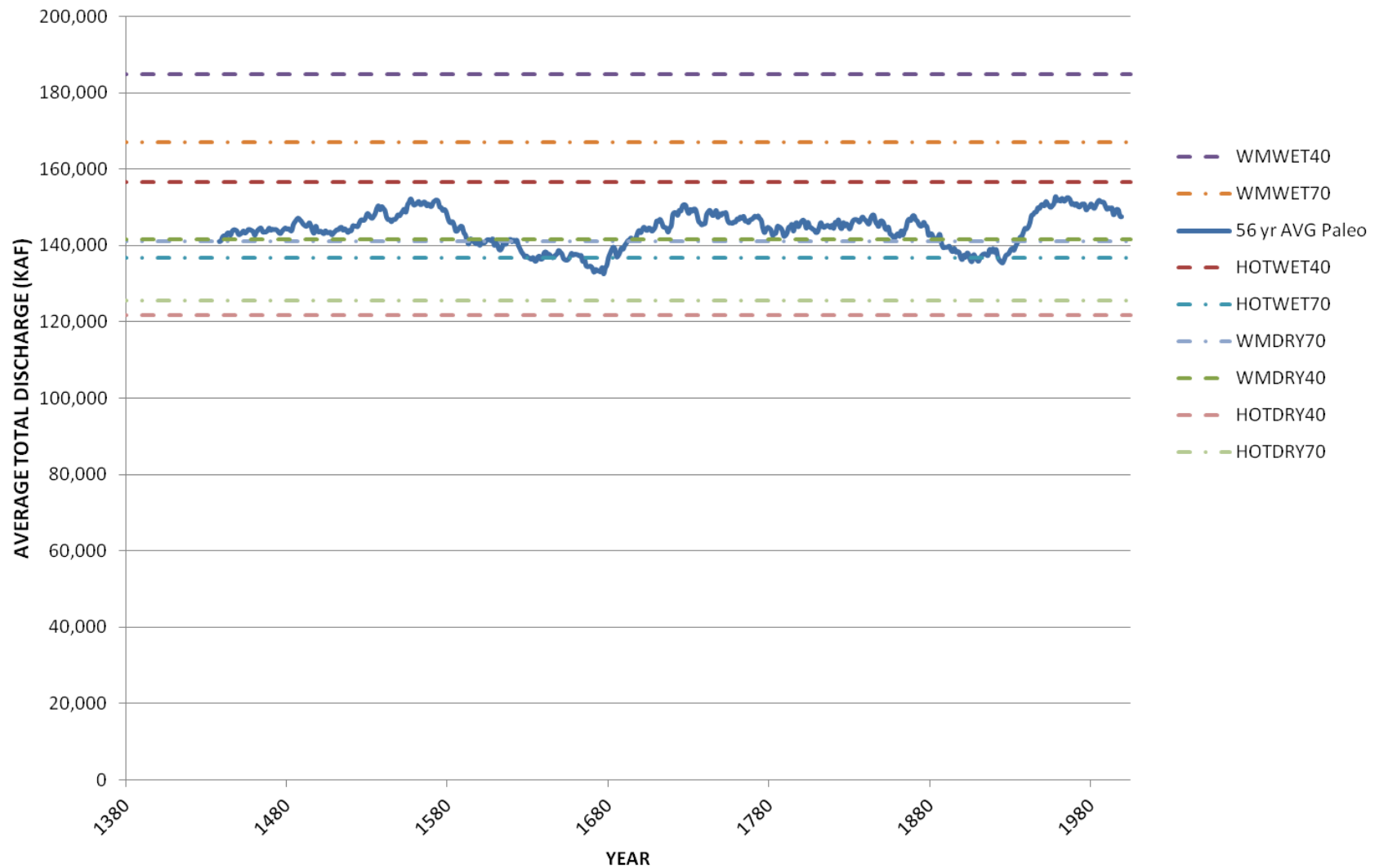
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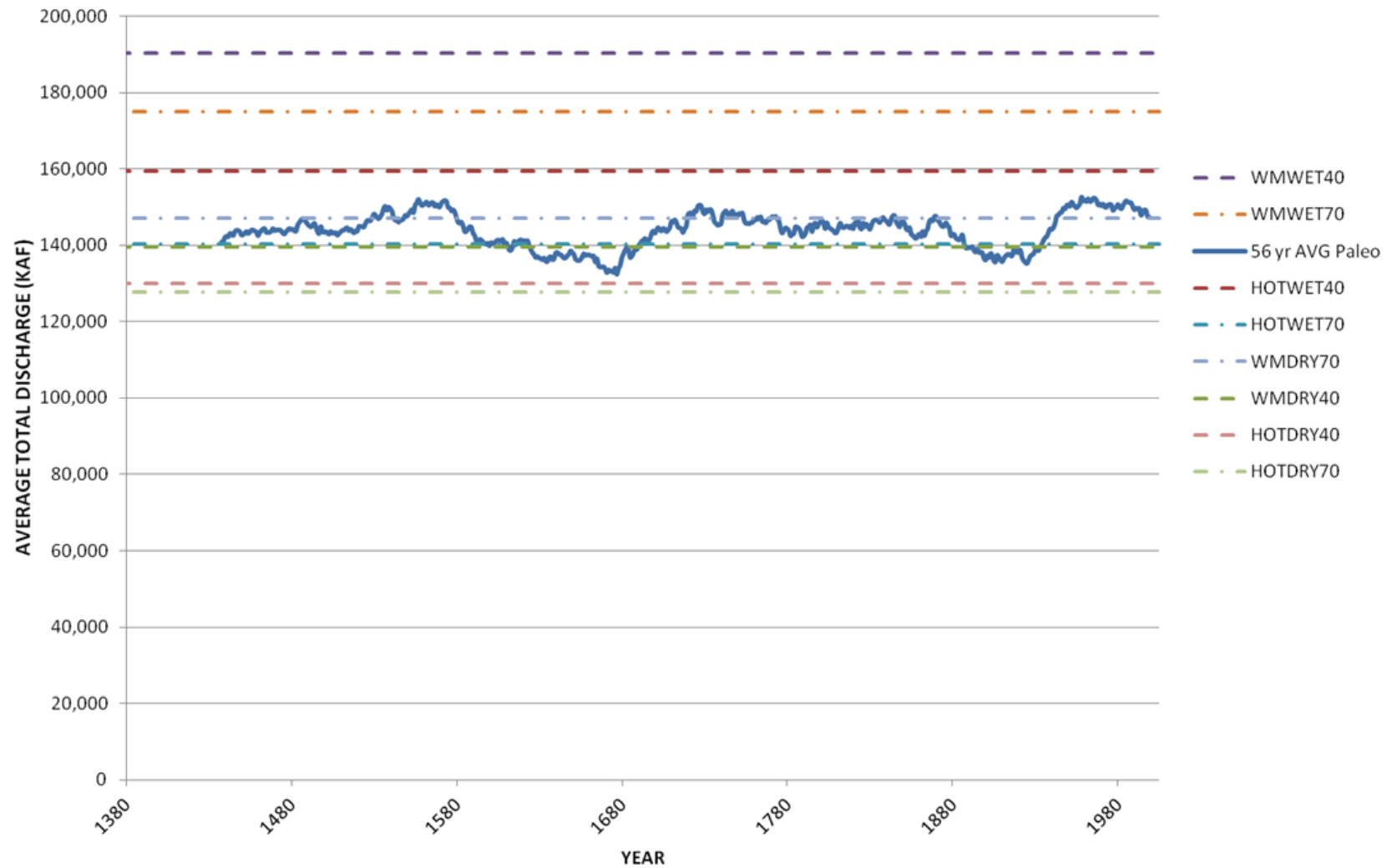
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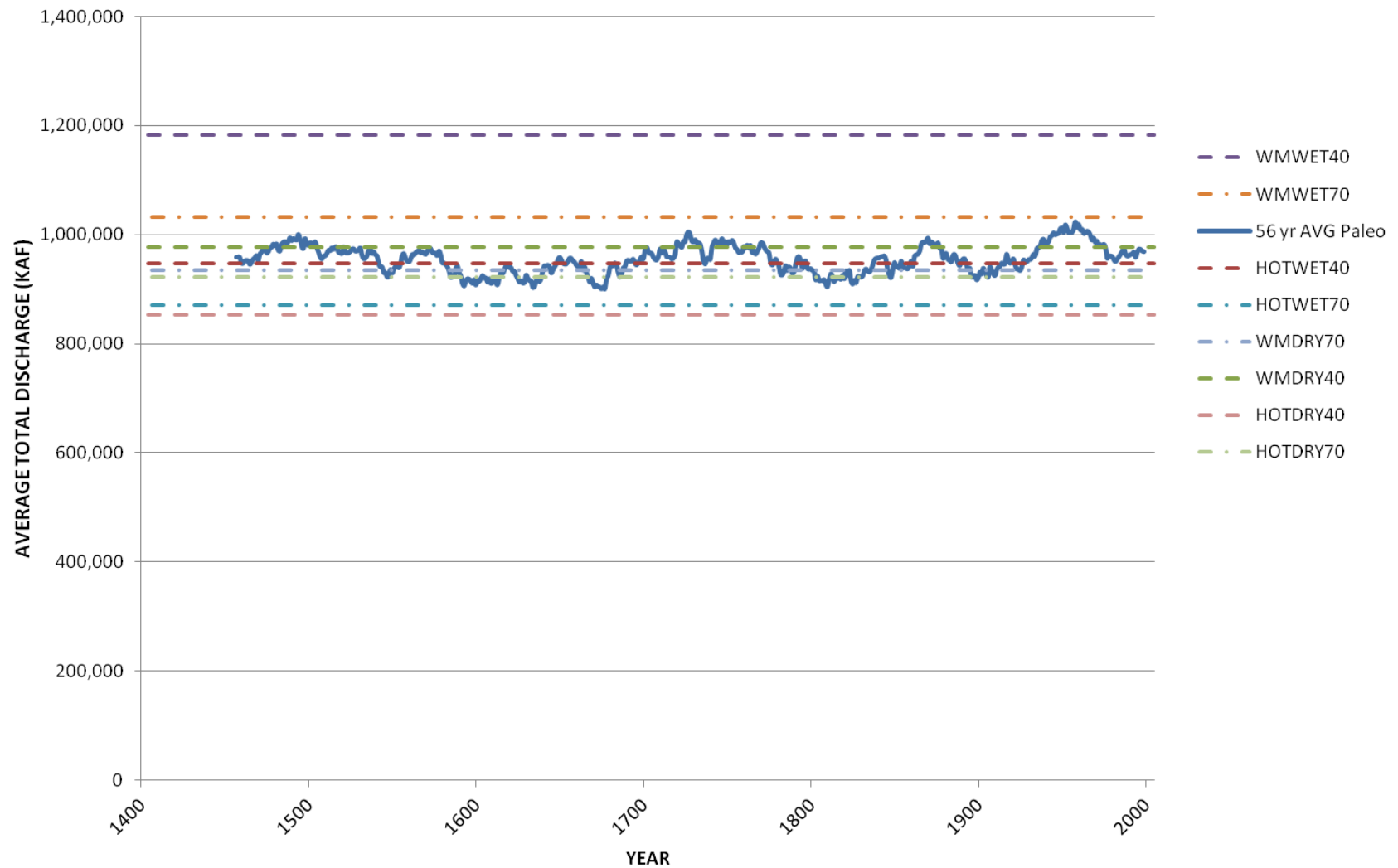
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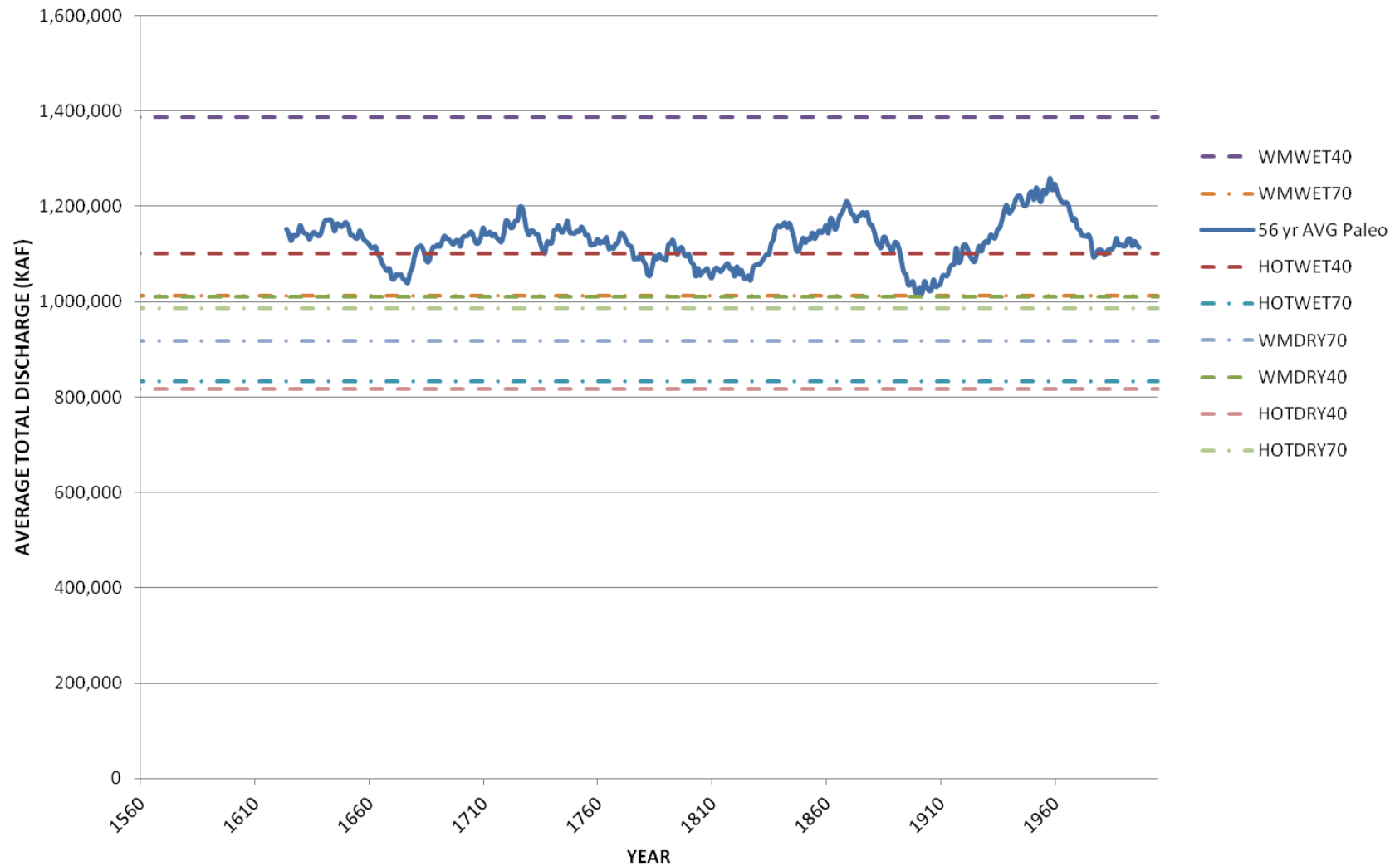
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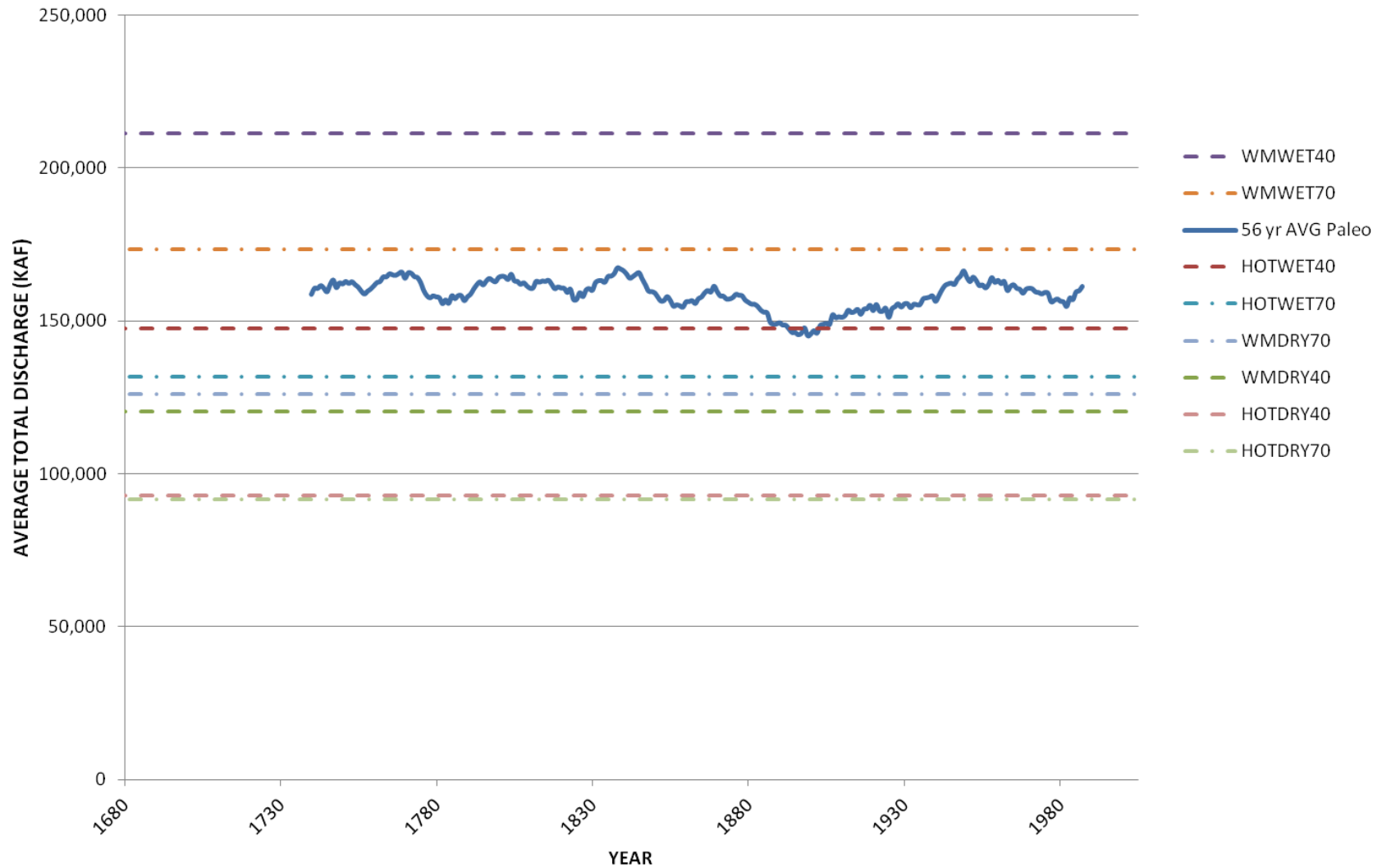
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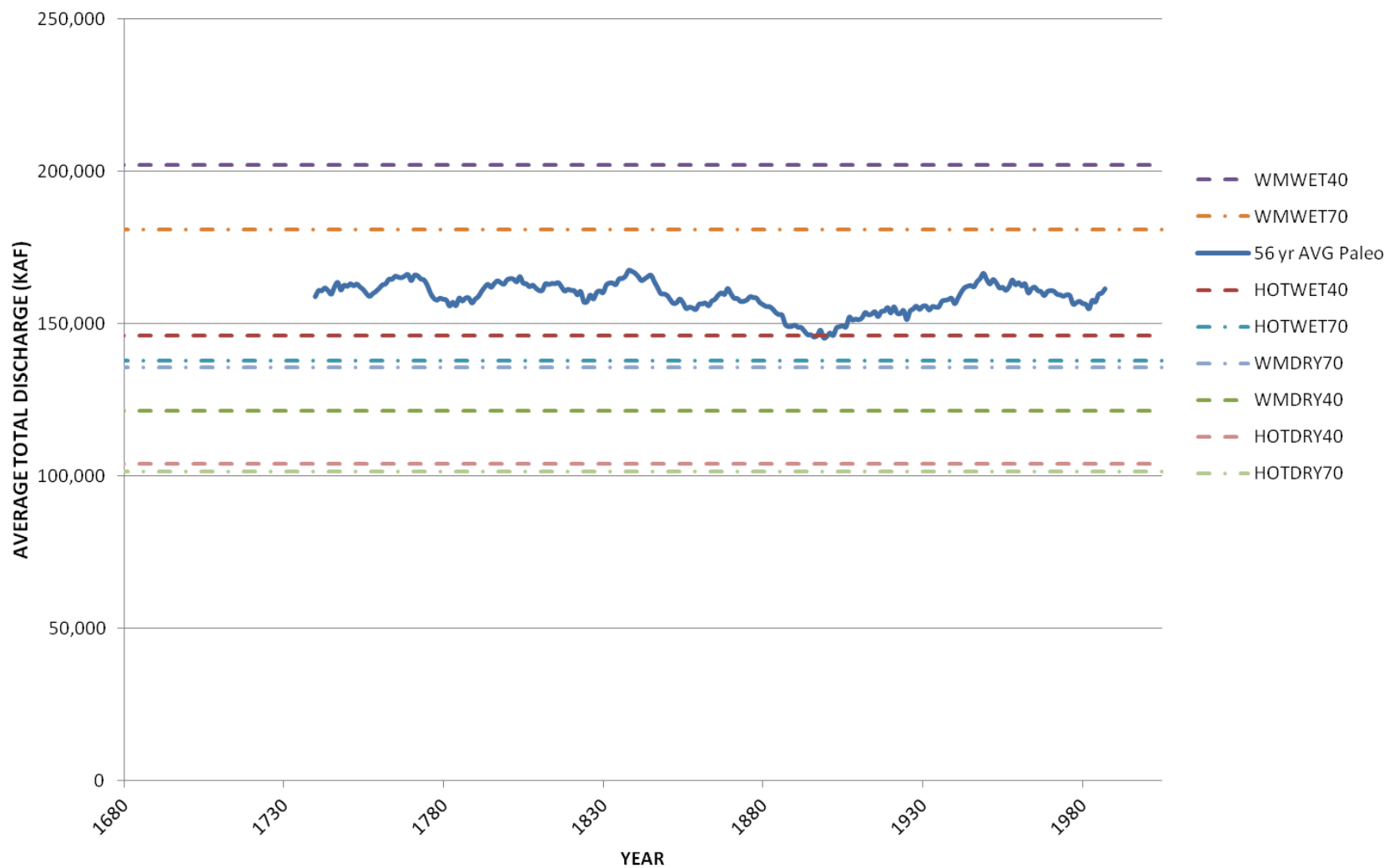
San Juan River near Archuleta 56-Year Average Flow - Paleo Reconstructions and Average CRWAS Projections



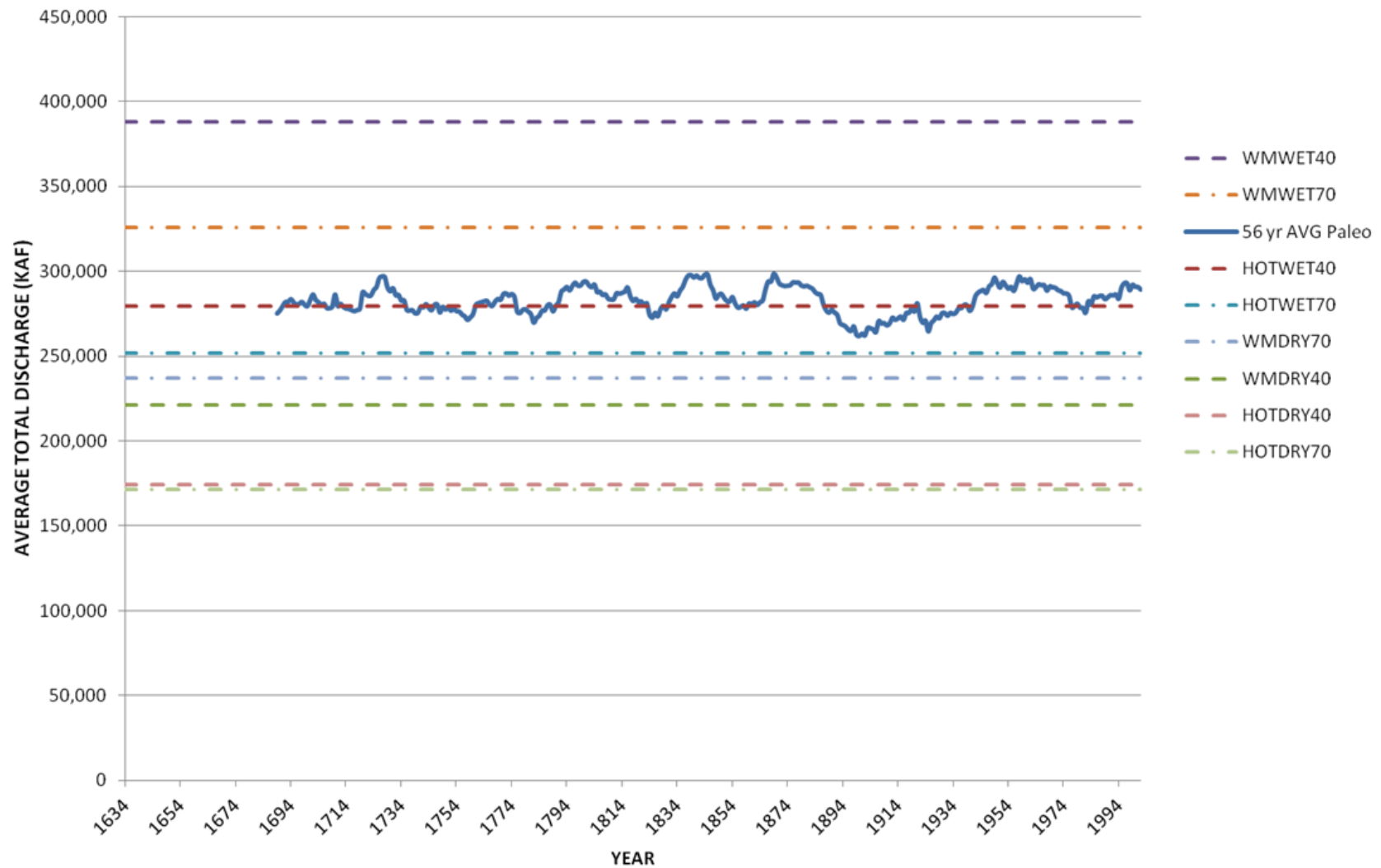
South Platte R below Cheesman 56-Year Average Flow - Paleo Reconstructions and Average Sacramento Projections



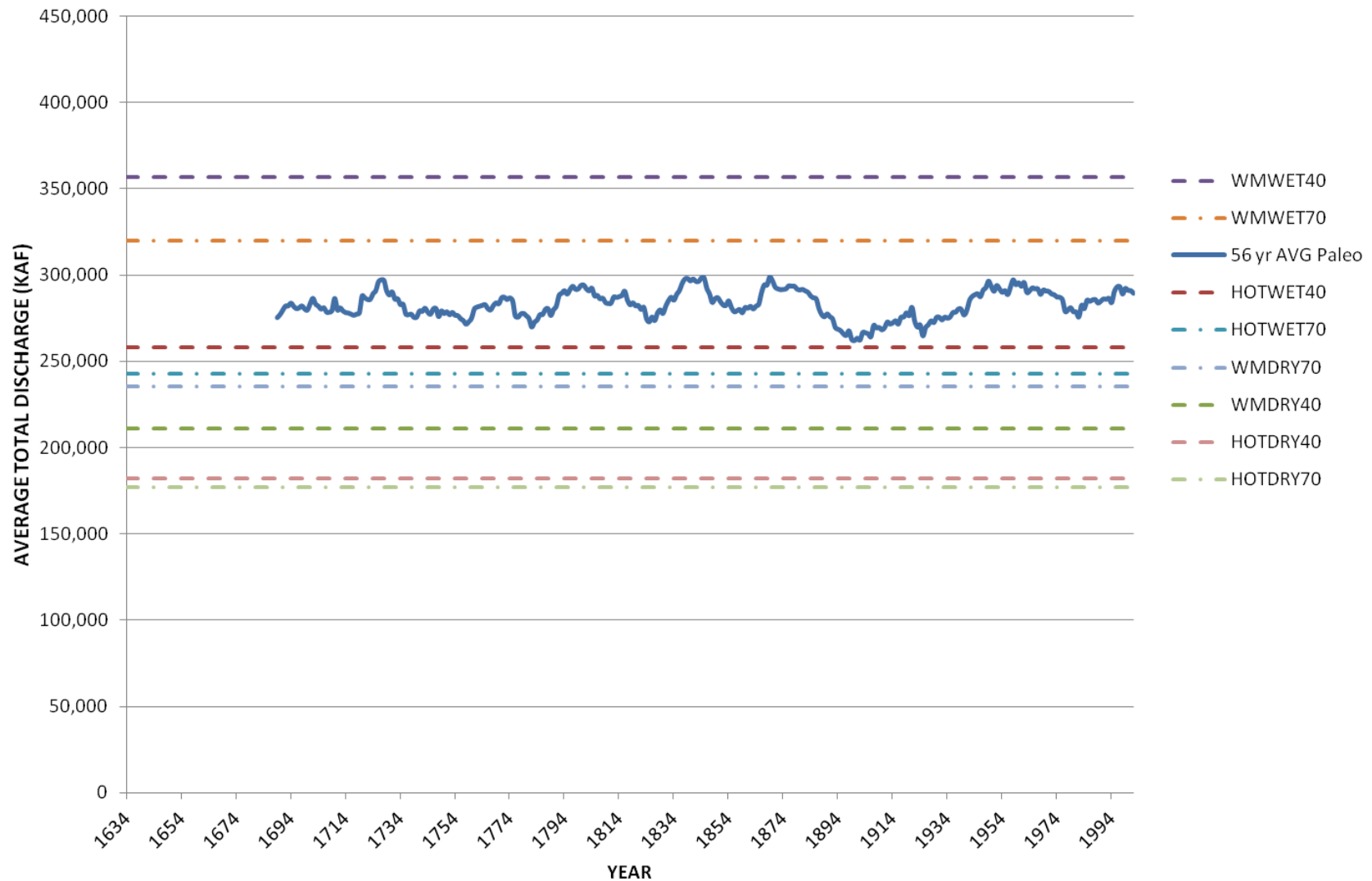
South Platte R below Cheesman 56-Year Average Flow - Paleo Reconstructions and Average WEAP Projections



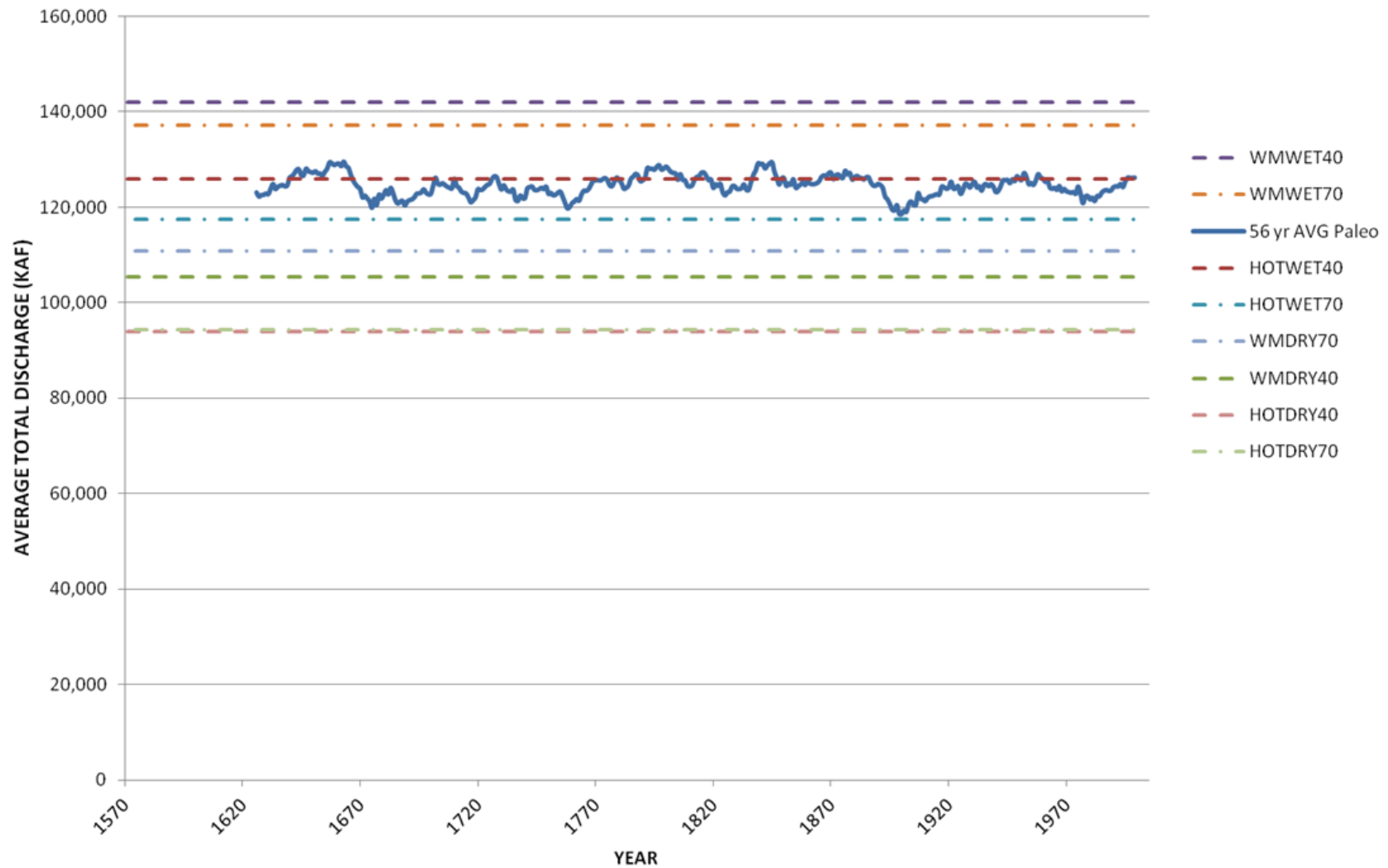
South Platte at South Platte 56-Year Average Flow - Paleo Reconstructions and Average Sacramento Projections



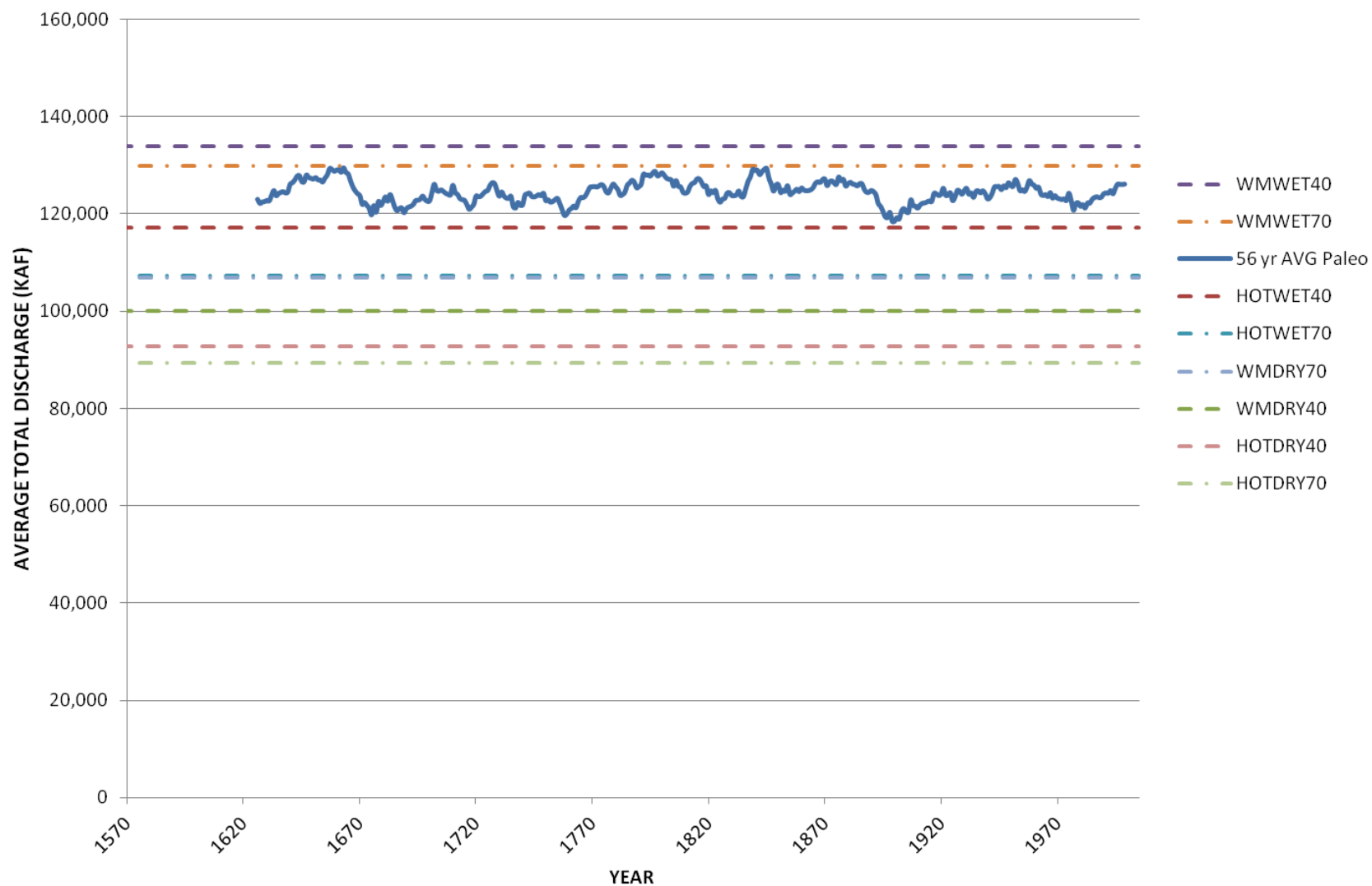
South Platte at South Platte 56-Year Average Flow - Paleo Reconstructions and Average WEAP Projections



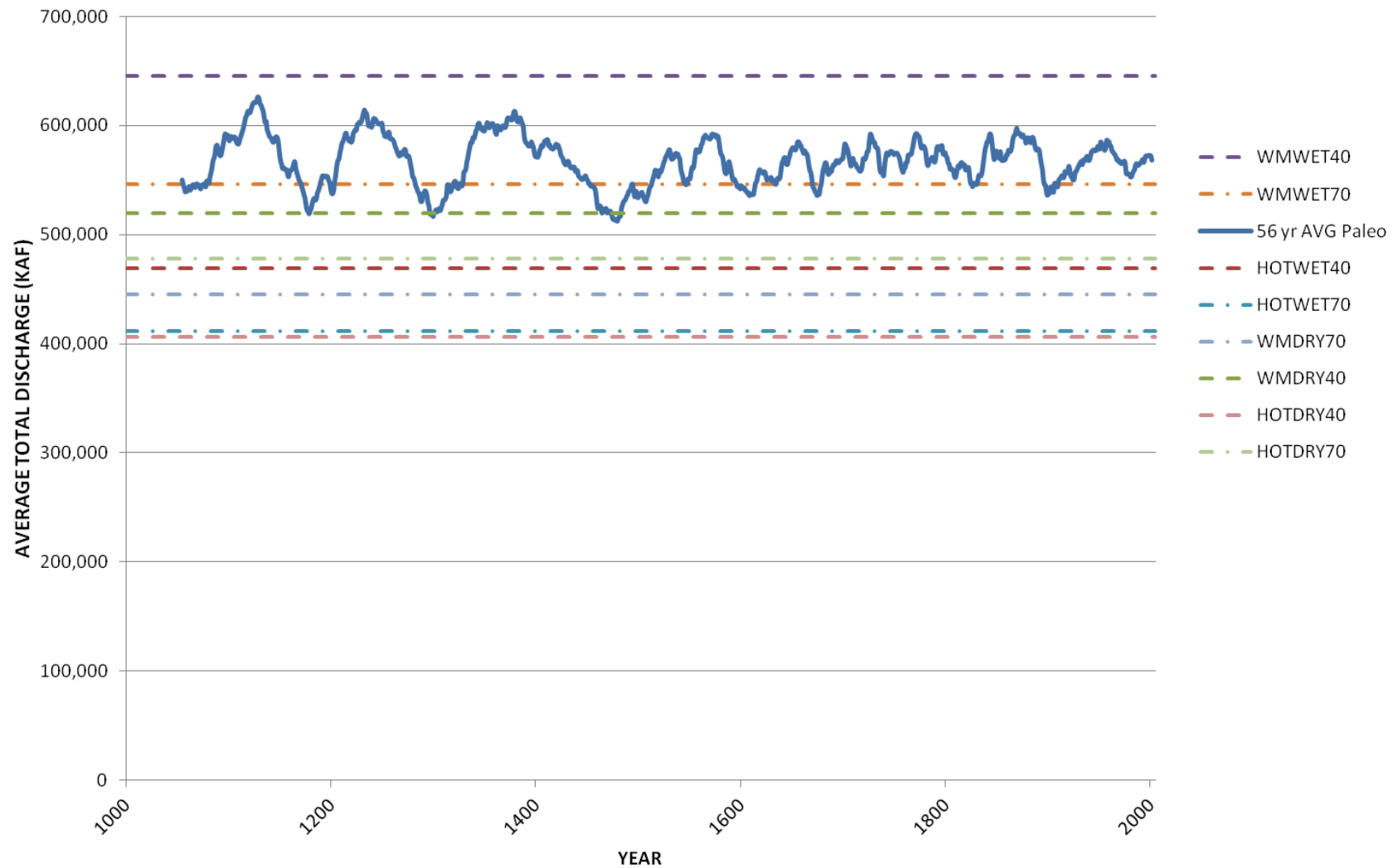
St Vrain 56-Year Average Flow - Paleo Reconstructions and Average Sacramento Projections



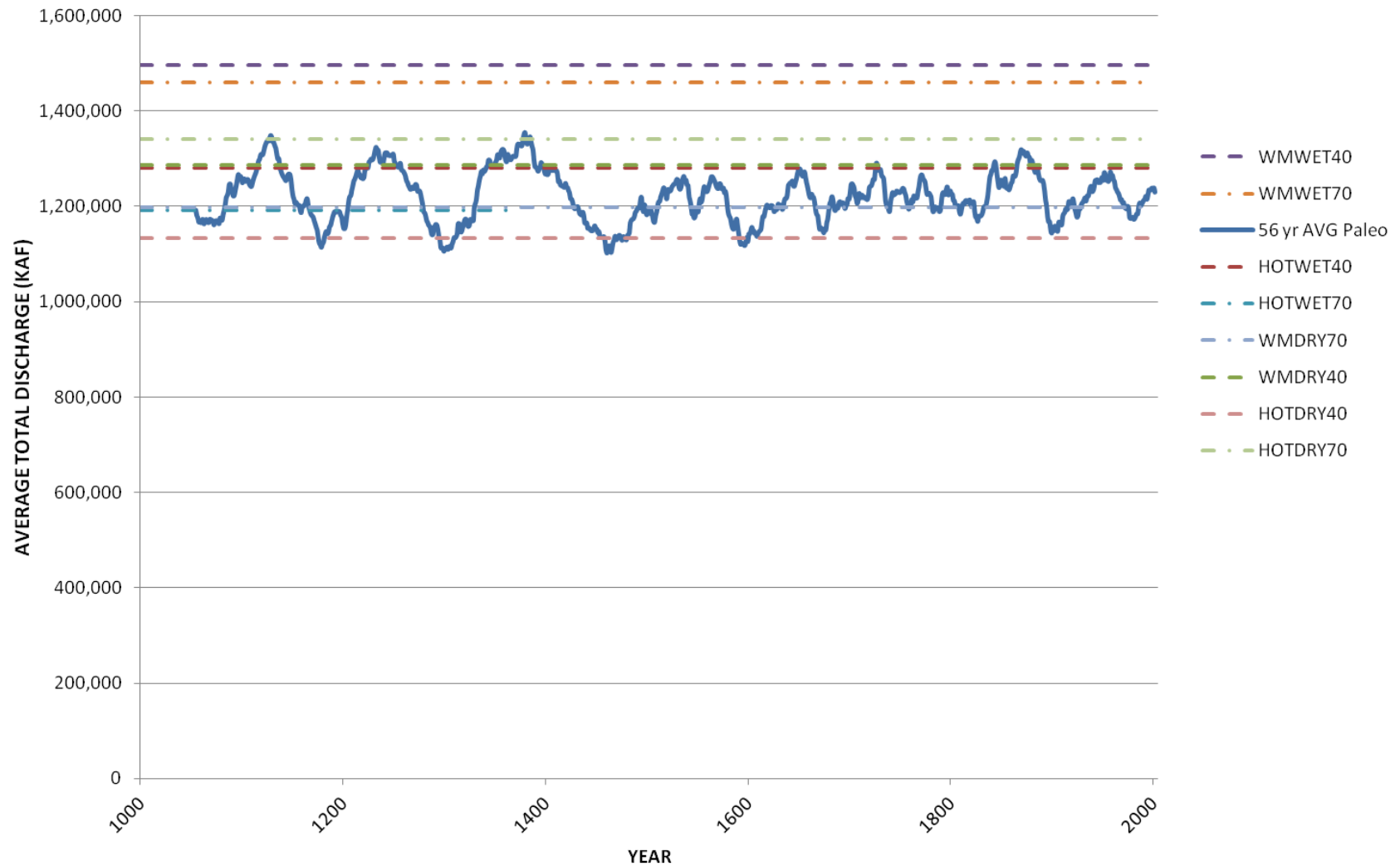
St Vrain 56-Year Average Flow - Paleo Reconstructions and Average WEAP Projections



Modeled White River near Watson, UT 56-Year Average Flow - Paleo Reconstructions and Average CRWAS Projections



Yampa R at Maybell 56-Year Average Flow - Alternate Paleo Reconstructions and Average CRWAS Projections



DROUGHT MONITORING INDICES

ANNEX D TO THE DROUGHT MITIGATION AND RESPONSE PLAN

August 2018

Table of Contents

1	Introduction.....	1
1.1	Overview of Strengths and Limitations of Drought Indices for Colorado Drought Monitoring.....	5
1.1.1	Standardized Precipitation Index (SPI)	5
1.1.2	Palmer Drought Index (PDSI).....	6
1.1.3	Surface Water Supply Index (SWSI).....	8
1.1.4	Colorado Monthly Precipitation and Percent of Normal Maps	9
1.1.5	Colorado Snowpack Accumulation and Ablation	10
1.1.6	Crop Moisture Index (CMI)	11
1.1.7	Keetch-Byram Drought Index (KBDI).....	12
2	Drought Indices for Future Consideration	12
2.1.1	Evaporative Demand Drought Index (EDDI)	13
2.1.2	Standardized Precipitation-Evapotranspiration Index (SPEI).....	15
2.1.3	VegDRI and QuickDRI	16
3	Drought Impact Reporting and Conditions Data	17
3.1.1	United States Drought Monitor (USDM)	17
3.1.2	NDMC Drought Impact Reporter	18
3.1.3	CoCoRaHS Condition Monitoring Reports	19
3.1.4	USDA National Agricultural Statistics Service	19
3.2	2012-2013 Case Study of Drought Monitoring for the Arkansas River	20
4	Recommendations	24
5	References.....	25

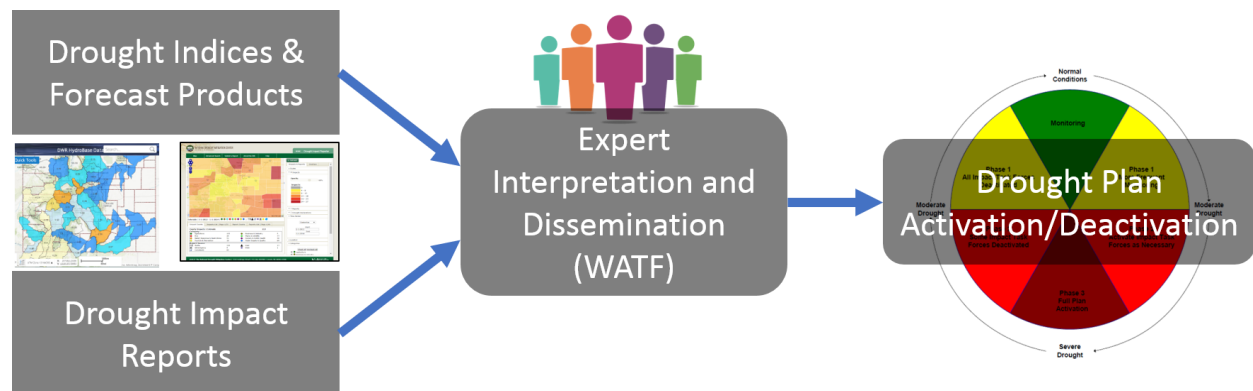
1 INTRODUCTION

Colorado's diverse needs for timely and reliable water resources results in a broad spectrum of stakeholders who hold different definitions of what constitutes drought. The great spatial variation in precipitation and temperature regimes across the state presents a unique challenge to state drought monitoring and planning. For these reasons, Colorado must apply a robust system of drought monitoring tools to ensure drought conditions are adequately tracked for water user groups throughout the state. To help new users become familiar with the drought monitoring tools currently available and provide existing users with an up-to-date summary, this annex is designed to provide a comprehensive outline of the most pertinent drought indices and their intended applications.

This annex replaces what was in Annex D in the 2013 and 2010 updates of the Colorado Drought Mitigation and Response Plan (Drought Plan or Plan). The annex to the previous versions of the Plan included an analysis of the Palmer Drought Severity Index (PDSI) and its applicability to Colorado, and discussed the modernization of the Surface Water Supply Index (SWSI). This update of the annex in 2018 provides a synopsis of the current state of the art in drought indices. Included is a discussion of their applicability in monitoring drought and activation of Annex A of the Colorado's Drought Mitigation and Response Plan. Strengths and limitations of drought indices are discussed. Other indices or remote sensing methods are discussed that, in the future, could play a more formal role in drought monitoring and Plan activation. In addition, the monitoring and reporting of drought impacts is also discussed.

The United States Drought Monitor (USDM), SWSI, PDSI and the Standardized Precipitation Index (SPI) make up the key drought tracking products defined in the Plan. Guideline index values for the SWSI, PDSI, and SPI and drought classifications from the USDM have been developed and documented within previous versions of the Plan and are actively used in the decision-making processes for the activation and deactivation of Plan Phases and Impact Task Force (ITF) groups. These index guidelines attempt to provide a comprehensive estimate of drought conditions (magnitude, duration, areal extent), while drought impact reports provide an essential observation-based verification component necessary for the local and regional activation, mitigation, and response decisions. The drought monitoring structure defined within the Plan is centered around the professional judgment of the WATF to evaluate current and projected drought conditions using drought index data and drought impact reports (Figure 1.1). By employing this convergence of evidence approach, the Plan allows decision makers to examine a wealth of data to make timely and informed drought mitigation and response decisions.

Figure 1.1 Workflow summary of the drought monitoring and response progression outlined in the Plan



While the USDM, SWSI, PDSI, and SPI indices represent the most widely applied drought tracking index tools, there are numerous other drought indices that have provided added benefit to the state’s ongoing drought monitoring practices as well as several newer indices that may soon provide further enhancements to drought monitoring in Colorado. A literature review of recent publications provided the framework for a brief overview of the indices commonly applied within the state and regional drought monitoring community. The Colorado Climate Center (CCC) and National Drought Mitigation Center (NDMC) also provided expert knowledge regarding index development and application for drought monitoring in Colorado. Each index summary includes a breakdown of documented applications as well as some of the most relevant strengths and weaknesses of the indices in their current state. By providing this information in an organized and detailed manner, future updates to the Plan may continue to evaluate the list of indices and focus efforts on linking local drought impact response/mitigation to the most appropriate drought indices and index values.

This annex also presents a synopsis of the 2012-2013 drought conditions in southeastern Colorado through a series of timeline plots. This high-level case study evaluation is intended to help illustrate the drought progression and decision-making processes performed via the Plan. This analysis also provides a simplified proof of concept example of a post-event evaluation that can be generated for future Plan updates to further refine indices and threshold values for improved localized monitoring.

The drought index “thresholds” outlined in Table 1.1 below were defined in previous drought Plans (Annex A in the 2013 Plan) and are actively incorporated as the set of guidelines for drought response activation and mitigation used by the WATF. The table includes a summary of the data inputs to each index, time frame coverage, update frequency, and intensity scale range for the four main drought indices along with the index value range guidelines for the defined drought phases. This table was developed as a supplement to Table 1 in the Colorado Drought Response Plan Annex A (2013).

Table 1.1 Outline of the primary drought indices currently documented in the 2013 Colorado Drought Plan

Drought Index	Primary Inputs	Calculated or Effective Time Frames	Update Frequency	Intensity Scale Typical Range	Index Value Range Guidelines (2013 Plan)				Link to Data Access/View
					Normal	Phase 1	Phase 2	Phase 3	
USDM	40-50+ indicators and indices; flexible for future input/indices to be implemented	1 month to 12 months	every week	D0-D4	D0 Abnormally Dry	D1 Moderate Drought	D2 Severe Drought	D3-D4 Extreme to Exceptional Drought	NDMC UNL
PDSI	Precipitation, Temperature	9 months	every month	-4.0 to +4.0 (can exceed these bounds)	> -1.0	-1.0 to -2.0	< -2.0	-2.0 to -3.9	WRCC WWDT
SWSI	Streamflow, Reservoir Storage, Forecasted Runoff (snowfall and precipitation)	3-6 months to several years	every month	-4.2 to +4.2 (can exceed these bounds)	+2.0 to -1.9	-2.0 to -2.9	-3.0 to -3.9	-4.0 to -4.9	CO DWR
SPI	Precipitation	Selectable; 1 month to 48 months+	daily	-3.0 to +3.0 (can exceed these bounds)	> -0.5 (six month)	-0.6 to -1.0	< -1.0 (six month)	< -1.0 to -1.99 (six month)	HPRCC

A list of some of the most prominent and comprehensive drought toolboxes/dashboards and drought impact reporting/tracking resources are provided below. Note that this list is just a sample of the many resources available for drought planning and monitoring.

Drought Indices Toolboxes and Dashboards

- [CO DWR CDSS SWSI Mapper](#)
- [ESRI Living Atlas Drought Tracker](#)
- [High Plains Regional Climate Center Map Generator](#)
- [NDMC U.S. Drought Risk Atlas](#)
- [NIDIS Drought Portal Data Search](#)
- [NIDIS Summary of Drought Outlook & Forecast Products](#)
- [NIDIS/CCC Intermountain West DEWS](#)
- [NRCS Interactive Map](#)
- [USDM Current Conditions Products](#)
- [WRCC WestWide Drought Tracker Dashboard](#)
- [WWA Intermountain West Climate Dashboard](#)
- [NRCS Colorado Snow Survey](#)
- [CBRFC Water Supply Forecasts](#)

Drought Impacts Reporting and Tracking

- [CoCoRaHS Condition Monitoring Reports](#)
- [NDMC Drought Impact Reporter](#)
- [USDA National Agricultural Statistics Service \(Colorado\)](#)

The general classification of each drought indicator/index is typically a direct reflection of the best application of each drought monitoring product. It is important for users to have a basic understanding of the purpose and limitations of each drought index before evaluating the output. As a basic starting point, the drought research community commonly groups indicators and indices into the following classifications:

- Meteorology (e.g. Standardized Precipitation Index)
- Soil moisture (e.g. Soil Moisture Deficit Index)
- Hydrology (e.g. Surface Water Supply Index)
- Vegetation (e.g. VegDRI)

The emergence of the term “flash drought” has gained substantial momentum within the drought research community as well as the drought monitoring community. Otkin et al. (2017) recently proposed a formalized definition of a “flash drought” to focus on the rate of rapid drought intensification rather than the duration of drought conditions. By formalizing a clearer definition, stakeholders who are susceptible to flash drought conditions can potentially be alerted to the initial warning signs and forecasts for rapid drought intensification.

The next section of this annex provides a brief overview of the typical application of each index for drought monitoring in Colorado.

1.1 Overview of Strengths and Limitations of Drought Indices for Colorado Drought Monitoring

The following subsections summarize the applicability of each drought monitor as well as a brief summary of the strengths and weaknesses identified in the literature review of recent publications and discussions with drought monitoring experts. The index summaries are intended to provide a high-level overview of the index purpose and application within the context of drought monitoring in Colorado. Effective drought monitoring in Colorado requires a robust set of tools. While each of the indices and monitoring products described below have valuable applications, it's also important to note where there is overlap between how indices are generated. When applying a convergence of evidence approach to drought monitoring is important to understand how individual index products are similar (e.g. precipitation input) and how they differ. Note that the USDM is also an important component of drought monitoring in Colorado, but since it is a mixture of other indices and drought impact monitoring products, it is discussed in Section 4 Drought Impact Reporting and Conditions Data.

1.1.1 Standardized Precipitation Index (SPI)

Developed at the CCC, this index is broadly used to track and quantify conditions related to meteorological drought. SPI uses historical precipitation records to calculate a probability of precipitation accumulation at timescales ranging from 1 month to 48 months or longer.

1.1.1.1 Colorado Application

The range of SPI timescales makes the SPI a robust product for evaluating meteorological drought onset, intensity, and duration for agriculture, water resources, and other sectors. The shorter-timeframe SPI data can provide an early indication of drought emergence which can be useful for implementing drought mitigation measures in a timely manner. Drought experts in Colorado typically use the 60- and 90-day SPI to look at more consistent patterns emerging and to make initial recommendations to the USDM while the 6-month SPI is frequently used to look at longer term patterns. It is also important to note that negative SPIs may carry more weight when monitoring drought during a wet season vs. a dry season.

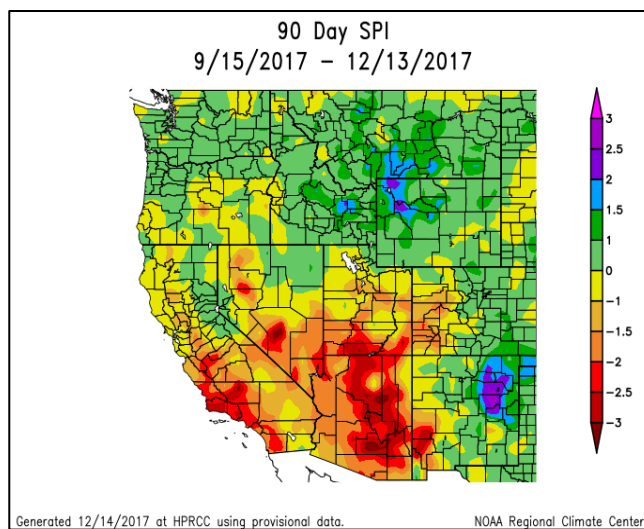


Figure 1.2 SPI image obtained from:
<https://hprcc.unl.edu/maps.php?map=ACISClimateMaps#>

1.1.1.2 Strengths

- SPI values for a range of timescale can be applied for multiple applications relating to the type of drought impacts in question (e.g. shorter timeframe for agricultural drought and longer timeframe for hydrologic drought).
- SPI is one of the easier indices to calculate and uses only precipitation data making it an ideal index for regions with sparse data coverage.
- SPI values can also be compared across widely varied climates.

1.1.1.3 Weaknesses

- There is no temperature component in SPI so it does not directly account for evaporative demand, an important component of the overall water balance. Drought events with similar SPI may have different impacts because of differences in evaporative demand.
- The calculation can be sensitive the quantity and quality of the underlying historical precipitation data used to generate the probability distribution (30+ years of historical data is recommended).
- Selecting the appropriate time scale of SPI (e.g. 3-month vs. 6-month) can be challenging for users when attempting to evaluate a range of potential drought vulnerabilities and impacts.

1.1.2 Palmer Drought Index (PDSI)

This prominent index was developed in the 1960s and has been widely applied to drought monitoring practices. PDSI is designed to use a simple supply and demand water balance approach with inputs of precipitation, temperature, and soil water capacity estimates. There are also two modified PDSI products commonly used within drought monitoring practices:

- Self-Calibrated PDSI: uses a mathematical calibration of model coefficients to represent local climate and soil properties
- Palmer Z: a measure of the relative wetness/dryness anomalies of a region evaluated against the full record at each location; often preferred for its normalized approach and better spatial comparison attributes

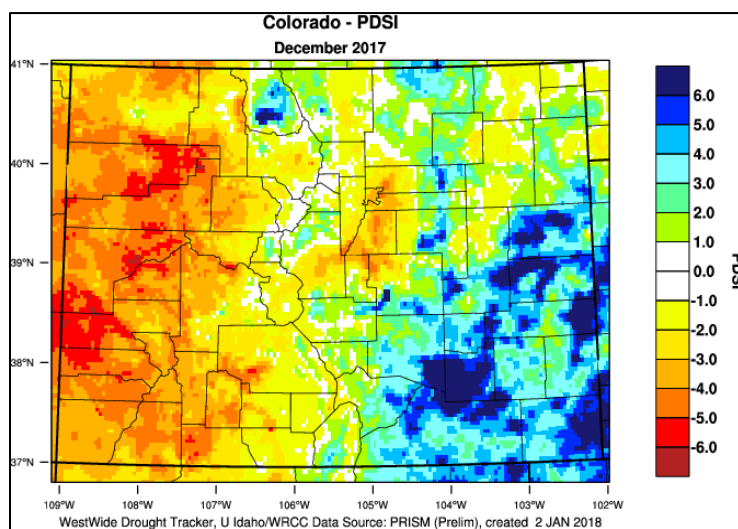


Figure 1.3: PDSI image obtained from:
<https://wrcg.dri.edu/wwdt/index.php?folder=pdsi>

1.1.2.1 Colorado Modified Palmer Drought Severity Index

Using the same water balance approach (temperature and precipitation inputs) as the PDSI, the CMPDSI was designed to evaluate drought conditions at a finer spatial scale across Colorado. The CMPDSI expanded on the original PDSI by enhancing the spatial resolution of the index from the original 5 sub-regions (climate divisions) to 26 sub-regions to better represent the range of topography and climate conditions within Colorado (Doesken et al. 1983). CCC discontinued the generation of the CMPDSI in 2016 in favor of using similar products operationally available (e.g. Western Regional Climate Center's West Wide Drought Tracker PRISM PDSI). The newer products use gridded climate data to provide a much higher resolution depiction of PDSI conditions.

1.1.2.2 Colorado Application

PDSI considers both evapotranspiration as well as the moisture deficit within the soil column making it a useful tool for detecting and quantifying meteorological and agricultural drought conditions. This index was primarily developed for identifying drought conditions impacting the agricultural sector, but its use has been expanded to other sectors (e.g. water supply). Within Colorado, PDSI is primarily used for the eastern plains as its performance in the mountains is largely inadequate.

1.1.2.3 Strengths

- PDSI is commonly applied around the world and has been extensively evaluated under a range of conditions and has been thoroughly documented within the drought community literature.
- The application of soil properties and water balance methodology allow for a comprehensive analysis of drought conditions compared to many other indices.
- As noted by Doesken & Ryan (2010), the CMPDSI has shown promising results for prediction of winter wheat harvest as well as streamflow across various areas of the state.

1.1.2.4 Weaknesses

- PDSI has a relatively long memory (about 9 months) and does not respond quickly to emerging dry conditions compared to other indices and is not ideal for short term evaluations of drought conditions.
- It does not have a flexible multi-timescale calculation feature.
- The time lag between snowfall and snowmelt is not directly accounted for, all precipitation is assumed to be immediately available.

1.1.3 Surface Water Supply Index (SWSI)

This index attempts to quantify the amount of surface water available in streams and reservoirs across the state of Colorado. SWSI is calculated for the seven major intrastate basins as well as the HUC 8 basins throughout Colorado (“Revised SWSI”). NRCS originally developed this index in 1981 and modernized the SWSI for Colorado as part of the Drought Plan update effort in 2010. This update included an improved spatial resolution calculation (using the HUC-8 statewide basins). The

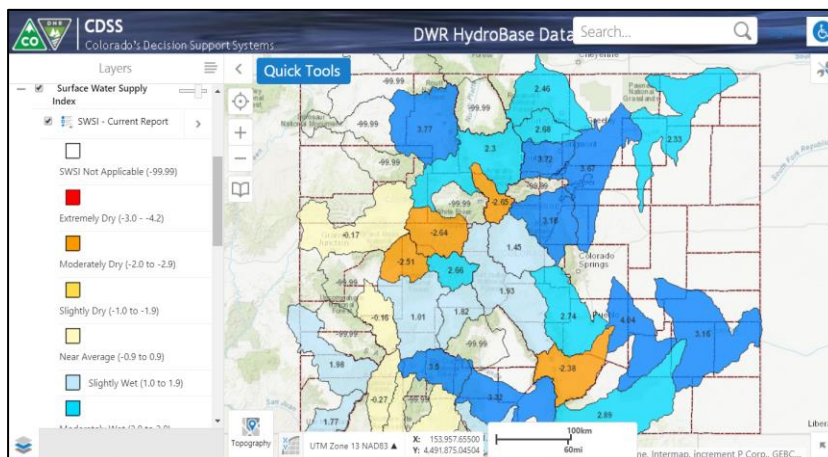


Figure 1.4: SWSI image obtained from:
<https://gis.colorado.gov/dnrviewer/Index.html?viewer=dwrhydrobaseviewer>

The Colorado Department of Water Resources (DWR) hosts a [database](#) of current and historical SWSI statistics (included non-exceedance probabilities) for HUC8 basins in Colorado.

The Index uses the following inputs based on the time of year:

- January-June: $SWSI = \text{Streamflow Forecast} + \text{Reservoir Storage}$
- July-September: $SWSI = \text{Reservoir Storage} + \text{Previous Month's Streamflow}$
- October-December: $SWSI = \text{Reservoir Storage}$

1.1.3.1 Colorado Application

This index is especially applicable for monitoring hydrologic drought conditions and month-to-month fluctuations for water supply planning. SWSI was specifically designed to quantify drought severity where water availability is driven by winter snow accumulation and ensuing snowmelt. During the 2018 update of the Drought Plan, a member of the Colorado Water Availability Task Force noted that SWSI has become decreasingly referenced in recent years; this could be the result of the SWSI acronym confusion (the SWSI acronym also represents the Statewide Water Supply Initiative).

1.1.3.2 Strengths

- SWSI takes into account the primary water supply components including snow accumulation, snowmelt/runoff, and reservoir contents. This calculation provides a comprehensive evaluation of the overall water balance of a given basin while accounting for manmade storage impacts (reservoirs).

- Several Colorado water supply organizations have implemented localized SWSI calculations into their monitoring system, making SWSI a relatively familiar index.

1.1.3.3 Weaknesses

- The index must be recalculated anytime there are underlying changes to the input data (e.g. reservoir capacity changes, diversion/return flow modifications, etc.).
- SWSI user's have noted some basin-to-basin irregularities likely influenced by differing reservoir and water supply management practices (at the Colorado HUC-8 scale). This may lead to confusion or added uncertainty when attempting to evaluate conditions or trends between neighboring basins.

1.1.4 Colorado Monthly Precipitation and Percent of Normal Maps

These indicators involve a simple statistical formula to generate using precipitation data as the only input. This index can be applied quickly to evaluate meteorological drought conditions by comparing recent precipitation values to mean historical data.

1.1.4.1 Colorado Application

Total precipitation and percent of normal precipitation data is primarily used for simple evaluations of meteorological drought conditions. These variables are relatively simple to understand and evaluate compared to other indices.

1.1.4.2 Strengths

- These statistics can be easily generated to cover a range of time periods in order to evaluate a range of drought conditions.

1.1.4.3 Weaknesses

- Percent of normal values can be difficult to compare among different climate regimes (differing precipitation climatology).
- “Normal” precipitation can be misunderstood when there are sizeable differences between the median and mean for a given period.

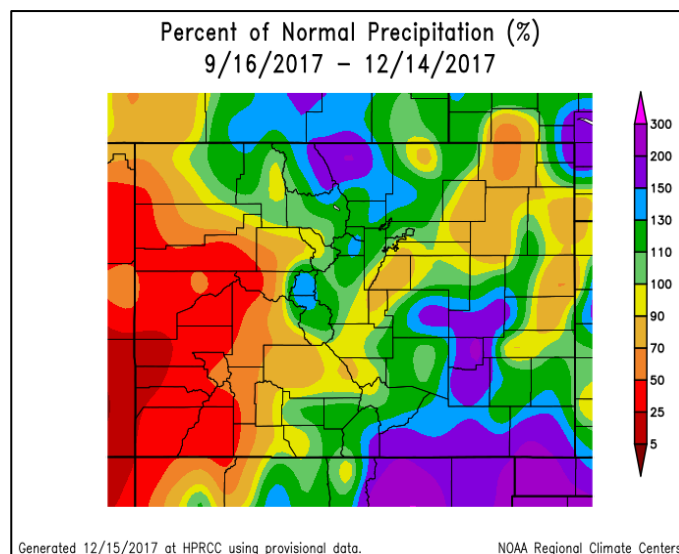


Figure 1.5: Percent of normal precipitation image obtained from:
<https://hprcc.unl.edu/maps.php?map=ACIS>
ClimateMaps#

1.1.5 Colorado Snowpack Accumulation and Ablation

Mountain snowpack in Colorado is a critical component of the hydrologic cycle. Higher elevation snowfall and subsequent melt is a key driver of the overall water supply for many of the water demands for both in-state and out-of-state users. Snow Telemetry (SNOTEL) instrumentation stations provide a relatively dense network of data points to monitor snowpack conditions. The Natural Resources Conservation Service (NRCS) and National Water and Climate Center provide current and historical data access for real time evaluation of snowpack conditions.

The National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) SNOw Data Assimilation System (SNODAS) is also routinely used by water supply managers and drought monitoring systems. SNODAS produces high-resolution (1km) gridded snowpack estimates through a modelling and data assimilation system. This data product merges ground observations (e.g. SNOTEL point measurements) with satellite/airborne measurements, and model estimates of snow cover.

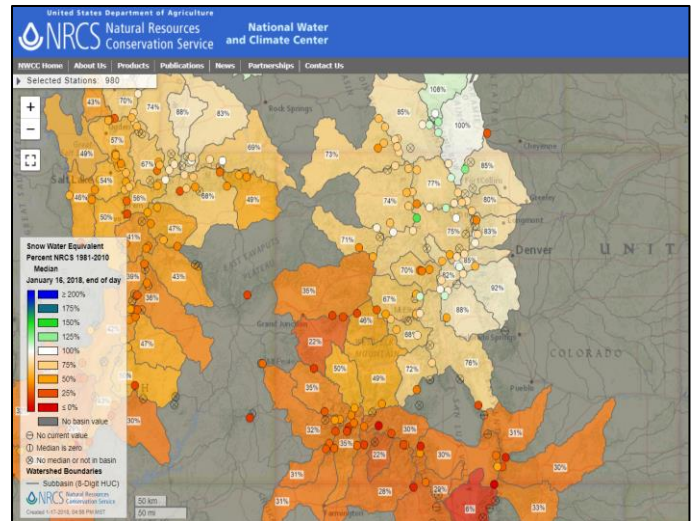


Figure 1.6: Snow water equivalent percent of normal image obtained from:
https://www.wcc.nrcs.usda.gov/snow/snow_map.html

1.1.5.1 Colorado Application

Maps and timeseries plots of the snowpack can be generated for SNOTEL stations as well as basin-scale estimates via online tools. This data provides water supply managers and drought planners with valuable estimates of the magnitude and timing of the snowmelt.

1.1.5.2 Strengths

- Snowpack data can provide an early indication of water shortages and potential drought conditions.
- Daily to hourly temporal resolution of observed and modeled data products.
- Percent of normal snowpack information is a relatively easy product to understand for drought planners and the public.

1.1.5.3 Weaknesses

- SNOTEL observations are point samples of an often complex and spatially variable snowpack which may lead to an over or under estimate of true basin-wide snowpack.

- Snowpack data should also be interpreted with reservoir storage levels and capacity to better understand the expected water availability for downstream users.
- Gridded products like SNODAS have a limited history, therefore it's difficult to assess how far from “normal” the snowpack is at a given time when there is not a long enough record to calculate a “normal”.

1.1.6 Crop Moisture Index (CMI)

This index was developed as a compliment to the PDSI in an attempt to address some of the shortcomings of PDSI. CMI is intended to be a quick responding index that evaluates the soil column moisture deficit using estimates of available moisture and potential evapotranspiration.

1.1.6.1 Colorado Application

Mainly used for agricultural purposes, the CMI gives a short-term status of a purely agricultural drought which can change rapidly. It is applicable in measuring drought on a week to week basis for warm season crops.

1.1.6.2 Strengths

- CMI is especially suited to evaluating drought conditions in relation to agriculture impacts.

1.1.6.3 Weaknesses

- As CMI is sensitive to quickly developing drought conditions, it may also produce a false sense of drought recovery if longer-term moisture deficits are important.
- CMI may not be applicable for cool season or shallow rooted crops.
- Current spatial resolution is limited for Colorado (five climate divisions)

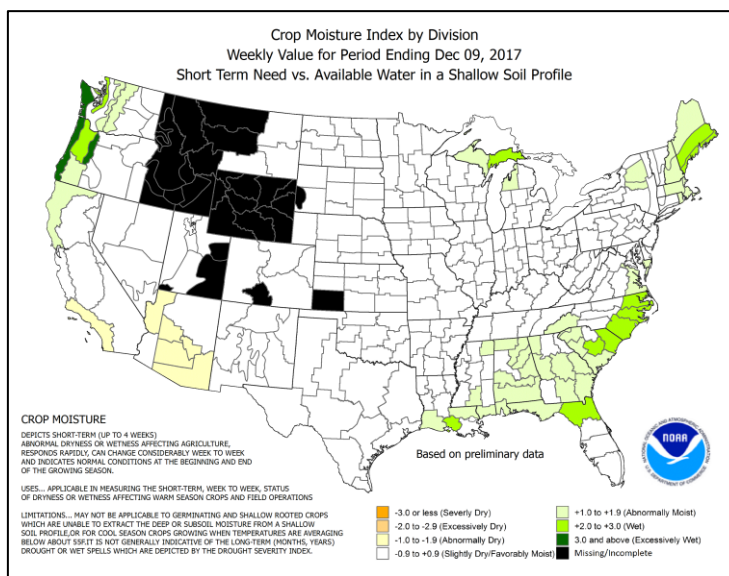


Figure 1.7: CMI image obtained from:
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/cmi.gif

1.1.7 Keetch-Byram Drought Index (KBDI)

KBDI was developed by the United States Fire Service (USFS) as a fire risk index for fire control managers. The index calculates the moisture deficiency in duff and the upper soil layers which is designed to evaluate the flammability of organic material on the ground. This measure is especially useful when examining wildfire conditions and potential drought stress on vegetation and crops.

1.1.7.1 Colorado Application

KBDI estimates the amount of precipitation necessary to return the soil to full field capacity, with values ranging from 0 to 800 units (corresponding to 0 to 8 inches of water in the soil). Wildfire potential is divided into four levels based on KBDI values (0 to 800): low, moderate, high, and extreme contribution to fire intensity. These levels correspond to typical seasonal variations.

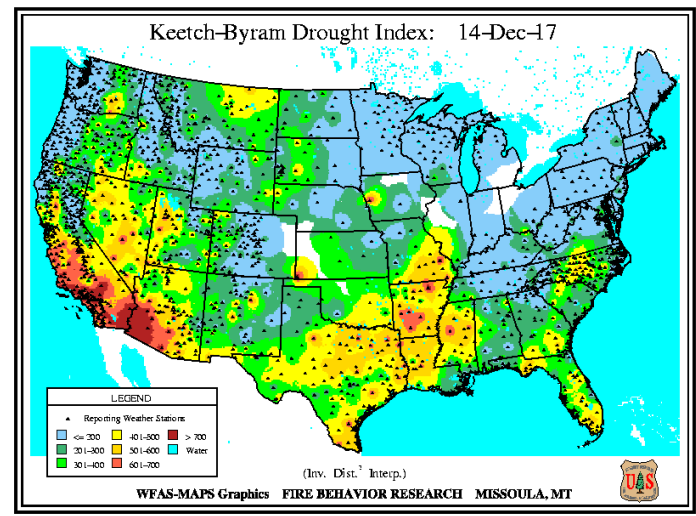


Figure 1.8: KBDI image obtained from:
<http://www.wfas.net/index.php/keetch-byram-index-moisture--drought-49>

1.1.7.2 Strengths

- The KBDI calculation is relatively simple index relying on daily maximum temperature and daily precipitation as inputs.

1.1.7.3 Weaknesses

- The calculation assumes a limit of available moisture based on regionalized climate estimates which may not be sufficient for every location.

2 DROUGHT INDICES FOR FUTURE CONSIDERATION

The following sections discuss some of the newer indices that have been the focus of recent drought monitoring research and development. While these indices have started to gain attention among Colorado drought monitoring experts, these products are still being tested and evaluated in regards to operational capabilities. For this reason, the following indices are not included in the formal drought monitoring guidelines; however, these indices can still provide a valuable resource while the vetting process continues. Future updates to the Plan should reevaluate these indices for updated information.

2.1.1 Evaporative Demand Drought Index (EDDI)

EDDI is an experimental drought monitoring tool specifically designed to capture the early warning signs of water stress through the emergence and/or persistence of anomalous evaporative demand. The EDDI calculation relies on North American Land Data Assimilation System (NLDAS) for gridded climate input data. The CCC routinely examines the EDDI products as part of their drought monitoring toolbox. While the application of EDDI to operation drought monitoring is in an early stage at this point in time, confidence is growing in that EDDI can be a very useful tool for future drought plans and early warning activation.

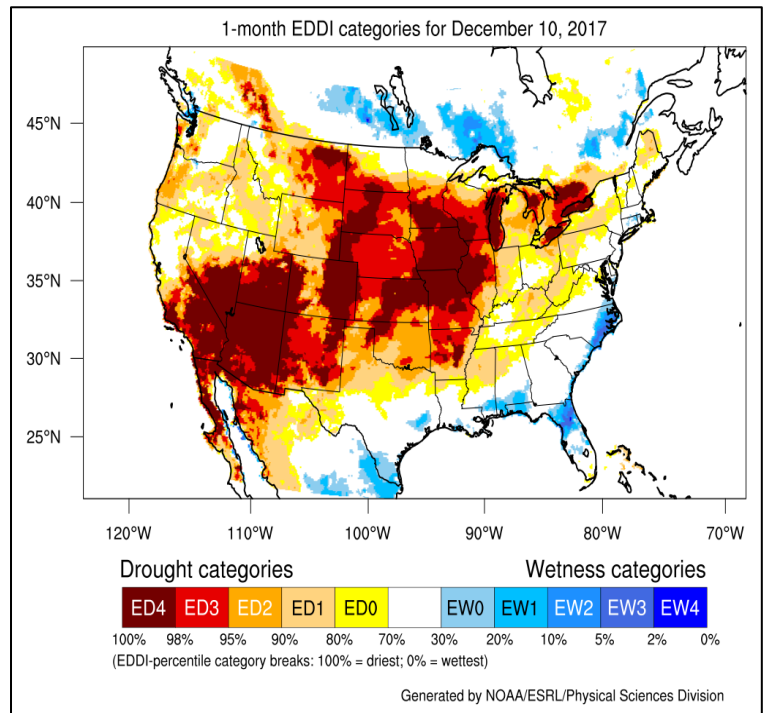


Figure 2.1: EDDI image obtained from:
<https://www.esrl.noaa.gov/psd/eddi/>

2.1.1.1 Future Colorado Application

EDDI is designed to be applicable for all land-cover types, which is especially useful for Colorado's diverse needs. The daily output (5-day lag) from EDDI provides a much-needed tool for monitoring "flash drought" conditions which can have substantial impacts to the agricultural sector in Colorado. EDDI can also be used as a fire-weather monitoring tool throughout the state.

2.1.1.2 Strengths

- Quick response time drought tool has long been a need for drought monitoring
- Capable of detecting "flash drought" conditions earlier than most other indices
- Drought category display colors can sharply highlight regions of drought concern
- EDDI model data have been validated using surface observations in Colorado
- EDDI is generated on the same range of timeframes as SPI

2.1.1.3 Weaknesses

- Still needs additional expert review and additional testing to fully understand and document strengths and limitations
- Colored display of drought categories can be over emphasized under some conditions and require user insight to fully evaluate (e.g. winter vs growing season anomalies)
- EDDI does not include any water supply information

Figure 2.2 below plots the 1-month to 12-month EDDI values (standardized anomalies in reference evapotranspiration) for the 2010-2015 period. The data were extracted for the southeastern quadrant of Colorado (spatially averaged output). This plot shows the early onset of dry conditions starting in late 2010 and persisting into 2014 (positive index values). For perspective, plots the EDDI timeseries for the 1990-2015 period. Note the anomalously dry conditions (magnitude and duration) during the 2011-2014 drought period. Note that unlike other drought indices, raw EDDI values are positive in dry conditions, and negative in wet conditions.

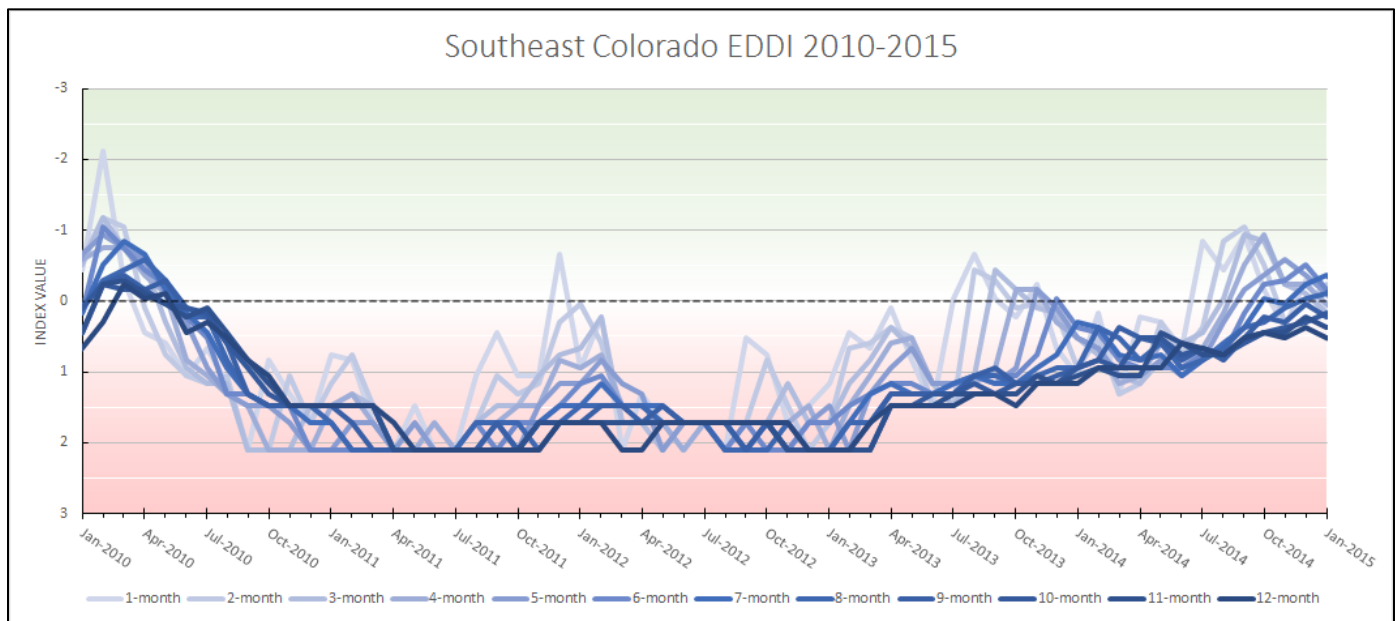


Figure 2.2: EDDI timeseries for southeastern Colorado for the 2010-2015 period
(data obtained from: <https://www.esrl.noaa.gov/psd/eddi/>)

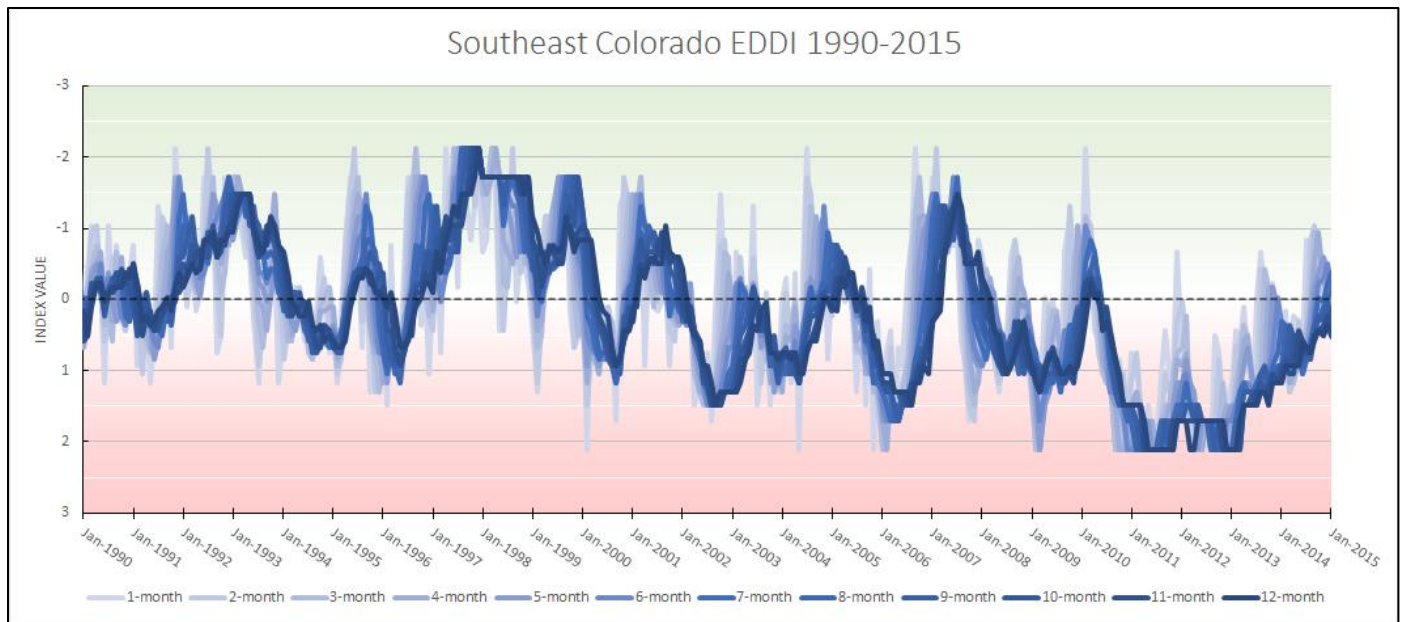


Figure 2.3: EDDI timeseries for southeastern Colorado for the 1990-2015 period (data obtained from: <https://www.esrl.noaa.gov/psd/eddi/>)

2.1.2 Standardized Precipitation-Evapotranspiration Index (SPEI)

This index is an extension of the SPI and incorporates temperature data to account for potential evapotranspiration in a basic water balance calculation. SPEI aims to improve the representation of drought duration and magnitude resulting from trends in potential evapotranspiration change.

2.1.2.1 Future Colorado Application

This index can be applied in all instances where SPI is currently used while providing a more reliable estimate of drought conditions resulting from air temperature influences.

2.1.2.2 Strengths

- Expected to be a more reliable estimate over the traditional SPI product especially when accounting for warming climate scenarios

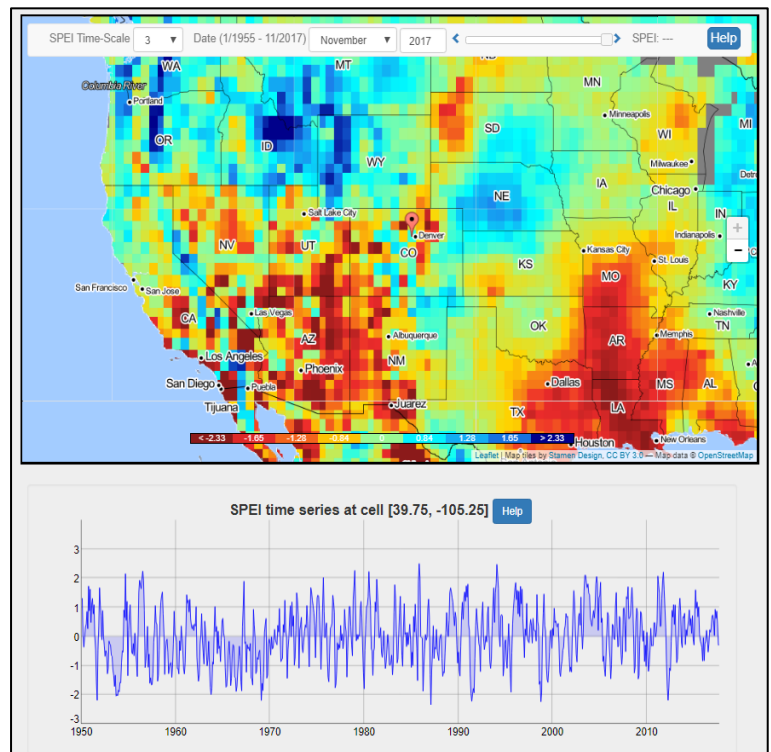


Figure 2.4: SPEI Global Drought Monitor image obtained from: <http://spei.csic.es/map/maps.html>

- Available on the same range of timeframes as SPI (<1-month to > 48-months+)

2.1.2.3 Weaknesses

- Real-time SPEI output is currently based on the Thornthwaite equation for potential evapotranspiration (temperature-based estimate) which can have limited reliability in western US applications
- Output is highly sensitive to the method used to calculate the PET product (e.g. Thornthwaite vs. Penman Monteith) especially in regions where wind can play a big role in varying evapotranspiration
- Not yet extensively tested and evaluated by the drought monitoring community

2.1.3 VegDRI and QuickDRI

The Vegetation Drought Response Index (VegDRI) and the Quick Drought Response Index (QuickDRI) and have been developed by the U.S. Geological Survey (USGS), Earth Resources Observation and Science (EROS) Center and the National Drought Mitigation Center (NDMC). These hybrid modeled drought indices incorporate satellite-based observations of vegetation properties, climate data, and other biophysical data products to quantify the current vegetative state. VegDRI has a seasonal time horizon for characterizing drought conditions, while QuickDRI is designed for detecting early onset and rapidly developing drought conditions on a roughly 1-month timescale (i.e. flash drought conditions).

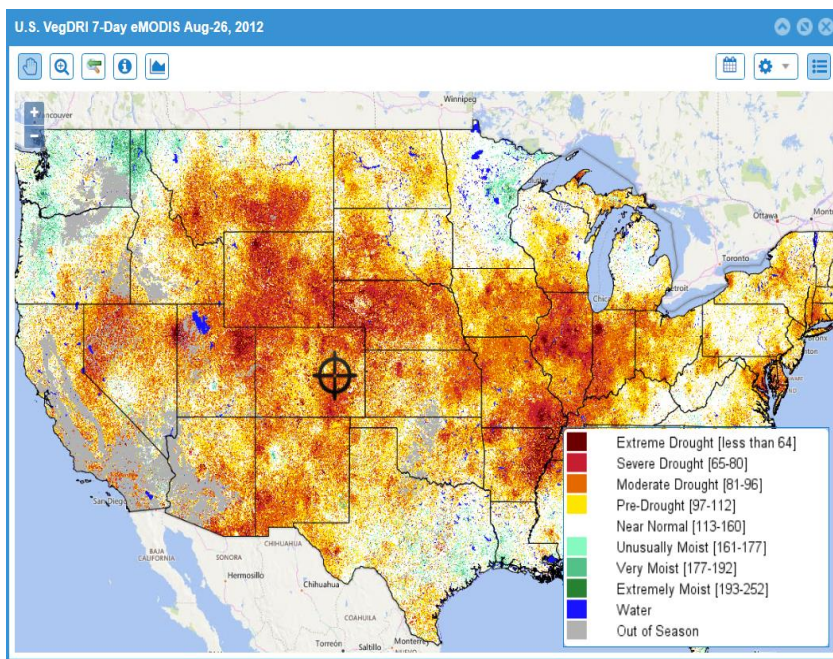


Figure 2.5: VegDRI image obtained from:
<https://veg dri.cr.usgs.gov/viewer/>

2.1.3.1 Future Colorado Application

These two indices provide a high-spatial resolution (1km) drought indicator specifically designed for vegetation stress and agricultural applications. VegDRI has provided valuable updates on the mid to late summer vegetation health within Colorado whereas the early growing season output is largely just a function of the input SPI blend. (personal communication with CCC, Jan 2018).

2.1.3.2 Strengths

- Both indices are a weekly product
- 1km spatial resolution
- Both indices are a hybrid index – incorporating numerous variables representing the hydrologic cycle and drought-related vegetation stress

2.1.3.3 Weaknesses

- Only applicable in areas with vegetation cover and during the growing season
- Relies on precipitation as an input which may lead to redundancies in output with other precipitation driven indices (e.g. SPI & PDSI)

3 DROUGHT IMPACT REPORTING AND CONDITIONS DATA

Comprehensive drought impact assessments are a well-known shortcoming within the drought monitoring community. Drought management decisions are ultimately focused on mitigating and responding to a range of drought related impacts; however, localized impact assessments are often complicated by a multitude of socioeconomic and physical factors relating to drought vulnerability and exposure. Aligning projected drought conditions with known impacts remains a critical link to developing a localized drought mitigation and response system.

While historical records of drought-related impacts have typically focused heavily on agricultural impacts, several drought impact reporting systems and databases have emerged in recent years to help meet the growing need for a comprehensive record of current and historical drought impacts across a range of sectors. Three resources are described in the following sections in an effort to continue to build usership and emphasize their application for continued improvements to drought mitigation efforts in Colorado.

3.1.1 United States Drought Monitor (USDM)

The USDM was the first operational composite-based drought monitoring product used in the US. While it is primarily based on a handful of key indicators (SPI at multiple time scales, PDSI, modeled soil moisture, weekly streamflow) it uses a flexible framework to incorporate up to 50+ inputs from a variety of sources with capabilities to continuously incorporate newly developed

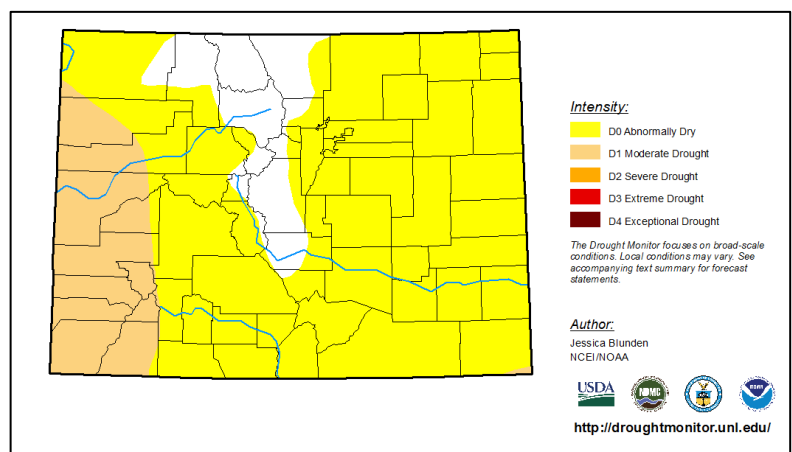


Figure 3.1: USDM image obtained from:
<http://droughtmonitor.unl.edu/CurrentMap.aspx>

data/indices as they become available. For example, snow-water equivalent is incorporated in the western US in the winter. The weekly map generation process also relies on human observations and impact reports. The Colorado Climate Center continues to provide and coordinate drought monitoring data and information input from Colorado water experts to the USDM on a weekly basis.

3.1.1.1 Colorado Application

The USDM is often a key focal point of drought monitoring efforts covering a wide range of applications throughout the state of Colorado. The USDM is not limited to seasonal interpretation (e.g. wet season or growing season) and can be consistently evaluated throughout the year. The WATF includes the percent coverage of drought categories at all monthly meetings.

3.1.1.2 Strengths

- USDM incorporates numerous indicators and indices covering a range of timescales to produce a robust drought identification and intensity classification.
- The five-scale drought intensity classifications are widely used throughout the country and familiar to stakeholders, the media, and the public. Other indices attempt to apply the same general intensity scale for data displays.

3.1.1.3 Weaknesses

- Very localized drought conditions may not be sufficiently represented within the USDM resolution
- Drought can only be depicted where the actual water shortage is present, not necessarily where the area of impacts is greatest. For example, a drought over the mountains (where the majority of the water resources reside) can have major implications over many other regions, including other states, but the USDM does not provide that information.

3.1.2 NDMC Drought Impact Reporter

The [Drought Impact Reporter](http://droughtreporter.unl.edu) (DIR) was initially released in 2005 as one of the first nationwide drought impact databases. This data catalog incorporates drought-related reports from a wide variety of sources including media reports, user-submitted reports, CoCoRaHS reports, NWS Drought Information Statements, and state agency reports. DIR documentation notes that media reports of drought-related news stories make up the largest contribution to

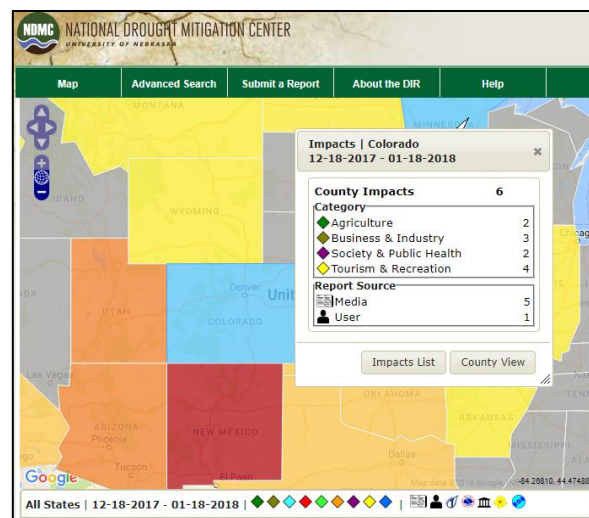


Figure 3.2: Drought Impact Reporter map interface
(<http://droughtreporter.unl.edu/map/>)

the database; however, user-submitted reports from the public are also an essential component of the database. The DIR is also designed to group drought impacts by relevant characteristics such as the drought category (e.g. agriculture, water supply/quality, tourism/recreation), drought duration, and affected locations.

3.1.3 CoCoRaHS Condition Monitoring Reports

Community Collaborative Rain Hail and Snow

(CoCoRaHS) is a network of community volunteers who provide detailed measurements and observations of daily weather conditions nationwide (and international). Started in Fort Collins in 1998, the network has grown to include thousands of active daily reports that provide a valuable database of localized weather observations. While initially designed to primarily record precipitation observations, the CoCoRaHS reporting system has adapted a condition monitoring reporting system.

The condition monitoring reports submitted by CoCoRaHS volunteers are designed to provide a constant stream of qualitative reports regarding the status of wet or dry conditions and the localized impacts. Condition monitoring reports provide date stamped observations with a relative conditions scale bar (ranging from severely dry to near normal to severely wet) as well as a description of the impacts affecting the reporter. The condition monitoring reports also include a classification structure similar to the DIR to help streamline the categorization of impacts by sectors (e.g. agriculture, fire, business etc.). Processed reports can be viewed through an interactive map interface or by a database search query.

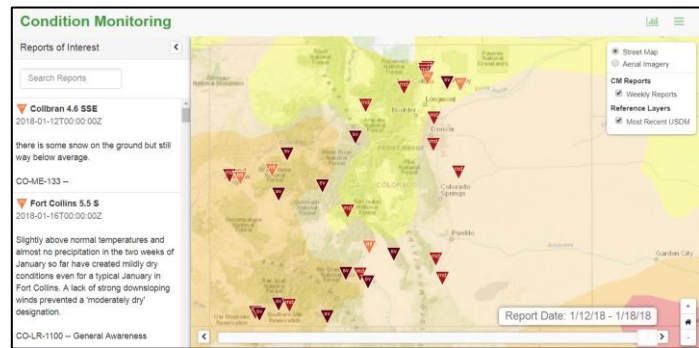


Figure 3.3: CoCoRaHS Condition Monitoring map interface
(<https://www.cocorahs.org/Maps/conditionmonitoring/#>)

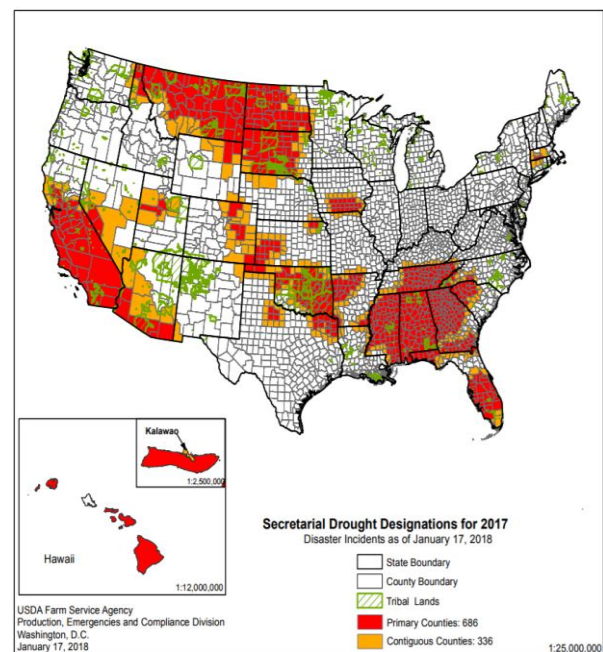


Figure 3.4: Secretarial county drought designations for 2017
(<https://www.usda.gov/sites/default/files/documents/usda-drought-fast-track-designations.pdf>)

3.1.4 USDA National Agricultural Statistics Service

The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) maintains a detailed record of crop,

livestock, pasture, and range conditions relating to drought impacts. With water availability playing such a significant role in the agricultural sector, crop conditions are routinely documented for large portions of the country through annual, monthly, and weekly reports. County and statewide crop progress reports provide records regarding commodity conditions, soil moisture conditions, and crop yields. The USDA also maintains a record of Secretarial Drought Designations by county.

3.2 2012-2013 Case Study of Drought Monitoring for the Arkansas River

The 2011-2013 drought conditions impacted the entire state of Colorado, but conditions were especially severe in the southeast quadrant of the state which includes most of the Upper Arkansas River basin. A simple case study re-analysis was developed for the 2011-2015 period to help illustrate the drought progression and subsequent drought mitigation and response actions applied throughout the state. Figure 3.5 is a snapshot of the USDM during the week of February 18, 2013 showing the widespread drought conditions over Colorado with exceptional drought conditions over a large portion of the eastern part of the state.

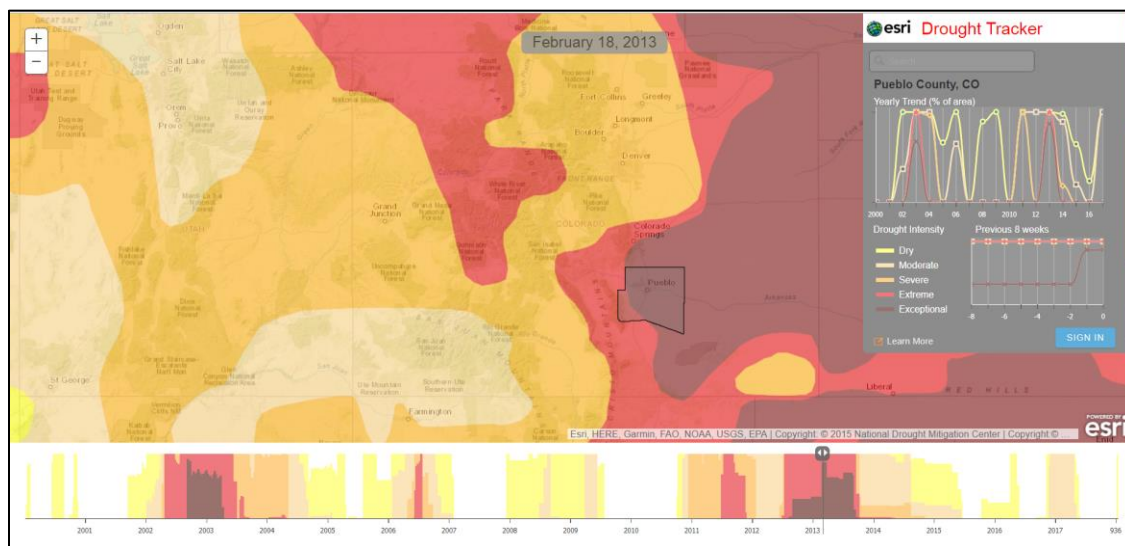


Figure 3.5: ESRI Drought Tracker showing the USDM drought severity in early 2013.

This case study aims to provide a simple synopsis of the drought conditions by plotting the historical drought indices timeseries along with a timeline of the documented drought mitigation/response actions, and drought impact reports. Figure 3.6, Figure 3.7, and Figure 3.8 outline the evolution of drought conditions evident by the USDM, several drought index timeseries, and a timeline of the drought Plan actions.

For simplicity, the drought indices datasets focus on the spatial average for the Upper Arkansas River basin (HUC 110200). The USDM drought index percent coverage time series plot for the

Upper Arkansas basin was obtained from the [USDM webpage](#). The historical timeseries of PDSI, Palmer Z, SC-PDSI, SPI (1-month), and SPEI (1-month) were obtained from the WRCC [WestWide Drought Tracker](#) (Abatzoglou et al., 2017). The WestWide Drought Tracker dataset applies the monthly gridded PRISM data products as the foundation for the calculation of the monthly historical index timeseries. Recall that the range of typical index values may differ from one index to the next, and the user should give special attention to the magnitude of each index when quantifying the overall drought signal. The SWSI timeseries data for the Arkansas basin were obtained from the Colorado DWR Information Marketplace. Drought Plan activation/deactivation dates and descriptions were mostly attained from monthly WATF Drought Update Reports and the Governor’s Memorandum documents (all archived files are available on CWCBLaserfiche WebLink database).

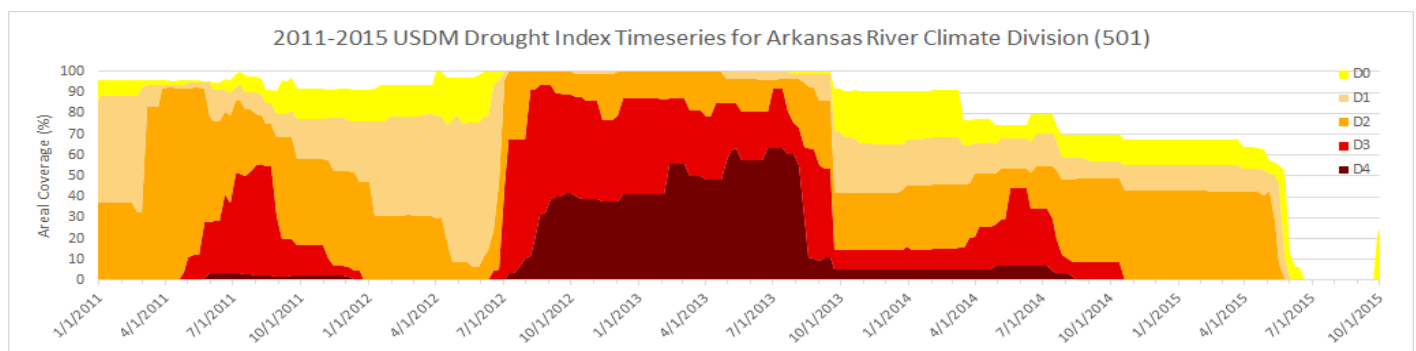


Figure 3.6: USDM Drought categories percent coverage for the Upper Arkansas (Climate Division 501) for the 2011-2015 period (data obtained from <http://droughtmonitor.unl.edu>)

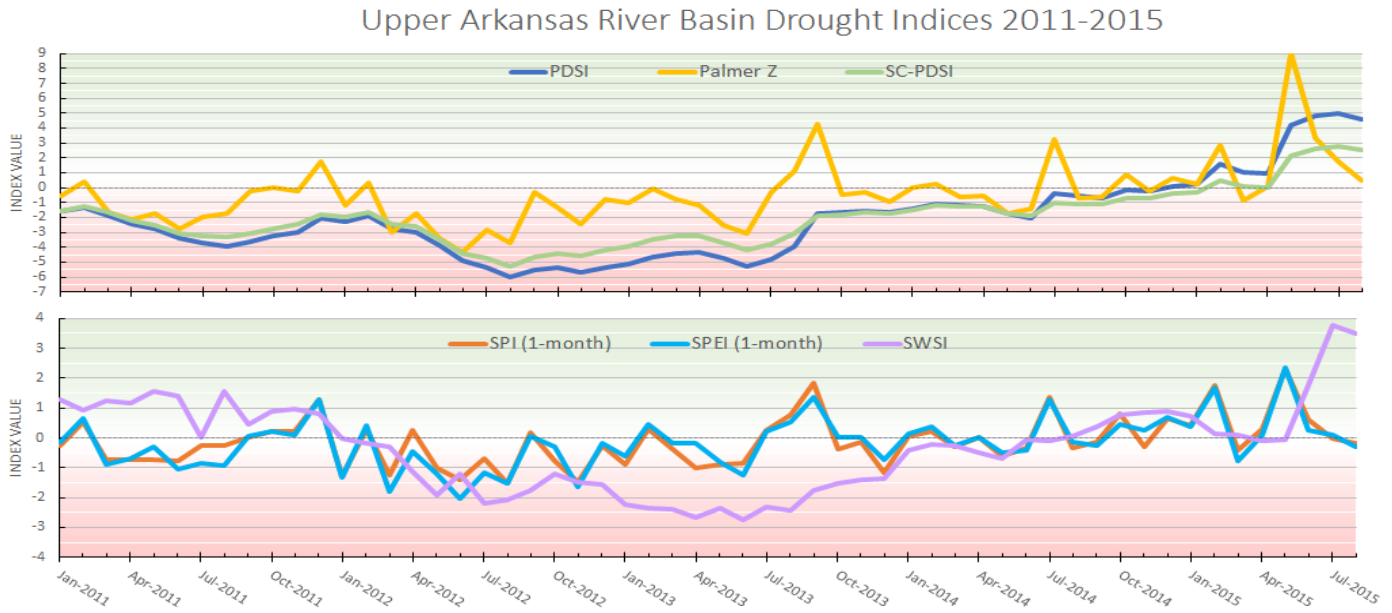


Figure 3.7: Monthly time series plots of drought index values for six drought indices during the 2011-2015 period (data obtained from the West Wide Drought Tracker and the Colorado DNR)

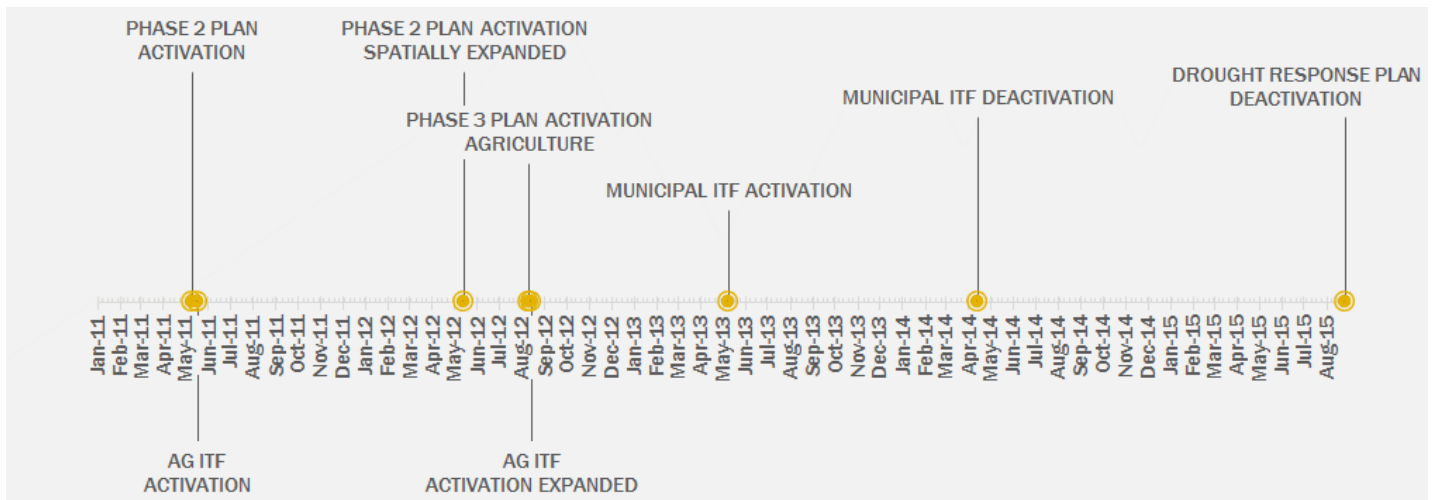


Figure 3.8: Timeline of drought Plan actions/phases including ITF activation and deactivation

By incorporating a variety of drought indices, a “convergence of evidence” approach can be applied for sound drought decision making. The USDM and drought indices timeseries data plots above attempt to illustrate the quantitative data available to the WATF and drought decision makers as the drought progressed; however, qualitative data sources are also important for identifying and validating drought impacts. Qualitative data includes information such as drought impact observations from a variety of sectors. These observations are essential for focusing drought mitigation and response resources prior-to and during a drought while also providing an

invaluable dataset to evaluate drought indices and refine future drought planning resources at a localized scale.

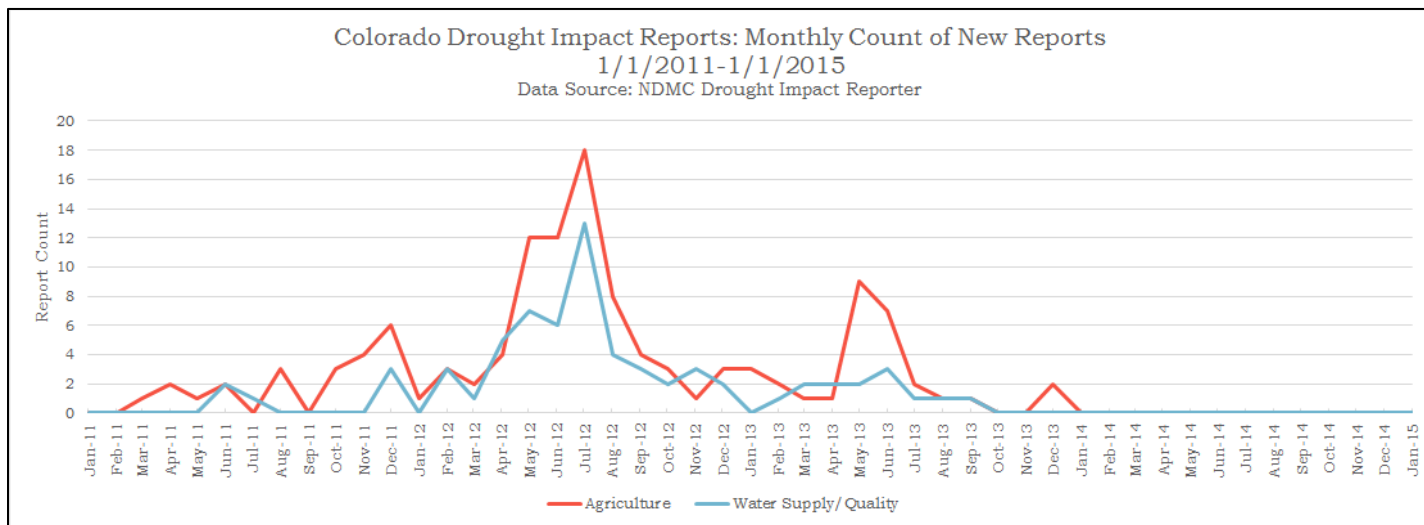


Figure 3.9: Summary of the 2011-2015 drought impact reports for Colorado

Figure 3.9 summarizes the monthly count of new drought reports categorized into agricultural and water supply/quality impacts. Impact data were obtained from the NDMC Drought Impact Reporter for the entire state of Colorado. Individual impact reports include a description, start and end date, and category classification tag(s). The data search yielded 213 reports that have a start date, end date, or timespan that occurs within the 2011-2015 period. It's important to note that the figure above represents the start date of each report and drought impacts may have extended months to years into the future. Numerous reports (78) did not include an ending date to fully examine the temporal component of drought impacts, and this finding further illustrates the continued need for comprehensive condition monitoring impact reporting prior to, during, and after drought periods. For added spatial reference, Figure 1.23 is a web map screenshot of the NDMC Drought Impact

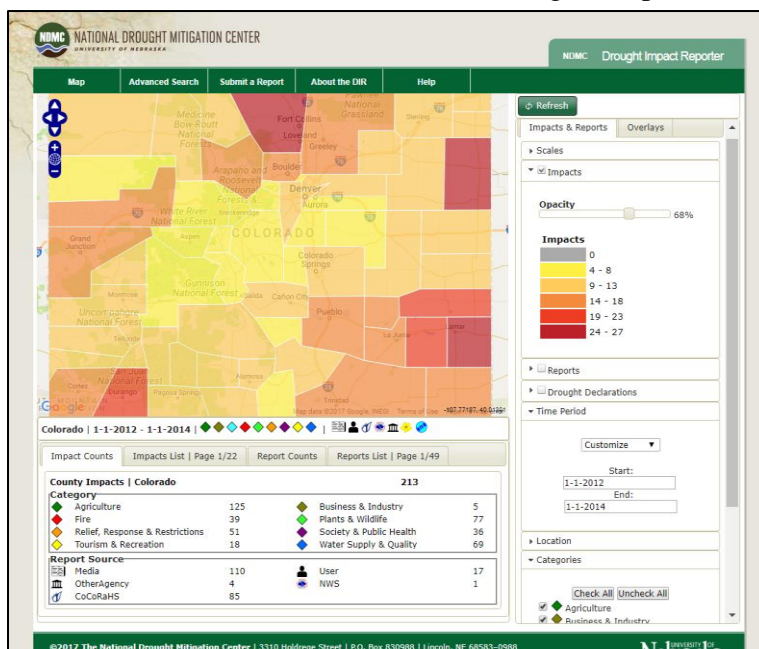


Figure 3.10: NDMC Drought Impact Reporter summary of county impact counts for the 2012-2014 period.

Reporter showing the total drought impact report counts by Colorado County for the 2012-2014 period.

4 RECOMMENDATIONS

After extensive discussions with leading experts in the drought monitoring field as well as representatives from the Colorado Impact Task Forces a list of key recommendations for continued development and improvement to the Colorado Drought Plan was developed.

1. Recommend the Water Availability Task Force and each individual Impact Task Force expand efforts to document drought impacts throughout Colorado as well as any mitigation actions or response measures put in place. Comprehensive records of dates, locations, and drought-related impact descriptions are difficult to come by but are extremely valuable for continued improvement to understanding drought vulnerabilities at a localized scale. A robust drought impact database can be combined with archived drought index data to provide a foundation for a future validation and refinement of drought monitoring practices and responses. Results of future validation efforts can be used to focus future drought Plan updates on linking drought vulnerabilities to specific drought indices (and index values) by location and stakeholder groups. Drought Plan Appendix B Actions Taken to Reduce Drought Impacts in Previous could be used as a starting point and should be updated periodically during future droughts.
2. Continue to monitor/evaluate EDDI and other newer indices currently being tested for future Plan implementation as they mature.
3. Consider future implementation of drought index guidelines as a function of both index values and index percentile ranking to allow for a streamlined comparison among the different indices.
4. Update and modernize the CWCB Drought Planning Toolbox website by providing newer resources to data hosting portals and dashboards.

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Appendix A DROUGHT MITIGATION AND RESPONSE PLANNING COMMITTEE

Table A.1 DMRPC Contact List

AGENCY	CONTACT	E-MAIL	ITF or Sector or DMRPC
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Appendix B ACTIONS TAKEN TO REDUCE DROUGHT IMPACTS IN PREVIOUS DROUGHTS

This appendix includes information on actions taken by the State during previous droughts. Information was taken from multiple sources including: “Recently Impacted States Historical Drought Information” by the Western Drought Coordination Council Drought Response Working Group in 1999; the 2003 Drought Impact and Mitigation Report prepared by the Colorado Water Availability Task Force following the 2002 drought; agency input during the 2010 and 2013 Plan revisions; Drought of 2012 in Colorado Climatology Report 13-01; and a summary of “Colorado Parks and Wildlife 2012 Drought Impacts Highlights.” This appendix is intended to serve as a reference in future droughts for the various Impact Task Forces that have the responsibility of tracking impacts and recommending mitigation and response actions (See Annex A Drought Response Plan). The table is organized by Impact Task Force. Refer to Annex B Drought Vulnerability Assessment Technical Information for additional information on State actions in past droughts and recommendations for adaptive capacities for future droughts.

Table B.1 Previous Actions Taken

Past Impact	Response Action Taken	Related Task Force
Crop/livestock losses (agriculture) ²	USDA Secretarial Disaster Declaration	AITF
Reduced forage/water for livestock (agriculture) ²	Conservation Reserve Program – emergency grazing; list of water haulers to livestock producers; Hay Hotline	AITF
Tax implications of herd reductions (agriculture) ²	Workshop re: tax implementation and information re: available drought assistance	AITF
Water supply reduction/watershed restoration ²	Thin/remove trees	AITF
Various Agricultural impacts ²	State/federal aid; monitor legislation for benefits to agriculture; communicate with legislature re: drought impacts	AITF
Lack of water storage ²	Assess legislation to provide for more stored water and to support temporary transfers of agricultural water to cities during drought	AITF
Increase cost of cattle production (e.g., feed, shipping, lease) (Agriculture) ¹	Offset cost of feed to rancher - Setup 800# to locate feed - Ship cattle to areas with feed - Reduce size of herds - Reserve stocks	AITF

Past Impact	Response Action Taken	Related Task Force
Loss of livestock production (Agriculture) ¹	Offset agricultural impact - Emergency Farm Loans - Livestock Indemnity Program - Emergency Conservation Program - Water Conservation and Enhancement Measures including wells, springs, pipelines, troughs, etc.	AITF
Agricultural contamination of groundwater (Environmental) ¹	Development of new database to focus on groundwater quality	AITF, MWITF
Need for public information dissemination (Social) ¹	Conduct workshops in affected areas	DTF
In rural communities, municipal water restrictions resulting from 1956 drought caused many schools to close (Social) ¹	Information on State response not available	DTF
Need for enhanced monitoring of water availability, blowing soils and agriculture, wildlife, and tourism (Social) ¹	Activation of State coordinating team	DTF
Transportation hazards – highway visibility reduced to ten feet at times (Social) ¹	Coordination with State Patrol	DTF
Loss of energy production ²	Review suppliers for ability to maintain supply; monitor snowpack/runoff; predict hydroelectric generation reductions; update contingency plans/improve communications; ensure adequate cooling water for plants	EITF
Public water system operational problems ²	Update list; provide impacted systems with technical/financial assistance information; update information on available funding sources for drought mitigation; develop technical/financial assistance plan for each system with problems based on prioritized needs	HITF
Risks associated with operational problems ²	Work with impacted systems to develop bottled water/ boil water advisories; approve new water supply sources	HITF
In-stream water quality problems (environmental) ²	Identify potential problems in key segments; assess low-flow-related fish kill impacts	HITF
Risks associated with body contact uses ²	Increase public awareness/education	HITF
Interrelated wastewater/drinking water treatment concerns ²	Identify potential problems caused by upstream wastewater discharges on downstream drinking water plants	HITF
Risks associated with intersystem impacts ²	Work with impacted systems to develop bottled water/ boil water advisories	HITF
Need for technical assistance to site new municipal wells (Economic) ¹	Technical assistance from universities	MWITF

Past Impact	Response Action Taken	Related Task Force
Greater reliance on water from wastewater treatment plant discharges (Environmental) ¹	Administration of “effluent bank”	MWITF
Possible water and wastewater treatment plan non-compliance due to increased salinity caused by inadequate streamflows. (Environmental) ¹	Additional Water Quality Control Division and enforcement activity	MWITF
Need ground and surface water management for drought protection (Social) ¹	Conjunctive use management	MWITF
Insufficient water supply for system ²	Identify systems with needs; potential funding sources; encourage water conservation planning/education; create incentives for those with less reliable sources to connect/consolidate with others with more reliable sources; support additional storage reservoirs	MWITF
Insufficient water system revenue due to reduced water sales ²	Identify ways to generate additional revenue to offset revenue losses; technical assistance	MWITF
Mechanical and process failures related to reduced water supplies, higher contaminant levels and high temperatures ²	Outreach to identify and assist needy systems; continued funding of emergency and long-term mitigation and infrastructure projects; assess President’s Healthy Forests Initiative to mitigate wildfire impacts on water quality/supply	MWITF
Lack of funding for municipal and wildlife related drought mitigation activities (Economic) ¹	Provide assistance in accessing grants and other resources	MWITF, WITF
Assessing downturn in tourism industry (Tourism) ¹	Financial analysis of impacts on local government tax revenues; analysis of credit needs at resort areas	TITF
Economic loss to recreation and tourism industries ²	Develop Local Community Mitigation and Response Plans; public outreach and education	TITF
Rafting industry impacts ^{2, 4}	Public education/outreach, maintain river flows wherever possible through coordination with multiple entities; keep river corridors open for commercial outfitters, In 2012 CPW along with many other municipalities, water districts and agencies worked together to maintain a flow of 350 cfs on the Arkansas River. Although this was half of the agreed upon flow, this helped to reduce impacts.	TITF
Golf industry impacts ²	Water conservation; public outreach/education	TITF
Ski industry impacts ²	Public outreach/education	TITF
State Parks impacts ^{2, 4}	Public outreach/education; lengthen boat ramps; fire bans	TITF
Local parks & recreation area impacts ²	Limit field access/practice hours in spring; close fields during periods of extreme duress; public outreach education; water conservation; BMPs	TITF

Past Impact	Response Action Taken	Related Task Force
Campground industry ²	Public outreach/education; fire bans	TITF
Fishing/hunting impacts ²	Public outreach/education; offset hatchery/fishery locations to provide best stocking coverage during drought events; monitor instream flows and reservoir levels for fish kill potential	TITF
Lodging industry impacts ²	Planning sessions with member properties; water conservation; public education/outreach	TITF
Food service industry impacts ²	Public outreach/education; reduced water usage	TITF
Competing Interest could require suspension of current water rights system ¹	Emergency water proclamation drafted to suspend statutes and rules regulating distribution of water in the state	WATF
Need to maximize supplies and minimize effects of drought on water users (Social) ¹	Aid in local water resources planning	WATF
Need for "Water Bank" to help water users buy water supplies and improve protection of fish and wildlife (Environmental) ¹	Administration of water bank, increase public awareness	WATF, WITF
Catastrophic Fires (Wildfire) ¹	Increased preparedness for fire suppression	Wildfire/ Forest Health
Loss of Fire Fighters (Wildfire) ¹	Research and improved firefighting equipment and tactics	Wildfire/ Forest Health
Fear of losing one's home (Wildfire) ¹	<ul style="list-style-type: none"> - Information on what can be done to protect homes from wildfire - Urban wildland interface programs for targeted high risk areas 	Wildfire/ Forest Health
Increased potential for wildfires in wildland interface areas ²	Technical/cost-sharing assistance for county Fire Management Plans; provide for wildland-urban interface management needs and fuels mitigation cost-sharing program; mechanism for State contributions to Emergency Fire Fund; statewide wildfire risk assessment; update roles in Colorado interagency Cooperative Fire Protection Agreement; expanded state support to zone dispatch center and extended attack; coordinate funding efforts for various programs; public education/outreach	WITF

Past Impact	Response Action Taken	Related Task Force
Low streamflow, low reservoir, high water temperatures, anoxic conditions, sediment impacts from wildfire and flash floods on fish have resulted in stress and fish kills ^{2, 3, 4}	Identify critical reaches, monitor, implement emergency habitat improvements; communication network; emergency instream flow protection; drought emergency closures; fishing restrictions; fish salvage operations; advance stocking; inform anglers to monitor water temperatures. CPW's management response to fisheries impacts from the Hayman Fire of 2002 included: 1) Increased stocking fingerling and sub-catchable size (5 to 8 inch) trout in some areas in order to replace year class losses to offset natural reproduction declines 2) Worked closely with water providers within the South Platte Basin to implement sediment trap areas on tributaries of the South Platte River, increasing opportunities for flushing flows to move the sediment bed load downstream, and 3) Worked on other stream and riparian habitat enhancements to restore watershed function. As of 2010, the CPW is still experiencing the residual impacts of the increased sediment load resulting from the Hayman fire, yet to a lesser extent than in 2002 as the ecosystem and watershed recovers slowly over time. In 2012, emergency releases were made from Lake Avery to maintain in-stream flows and protect cold water fish in the White River. In 2012, the Colorado Water Trust launched the "Request for Water 2012" program and was able to purchase temporary water rights that were unclaimed in Stagecoach Reservoir. These rights were purchased within the Colorado water rights framework and used as in-stream flow to keep water flowing through the Yampa River near Steamboat Springs, CO during the summer recreation season. ^{.5}	WITF
Decrease in recreational angling ²	Public education/information activities	WITF
Reduced hatchery production ²	Monitor hatchery water levels/stocking conditions; modify production levels and stocking procedures	WITF
Reduction in quality habitat for wildlife including reductions in supplies of food, water and cover ^{2,4}	Identify priority areas; monitor impacts on T&E species; implement emergency habitat improvements; application of good herd management	WITF
Increases in predator/human/livestock interaction ^{2, 4}	Identify/assess impacts; public education; issuing public advisories on black bear activity and need for good public hygiene practices on food and garbage management	WITF
Increased impacts to big game including game damage and habitat reduction from drought stressed lands; higher risk of starvation, predation and survival of the young ^{2,4}	Evaluate compensating private landowners; reduce herd sizes via drought mitigation hunting licenses	WITF
Changes in migratory bird patterns and waterfowl production rates; reduction in chick survival, increased predation; declines in nesting and brood rearing habitat for some species ^{2, 4}	Monitor/identify impacts; develop emergency habitat improvements	WITF

Past Impact	Response Action Taken	Related Task Force
Fish migration impacts due to low flows ³	Due to the extremely low flows in the Gunnison River during late summer of 2002, the kokanee salmon run wasn't able to get beyond a barrier west of the town of Gunnison. As a result, CPW staff netted the trapped fish and transported them manually to the Roaring Judy Fish Hatchery on the East River for spawning operations. Kokanee salmon is a high value sport fishery in Colorado and the spawning run on the Gunnison River is a critical component of maintaining this high value fishery. Further, a long-term solution was implemented as the concrete barrier was removed, re-designed, and re-constructed under the direction of a CPW aquatic biologist in order to allow fish passage.	WITF
2011-2013 Drought impacts in southeast Colorado	Agricultural Impact Task Force Activation The agricultural impact task force met for much of 2012, bringing together Farm Service Agency personnel and state water managers to report failed and prevented planting acreages, updates on CRP (Conservation Reserve Program) grazing availability as well as emergency loan status and disaster declarations status by county. Reports were also given on (although hard numbers were rarely available) cattle being sold, which mainly occurred in the Arkansas basin. These reports were integral for understanding impacts in different regions of the state. ⁵	AITF
2013 Drought - Municipal water impacts	Municipal Water Impact Task Force Activation	MWITF
Inability to share water restrictions and other drought related information specific to communities	The Colorado Drought Response Portal, which is maintained by CWCB was developed to help individuals determine what restrictions are specific to their community. http://www.coh2o.co/	All
2018 Drought impacts on agricultural industry	Agricultural Impact Task Force Activation	AITF

¹ 1999 Western Drought Coordination Council Drought Response Working Group

² 2003 Drought Impact and Mitigation Report

³ 2010 state agency input

⁴ 2013 Colorado Parks and Wildlife 2012 Drought Impacts Highlights

⁵Ryan, Wendy, and Nolan Doesken, 2013: Drought of 2012 in Colorado. Climatology Report 13-01. Dept. of Atmos. Sci., CSU, Fort Collins, CO. June, 2013.

AITF – Agricultural Impact Task Force

DTF – Drought Task Force

EITF – Economic Impact Task Force

HITF – Former Health Impact Task Force (no longer exists as of 2010)

MWITF – Municipal Water Impact Task Force

TITF – Former Tourism Impact Task Force (no longer exists as of 2013)

WATF – Water Availability Task Force

WITF – Wildlife Impact Task Force

Appendix C DROUGHT MITIGATION CAPABILITIES SUMMARY

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Socioeconomic										
Colorado Disaster Emergency Act of 1992	Office of the Governor	CRS 24-32-2101 March 12, 1992	Part 21 shall be known and may be cited as the "Colorado Disaster Emergency Act of 1992"	x	x	All	x			No funding associated with the establishment of the "Act"
Colorado Disaster Emergency Act of 1992 - Purpose	Office of the Governor	CRS 24-32-2102 March 12, 1992	(a) Reduce vulnerability of people and communities of this state to damage, injury, and loss of life and property resulting from natural catastrophes or catastrophes of human origin, civil disturbance, or hostile military or paramilitary actions. (b) Prepare for prompt and efficient search, rescue, recovery, care and treatment of persons lost, entrapped, victimized, or threatened by disasters or emergencies. (c) Provide for a rapid and orderly start of restoration and rehabilitation of persons and property affected. (d) Clarify and strengthen roles of the governor, state agencies, and local governments in prevention of, preparation for, response to and recovery from disasters. (e) Authorize and provide for cooperation in disaster prevention, preparedness, response and recovery. (f) Authorize and provide for coordination of activities relating to disaster prevention, preparedness, response and recovery by agencies and officers of this state...	x	x	All	x			At the discretion of the Governor
Definitions	Department of Public Safety	CRS 24-33.5-701 July 1, 2012	"Disasters" means the occurrence or imminent threat of widespread or severe damage, injury, or loss of life or property resulting from any natural cause or cause of human origin, including but not limited to fire, flood, earthquake, wind, storm, wave action, hazardous substance incident, oil spill or other water contamination requiring emergency action to avert danger or damage, volcanic activity, epidemic, air pollution, blight, drought, infestation, explosion, civil disturbance, hostile military or paramilitary action, or a condition of riot, insurrection, or invasion existing in the state or in any county, city, town, or district in the state.			All	x			Drought has equal status with other natural and man-made hazards
The Governor and Disaster Emergencies	Department of Public Safety	CRS 24-33.5-702 July 1, 2012	Suspend provisions of any regulatory statute prescribing the procedures of conduct of state business or the orders, rules, and regulations of any state agency.		x	All	x			

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Governor's Disaster Emergency Council	Department of Public Safety	CRS 24-33.5-704(3)(a) July 1, 2012	"Council" consisting of not less than six nor more than nine members. The attorney general, the adjutant general and the executive directors of Personnel, Transportation, Public Safety, Natural Resources. Additional members shall be appointed by the governor from among the executive directors of the other departments.	x	x	All	x			The "Council" has not been utilized to its fullest potential in the past to serve its purpose for creation.
Office of Emergency Management	Department of Public Safety	CRS 24-33.5-705(2) July 1, 2012	OEM shall prepare and maintain a state disaster plan which complies with all applicable federal and state regulations and shall keep such a plan current.	x	x	All	x			State agencies have made significant progress in developing disaster response and recovery plans relative to their area of expertise. State Hazard Mitigation Funds for mitigation plans and projects.
Disaster Emergency Fund	Office of the Governor	CRS 24-32-2106.(2)(a)(I) March 12, 1992 amended June 3, 2009	Disaster Emergency Fund established. The General Assembly declares that funds to meet disaster emergencies shall always be available.	x	x	All	x			The amount designated for each disaster varies based on damage assessment and unmet needs. Appropriated by the General Assembly. If demands are unreasonably great, the Governor, with concurrence of the council may transfer and expend moneys appropriated for other purposes.
Disaster Prevention	Department of Public Safety	CRS 24-335-710	The Governor shall consider steps that could be taken on a continuing basis to prevent or reduce the harmful consequences of disasters.	x		All	x			Programs established depending on disaster circumstances.

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
National Guard	Department of Public Safety	CRS 28-3-104	Governor can activate resources of the State National Guard.		x	All	x			The Guard is reimbursed with funds from the Disaster Emergency Fund.
Natural Hazards Mitigation Council	Office of the Governor	Executive Order B044-89	Council established by Governor's Executive Order to address Natural Hazard Mitigation.	x	x	All	x			EO had a sunset date of 1999. No longer an active Council but some subcommittees still active on a periodic basis (e.g. Earthquake Subcommittee).
The Governor and Disaster Emergencies		CRS 24-33.5-704 (4) July 1, 2012	An executive order will be disseminated promptly to bring its contents to the attention of the general public.	x	x	All	x			
Environment (includes Water Quality)										
Concerning the Establishment of Community Wildfire Protection Plans (CWPP) by County Governments	County Sheriffs, Board of County Commissioners	CRS 23-31-Part 3(VI)(b) SB09-001 August 4, 2009	By enacting this section, the general assembly intends to facilitate and encourage the development of CWPPs in counties with fire hazard areas in their territorial boundaries...	x		All	x			Grant funding from other agencies and private organizations available to local governments and fire protection districts.
Responsibility of Responding to Wildland Fires	Colorado State Forest Service	CRS 29-22.5-101(d) SB09-020 April 30, 2009	The development of a county wild land fire plan, in cooperation among the sheriff, the fire chiefs, the board of county commissioners of the county based on the resource capabilities specific to the county will assist in clarifying the roles and responsibilities of local emergency response agencies, in the management of wild land fire incidents, and for these reasons the development of such a plan is encouraged.		x	All	x			
County Wildfire Preparedness Plan	County Sheriff	CRS 29-22.5-104(1)	The Sheriff of each county may develop and update as necessary a wildfire preparedness plan for the unincorporated area of the county in cooperation with any fire district with jurisdiction over such unincorporated area.	x	x	E,S		x		

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Fire Planning Authority	County Government, Board of County Commissioners	CRS 30-11-124 HB 00-1283 Section added; May 26, 2000	The Board of County Commissioners of each county in the state, subject to the requirements of section 25-7-123 CRS (Open Burning - Penalties) may prepare, adopt and implement a county fire management plan that details individual county policies on fire management on prescribed burns, fuels management, or natural ignition burns on lands owned by the state or county. Such plans will be in coordination with the County Sheriff, the Colorado State Forest Service and the appropriate state and local governmental entities.	x		All		x		
Wildfire Emergency Response Fund	Colorado State Forest Service	CRS 23-31-309 August 3, 2007 amended August 5, 2009	Administered by CSFS and all moneys that may be appropriated, all private and public moneys received through gifts, grants, reimbursements, or donations are authorized to be used for wildfire emergency response.		x	All	x			Reimbursement funding for first aerial tanker flight or the first hour of firefighting helicopter to a wildfire at the request of any county sheriff, municipal fire department or fire protection district.
Wildfire Preparedness Fund	Colorado State Forest Service	CRS 23-31-309(4)(a)	All moneys that may be appropriated, all private and public moneys received through gifts, grants, reimbursements, or donations transferred to be used for wildfire preparedness activities.	x		All	x			Funding for wildfire preparedness activities
State Emergency Fire Suppression Fund	Colorado State Forest Service	CRS 24-33.5-1207.6	Trust fund managed by State Forest Service. Can be used to offset the cost of fire suppression.		x	All	x			Funding for assistance to local governments within the first suppression period (usually 12 hours).
Fire Bans	County Sheriff's	CRS 23-30-308	Authorized by Governor, bans on open burning in designated areas.	x	x	All	x			
Federal "Healthy Forest Restoration Act of 2003" PL 108-148	Colorado State Forest Service and County Governments	CRS 23-31-312 August 5, 2009	Facilitate and encourage the development of CWPP's in counties with fire hazard areas and to provide more statewide uniformity and consistency with respect to the content of CWPP's. The State Forester, in collaboration with representatives of the USFS, the Colorado DNR, county governments, municipal governments, local fire departments or fire protection districts, electric, gas, and water utility providers shall provide guidelines and criteria for counties to consider in preparing their own CWPP's	x	x	All	x			
Determination of Fire Hazard Area - Community Wildfire Protection Plans - Adoption - Legislative Declaration - Definitions.	Board of County Commissioners of Each County	CRS 30-15-401.7 (3)(a)	No later than January 1, 2011, the board of county commissioners of each county, with the assistance of the state forester, shall determine whether there are fire hazard areas within the unincorporated areas of the county. Not later than 180 days after determining there are fire hazard areas within the unincorporated portion of a county, the board of county commissioners, in collaboration with the representatives of the organizations or entities enumerated in section 23-31-312(3) that established the guidelines and criteria, shall prepare a CWPP for the purpose of addressing wildfires in fire hazard areas...In preparing the CWPP, the board shall consider the guidelines and criteria established by the state forester..	x		E, S, R				Technical Assistance from the State Forester

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Wildlife Cash Fund	Division of Parks and Wildlife	CRS 33-1-112	Can be used to fund both response and mitigation actions affecting wildlife during drought periods.	x	x	E, S,	x			
Income Tax Imposed on Individuals, Estates, and Trusts - Single Rate - Definitions - Repeal	Colorado State Forest Service	CRS 39-22-104(4)(n)(l)(A) HB08-1110	Tax relief for landowners who conduct wildfire mitigation measures on their property up to \$2,500.	x		E, S				2009–2014 - up to \$2,500 federal tax deduction for land owners for conducting wildland urban interface wildfire mitigation measures meeting the Colorado State Forest Service standards.
Economic Development	Office of Economic Development and International Trade	CRS 24-46-101 through 106 July 8, 1987; Section added July 1, 1998	The purpose of this article is to bring together people representing a broad spectrum of interests, including higher education, agriculture, advanced technologies, finance and banking, venture capital, energy and industry to review the economic condition of Colorado, to develop and implement programs for the promotion of economic development in Colorado.	x	x	S	x			
U. S. Department of Commerce	EDA Denver Region	Economic Development Administration and Reauthorization Act 2004 (P.L. 108-373)	Economic Development Administration (EDA) is an agency within the U.S. Department of Commerce that partners with distressed communities throughout the United States to foster job creation, collaboration and innovation		x	S	x			Job losses from natural disaster Economic Adjustment Program \$25,000 to \$2 million.
Drinking Water Revolving Fund (DWRF)	Colorado Water Quality Control Division (WQCD), Division of Local Government (DLG), Water Resources and Power Development Authority (CWRPDA)	CRS 37-95-107.8	Loans: If the project will help the water system maintain compliance with drinking water standards, or will further the health protection of goals of the Safe Drinking Water Act. Small grants (up to \$10,000) are available for system planning and design.	x	x	PHS	x			
Owner may loan agricultural water right (loans to CWCB for instream flows)	CWCB	CRS 37-38-105	Enables entities in collaboration with CWCB to lease water for streams on short notice to protect the environment. This tool has been available since 2003 however	X	X	E	X			

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
			it was first utilized by the Colorado Water Trust in 2012 to maintain water flows in at-risk stream reaches during the drought.							
Water Pollution Control Revolving Fund (WPCRF)	Colorado Water Quality Control Division (WQCD), Division of Local Government (DLG), Water Resources and Power Development Authority (CWRPDA)	CRS 37-95-107.6	Loans: If the project will help the waste water system maintain compliance with sewer discharge permit requirements, or will further the health and environment protection of goals of the Clean Water Act. Small grants (up to \$10,000) are available for system planning and design.	x	x	PHS	x			Annual funding through EPA as well as revenues generated by the program
Colorado Water Institute - Creation	Colorado State University	CRS 23-31-801 Section amended March 20, 2008	Conducting scientific research and policy analysis in areas of drought planning and mitigation. Establish and maintain a clearinghouse and archive of water research, water quality, and climate projection data.	X		All	x			State funds granted
Colorado Noxious Weed Act	CSFS and CDA	CRS 35-5.5-101 through 119	In enacting this article the general assembly finds and declares that there is a need to ensure that all the lands of the state of Colorado, whether in private or public ownership, are protected by and subject to the jurisdiction of a local government empowered to manage undesirable plants as designated by the state of Colorado and the local governing body. In making such determination the general assembly hereby finds and declares that certain undesirable plants constitute a present threat to the continued economic and environmental value of the lands of the state and if present in any area of the state must be managed. It is the intent of the general assembly that the advisory commissions appointed by counties and municipalities under this article, in developing undesirable plant management plans, consider the elements of integrated management as defined in this article, as well as all appropriate and available control and management methods, seeking those methods which are least environmentally damaging and which are practical and economically reasonable.	x		E	x			1. Restore stream channel capacity and reduce flood hazards 2. Provide habitat for aquatic and terrestrial species 3. Intensive restoration of riparian areas 4. Reduce erosion 5. Improve water quality 6. Enhance recreational access, and 7. Increase the capacity to utilize water through demonstrated reductions in the non-beneficial consumption of water by TRO.
Water Suppliers (Water Quantity)										
Local Government Land Use Control Enabling Act of 1974	Local Governments	CRS 29-20-101 through 205 1974	Grants counties and municipalities broad authority to plan for and regulate the use of land with no specific procedures proscribed for local governments to follow.	x	x	All			x	
Land Use Planning Subdivision regulations (County)	County Government,	CRS 20-28-133 1972	Requires counties to adopt subdivision regulations, including "adequate evidence that a water supply that is sufficient in terms of quality, quantity, and dependability will be available", subject to state review. Evidence includes: ownership or use of	x	x	E, S WS		x		

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
	Board of County Commissioners		water right, estimated yield of water right, amenability to change in use, etc. (Takes into account dry year yield.) The Department of Water Resources reviews this evidence and provides comments regarding the reliability and potential water rights injury for the proposed water supply.							
Local Government Land Use Control Enabling Act - Adequate Water Supply (Curry Bill, HB08-1141)	Local Governments	HB08-1141	Requires a local government to make a determination as to whether an applicant for a development in excess of 50 units or a single-family equivalents, or fewer as determined by the local government, has demonstrated that the proposed water supply is adequate to serve the proposed development	x	x	S, WS	x			
Local Government Land Use Control Enabling Act - Adequate Water Supply (Curry Bill, HB08-1141)	Local Governments	CRS 24-65.1-101 HB08-1141 Powers	Allows local government to identify, designate, and regulate (through a permitting process) 21 statutorily defined "areas of state interest" including: site selection and construction or major new water and sewage treatment systems; major extensions of existing domestic water and sewage treatment systems. Allows some local control over matters of statewide interest. The State Engineer's Office does not implement Act.	x	x	S, WS,	x			
Land Use Planning	Local Governments	CRS 30-28-106; CRS 31-23-206 1939 through 2007	Counties and municipalities meeting certain growth standards are required to adopt a master plan (comprehensive plan) for the physical development of their jurisdictions; MUST include a recreation and tourism element; extraction commercial mineral deposits. May include a "water supply element." If included, the county or municipality needs to coordinate with the local water supply entities.	x	x	E, S, WS	x			
Land Use Planning	Subdivision Notification	CRS 30-28-136	Requires counties to submit a copy of preliminary plans for subdivisions to affected governments, including school districts, special and other districts, counties and municipalities located within two miles of the proposal and other agencies.	x	x	All	x			
Land Use Planning	Local Governments	CRS 29-20-104.5	Grants broad impact fee authority to counties and statutory municipalities to have new development pay for certain costs associated with growth; home rule municipalities always had this authority through their constitutional home rule powers. Nearly half of Colorado's cities have implemented impact fees. The most commonly used fee is for water 40% and sewer 27%. (CML 2004b) Impact fees may only be used to offset the impacts of new development on existing infrastructure and capital improvements and may not be used to pay for improvements needed to correct existing deficiencies in levels of service.	x	x	All	x			
Waterworks	Municipal Governments	CRS 31-15-707	Allows municipalities to construct waterworks outside its boundaries and protect the waterworks and water supply from pollution up to five miles above the point from which the water is taken.	x	x	All	x			

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Weather Modification Operations	Colorado Water Conservation Board	CRS 36-20-101 through 127	CRS 36-20-108(4)(b) The Director may direct the State and assist counties, municipalities and public agencies in contracting in commercial operators for the performance of weather modification or cloud seeding operations.	x	x	All	x			See Non Reimbursable Investment
The Colorado Water Conservation Act of 1991 HB91-1154	Colorado Water Conservation Board	CRS 37-60 124 and CRS 37-60-126	Creates the Office of Water Conservation and Drought Planning under the Colorado Water Conservation Board to promote water conservation and drought mitigation planning	x	x	All	x			
Water Conservation Board and Compacts	Colorado Water Conservation Board	CRS 37-60-101 to 210	Provides voluntary guidelines for use by water utilities and funding for water conservation projects for those who have a plan.	x	x	All	x			
Duties of the Board	Colorado Water Conservation Board	CRS 37-60-106(1)(c) & (d)	Authorizes CWCB to formulate plans for bringing about the greater utilization of the waters of the state.	x		All	x			
Water Studies	Colorado Water Conservation Board	CRS 37-60-115	Authorizes CWCB to study water resources toward a unified and harmonious development of all waters for beneficial use in Colorado to the fullest extent possible under the law including studies regarding interbasin transfers.	x		All	x			Each sponsor shall submit a final report to the board and the state engineer by January 15, 2025. The board and the state engineer shall provide a final briefing to the water resources review committee by July 1, 2025. and irrigation practices.
Colorado Water Conservation Board Construction Fund	Colorado Water Conservation Board	CRS 37-60-121	Funds projects dealing with Water resources, instream flows, etc. The CWCB Loan Program provides low interest loans to agricultural, municipal and commercial borrowers for the development of water resource projects in Colorado.	x	x	A, E, S, WS	x			
Flood and Drought Response Fund	Colorado Water Conservation Board	CRS 37-60-123.2	Transfers up to \$500,000 from CWCB's construction fund to support flood and drought preparedness in addition to response and recovery activities following flood or drought events.	x	x	All	x			
Agricultural Emergency Drought Response	Colorado Water Conservation Board	CRS 37-60-123.5	Appropriates funds to CWCB for use in making loans and grants to agricultural organizations for emergency drought related water augmentation purposes.		x	A	x			up to \$1 million
Water Conservation and Drought Planning - Programs - Relationship to State Assistance for Water	Colorado Water Conservation Board	CRS 37-60-126	Defines the requirements that cover water conservation and drought mitigation planning. Creates the water efficiency grant program for purposes of providing state funding to aid in the development and implementation of water conservation plan, and drought mitigation plans in addition to efforts for water resource conservation public education and outreach. Funds are continuously appropriated	x	x	S	x			

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Facilities - Guidelines - Water Efficiency Grant Program			to the CWCB for this purpose, to be available until the programs financed by the grants have been completed. CWCB has also developed M&I drought and conservation guidance documents and sample plans for the purposes of assisting water providers in developing such plans in addition to various stakeholder outreach efforts to encourage drought planning throughout the State.							

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Water Conservation and Drought Planning - Programs - Relationship to State Assistance for Water Facilities - guidelines - Water Efficiency Grant Program	Colorado Water Conservation Board	CRS 37-60-126.4	Minimum water conservation plan elements for an entity that seeks financial assistance from either the CWCB or Colorado Water Resources and Power Development Authority. (I) Water-efficient fixtures and appliances, including toilets, urinals, showerheads, and faucets. (II) Low water use landscapes, drought-resistant vegetation, removal of phreatophytes, and efficient irrigation. (III) Water-efficient industrial and commercial water-using processes. (IV) Water reuse systems; (V) Distribution system leak identification and repair; (VI) Dissemination of information regarding water use efficiency measures, including by public education, customer water use audits, and water-saving demonstrations; (VII) Water rate structures and billing systems designed to encourage water use efficiency in a fiscally responsible manner; (VIII) The department of local affairs may provide technical assistance to covered entities that are local governments to implement water billing systems that show customer water usage and that implement tiered billing systems; (IX) Regulatory measures designed to encourage water conservation; (X) Incentives to implement water conservation techniques, including rebates to customers to encourage the installation of water conservation measures; (b) A section stating the covered entity's best judgment of the role of water conservation plans in the covered entity's water supply planning; (c) The steps the covered entity used to develop, and will use to implement, monitor, review, and revise, its water conservation plan; (d) The time period, not to exceed seven years, after which the covered entity will review and update its adopted plan; and (e) Either as a percentage or in acre-foot increments, an estimate of the amount of water that has been saved through a previously implemented conservation plan and an estimate of the amount of the water that will be saved through conservation when the plan is implemented.	x		S	x			
Water Conservation and Drought Planning - Programs - Relationship to State Assistance for Water Facilities - guidelines - Water Efficiency Grant Program	Colorado Water Conservation Board	CRS 37-60-126.4.5	Calls for the establishment of guidelines regarding the reporting of water use and conservation data by covered entities. The purpose of data reporting is to provide water use and conservation data to be used for statewide water supply planning. The data collection process described in these Guidelines, developed as part of HB10-1051, is designed to provide better, more frequent, and more reliable data than currently available. These Guidelines create standardized reporting in that each covered entity is required to report the same type of information. However, this does not necessarily standardize the data collection process and does not require entities to change their data/billing systems to report in a particular format. Specific reporting categories were identified to allow the data to be utilized for annual forecasting purposes and to predict how water demands for different customer categories may evolve over time, through considering potential effects of water conservation.	x		S	x			

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Drought Mitigation Planning - Programs - Relationship to State Assistance	Colorado Water Conservation Board	CRS 37-60-126.5	Regulates drought mitigation planning programs and the relationship to State assistance to manage water supplies and water demand appropriately.	x			x			
Drought Mitigation Planning - Programs - Relationship to State Assistance	Colorado Water Conservation Board	CRS 37-60-126(11)(a)	Homeowners associations cannot enforce restrictive covenants that prohibit or limit xeriscape, installation or use of drought-tolerant vegetative landscapes, or require cultivated vegetation to consist exclusively or primarily of turf grass.	x	x	S	x			
Water Availability Task Force - drought condition recommendations - legislative declaration - repeal.	Colorado Water Conservation Board	CRS 24-32-2105.5	Encourages Water Availability Task Force to continue to monitor drought conditions to recommend legislation addressing drought emergencies.	x	x	All	x			
Reservoirs and Ditches May Exchange	Colorado Water Conservation Board	CRS 37-83-104	Allows water users to release stored water to the stream or ditch and in exchange divert an equal amount of water from a point higher upstream without adjudicating an exchange. Such exchanges are subject to the no injury rule and a water user undertaking such an exchange may be required by the State Engineer to release additional water from storage to make up for delivery losses.		x	WS	x			
Owner may loan agricultural water right - loans to Colorado water conservation board for instream flows.	Colorado Water Conservation Board	CRS 37-83-105	Allowing persons taking water from the same stream or ditch to exchange or loan water to one another for a limited time for the purpose of saving crops or using water in a more economical manner without requiring an adjudication of a change of water rights. Recently amended to allow temporary loans of water to CWCB for instream flow purposes.	x	x	WS	x			Ongoing
Authority of political subdivisions to lease or exchange water.	Colorado Water Conservation Board	CRS 37-83-106	Allowing water conservancy and conservation districts to enter into cooperative agreements with other political subdivisions for the lease or exchange of water outside district boundaries.	x	x	S	x			
Interruptible water supply agreements - special review procedures - rules - water adjudication cash fund - legislative declaration.	Colorado Water Conservation Board	CRS 37-92-309	This section, adopted during last legislative session. Gives State Engineer authority to approve temporary, interruptible water supply agreements, between water users providing for the temporary transfer of historic consumptive use credit to another type and or place of use without requiring adjudication of a change of water rights. Subject to approval by State Engineer upon a finding of non-injury to other water users. And non-interference with interstate compact requirements and will only be approved for operation during a calendar year in which a drought or other emergency has been declared by the Governor and the first full calendar after the declared emergency terminates.	x	x	WS	x			

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Water Conservation in State Landscaping	Colorado Water Conservation Board	CRS 37-96-101 to 103 1989; amended 1991, 99	Requirements of public project landscaping to promote water efficiency and conservation. Any governmental or quasi-governmental agency of the state and political subdivision of the state that receives State financing for a project or facility is subject to the requirements.	x	x		x			
Rooftop Precipitation Collection	State Engineer's Office	CRS 37-96.5-103 HB 16-1005	Allows for the installation of a maximum of two rain barrels with a combined capacity of 110 gallons at single-family and multi-family households with four or fewer units. Rain barrels can only be used to capture rainwater from rooftop downspouts and the captured rainwater must be used to water outdoor lawns, plants and/or gardens on the same property from which rainwater was captures. Rain barrel water cannot be used for drinking of other indoor water use. On or before March 1,2019 and on or before March 1, 2022, the State Engineer shall report to the committees of reference in each House of the General Assembly with jurisdiction over agriculture on whether the allowance of small-scale residential precipitation collection pursuant to this article has caused any discernible injury to downstream water rights.	x		E, WS	x			
Water Metering Act	Colorado Water Conservation Board	CRS 37-97-101 to 103 July 1, 1990; 2004	Every water service supplier providing water to over 600 taps in this state shall provide a metered water delivery and billing service to its customers - residential, commercial and industrial. New construction will have meters installed at the time of construction. Existing construction are to have had meters installed by January 1, 2009.	x	x	PHS	x			
Colorado Water Resources and Power Development Authority Act	Not an agency of State Government, but a body corporate and a political subdivision of the state	CRS 37-95 July 1, 1981	To preserve, protect, upgrade, conserve, develop, utilize and manage the water resources of the state.	x		All, PH S	x			
Local Government Energy and Mineral Impact Assistance Fund	Department of Local Affairs	CRS 34-63-102, CRS 39-29-110	To assist political subdivisions that are socially and/or economically impacted by the development, processing, or energy conversion of minerals and mineral fuels.	x			x			
Community Development Block Grant	Department of Local Affairs		Benefit persons of low and moderate income, prevent or eliminate slums or blight, and address other urgent needs.	x	x		x			
Water Resources Review Committee	CWCB	CRS 37-98-102	Creates a water resources review committee to monitor the conservation and development of water resources in Colorado.	x	x	All	x			

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
State Engineer	State Engineer's Office	CRS 37-80, CRS 24-1-124, CRS 24-33-104	Reservoir, streamflow, and water resources data collection dissemination. Real time satellite stream gauge system: river basin simulation models, production of surface water supply index.	x	x	WS	x			
County Control of Reservoirs	County Commissioners	CRS 37-88-109(2)	Shall maintain and keep reservoirs in good condition and provide for the storage of water and for distribution of water under the direction of the division engineer for the district in which the reservoir is situated and should be replenished for agricultural purposes during water scarcity.	x	x	PHS	x			

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Arkansas River Water Bank Pilot Program	State Engineer	CRS 37-80.5-106	To authorize the creation of water banks within each water division to be operated under strict parameters established by rules approved by the water court. Accordingly, this article provides for the promulgation of rules concerning water banks and requires the water court to approve the rules and the state engineer to report to the general assembly regarding the operation of the banks. The water bank program created by this article is intended to simplify and improve the approval of water leases, loans, and exchanges, including interruptible supply agreements, of stored water within each river basin, reduce the costs associated with such transactions, and increase the availability of water-related information. It is also the purpose of the water banks to assist farmers and ranchers by developing a mechanism to realize the value of their water rights assets without forcing the permanent severance of those water rights from the land.	x	x	WS	x			
Substitute Water Supply Plans	State Engineer	CRS 37-92-308(7) HB 02-1414	The State Engineer may approve such a plan if it is needed to address an emergency situation meaning "affecting public health or safety".		x	PHS	x			Allows 90 days of operation with no notice requirement.
Substitute Water Supply Plans	State Engineer	CRS 37-92-308(5)	SWSP allows one year of operation but only in situations where the depletions from the operation will not go out for a duration of more than five years. For this SWSP, no water court application is required as a prerequisite but the applicant must still give notice through the SWSP Notification List and allow 30 days for comments.		x	PHS, Ag	x			
Substitute Water Supply Plans	State Engineer	CRS 37-92-308(4)	Allows for temporary operation of a plan for augmentation that has been filed in water court but has not received judicial approval. The applicant must have an active application in water court. The SWSP must not allow more than that which has been applied for in water court and the applicant must give notice to objectors to the water court application.		x	PHS, Ag	x			
Substitute Water Supply Plans	Colorado Water Conservation Board	CRS 37-92-308	Calls for the CWCB to update the Criteria and Guidelines to allow for the establishment of Regionally Applicable Factors that specify the amount of precipitation consumed through evapotranspiration of preexisting natural vegetative cover. If a sponsor submits an application in a region where a Regionally Applicable Factor has been adopted under these Criteria and Guidelines, the sponsor may propose the use of the Regionally Applicable Factor in SWSPs applied for pursuant to section 37-92-308(4) or (5), C.R.S. and associated with the sponsor's pilot project. The State Engineer shall give the sponsor's use of the Regionally Applicable Factor in said SWSP applications a presumptive effect, subject to rebuttal. Each sponsor shall submit a final report to the board and the state engineer by January 15, 2025. The board and the state engineer shall provide a final briefing to the water resources review committee by July 1, 2025.		x	PHS, Ag	x			Allows for easier entry into pilot program and creates an incentive for more sponsors to implement precipitation harvesting.

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Colorado Healthy Rivers Fund	Colorado Water Conservation Board	CRS 39-22-2403 2002; title amended in 2008	Creates a fund to be added to the Colorado Individual Income Tax Refund Check-off Program to give taxpayers the opportunity to voluntarily contribute to watershed protection efforts in Colorado. Moneys in the fund are available through a grant program jointly established by the CWCB and the Water Quality Control Commission, and the Colorado Watershed Assembly. Two categories of grants: 1) Project grants that support the improvement and/or protection of the condition of the watershed. 2) Planning grants to support development of plans for restoration or protection projects.	x	x	E	x			Provides additional contribution for a variety of funds.
The Construction Fund	Colorado Water Conservation Board (1971)	CRS 37-60-121	This fund provides low-interest loans for water projects. The fund has financed up to 90% of engineering and construction costs for more than 370 locally sponsored water projects. The fund may also provide non reimbursable investments. The Construction Fund is a revolving loan fund that allows the CWCB to be self-supporting and operate without money from the General Fund.	x	x	WS				Revenues come from interest earned on outstanding loans and on the fund's cash balance in the state treasury, and royalty distributions from federal mineral leases (FML). The Construction Fund's ability to support CWCB's operations and programmatic activities was significantly impacted by a \$10 million general fund transfer in FY08/09.
Severance Tax Trust Fund	Colorado Water Conservation Board (1997)	CRS 39-29-109	Creates the water supply reserve account in the severance tax trust fund. CWCB oversees the fund and makes loans or grants for water activities approved by a basin roundtable, including: Competitive grants for environmental compliance and feasibility studies; Technical assistance regarding permitting, feasibility studies, and environmental compliance; Studies or analysis of structural, nonstructural, consumptive, and non-consumptive water needs, projects, or activities; and Structural and nonstructural water projects or activities.	x	x	S, WS	x			\$10 million each year
Recommended Non Reimbursable Investments	Colorado Water Conservation Board (1997)		Projects or studies of statewide impact or importance. Feasibility studies and projects designed to address statewide, region-wide, or basin-wide issues. The Board examines whether such studies will result in new loans. CWCB can approve loans up to \$10 million without legislative approval.	x			x			
Colorado Water Quality Control Act	Colorado Department of Public Health and Environment	CRS 25-8-101 through 703 1963; repealed and reenacted 1981	In order to foster the health, welfare, and safety of the inhabitants of the state of Colorado and to facilitate the enjoyment and use of the scenic and natural resources of the state, it is declared to be the policy of this state to prevent injury to beneficial uses made of state waters, to maximize the beneficial uses of water, and to develop waters to which Colorado and its citizens are entitled and, within this context, to achieve the maximum practical degree of water quality in the waters of the state consistent with the welfare of the state.	x		E				Principal funding comes from the taxes paid by the producers of gas, oil, coal and other minerals. Also used for water supply projects. Loan rates are 2.75% for agriculture

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
										loans, 4% to 5.25% for municipal loans, and 6.25% for commercial loans (adjusted annually).
Regional Wastewater Management Plans	Colorado Department of Public Health and Environment	CRS 25-8-105 1963; repealed and reenacted 1981	Wastewater management plans guidelines; creates water quality control commission to ensure provision of continuously safe drinking water by public water systems; permit system for pollutant discharge; violation, remedies, penalties; construction of domestic wastewater treatment works. Covered governmental entities include "any regional commission, county, metropolitan district offering sanitation service, sanitation district, water and sanitation district, water conservancy district, city town, Indian tribe or authorized Indian tribal organization or any two or more of them which are acting jointly in connection with a sewage treatment works."	x	x	S, WS	x			
Colorado Water Resources Research Institute	Colorado State University	CRS 23-35-101 moved to Part 8 of Article 31	Program provides for funding of water resources related research and dissemination of findings, including drought as well as the dissemination of information of a water policy nature.	x	x	A, E, W	x			
Power and Mining										
Colorado Energy Assurance Emergency Plan Recovery Act -	Colorado Energy Office	CRS 24-38.5-101 through 103	Establishment of the Energy Office to fulfill the offices mission to lead Colorado to a new energy economy by advancing energy efficiency and renewable, clean energy resources.	x	x	All	x			Enhances State government energy assurance capabilities and planning ; multiple grant programs
Colorado Renewable Energy Standard	Colorado Energy Office	HB 1001	The new law requires utilities to supply at least 12% of their retail electric sales from such sources from 2011 to 2014, 20% from 2015 to 2019, and 30% for 2020 and thereafter. Those requirements apply to all providers of retail electric service in the state, with the exception of municipal utilities serving 40,000 customers or fewer. In-state power facilities receive extra credit towards the requirements. More rooftop solar, community wind farms and other distributed resources such as small hydro, biomass, and geothermal will enhance the stability of the electric grid and create predictability in the renewable market, allowing us to bring more clean resources onto the system.							Increases the Renewable Energy Standard to 30% of retail electric sales (from 20%) by 2020 for Investor-Owned Utilities (Xcel Energy and Black Hills Corp.) Creates a minimum requirement for renewable distributed generation of at least 3% of total retail electric sales by 2020. Sets a standard for solar photovoltaic system installations. Keeps in statute the existing standard for rural electric associations (REAs).

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Recreation & Tourism										
Creation of Colorado Tourism Office	Colorado Tourism Office	CRS 24-49.7-101 through 109 May 22, 2000	Tourism and travel industries are vital to the general welfare, economic well-being, and employment opportunities of the state and its communities and citizens and that the continued health and expansion of these industries requires a long-term and continuing investment by the State in the planning promotion, coordination and development of Colorado as a quality national and international tourist and travel destination.		x	All	x			Colorado Travel and Tourism Promotion Fund
Colorado Office of Economic Development	Office of Economic Development and International Trade	CRS 24-46-Part 1	Declares that the commission encourages, promotes, and stimulates economic development and employment in Colorado by awarding economic development incentives to employers in the form of grants, loans, and performance-based incentives. The general assembly further finds that it is in the best interest of the people of the state to ensure that United States citizens and others lawfully present in the state are the beneficiaries of employment opportunities that are made possible through moneys awarded to employers.	x	x	All	x			Colorado Economic Development Fund
Colorado Regional Tourism Act	Office of Economic Development and International Trade	CRS 24-46- Part 3 June 4, 2009	The health, safety, and welfare of the people of the state of Colorado are enhanced by a diverse revenue stream, and the people of the state would benefit from an expansion of opportunities for investment in large-scale regional tourism projects that will attract significant investment and revenue from outside the state.	x		All	x			Funds for regional tourism projects
Agriculture										
Colorado Agriculture Extension Service. Public Information Technical Assistance		CRS 22-34-101	Program provides for dissemination in a timely manner to the agriculture community of drought related information and provision of technical assistance to deal with drought impacts.	x	x	A	x			

Title	Lead Agency	Statute	Description	Pre-disaster	Post Disaster	Impact Sector*	Effect on Loss Reduction			Comments
							Supports	Facilitates	Needs Improvement	
Agriculture	FMA, FCA, FSA, FEMA, SBA,	Title 7 CFR Part 1945 Subpart A	This subpart describes and explains the types of incidents which can result in an area being determined a disaster area, thereby making qualified farmers in such areas eligible for Farmers Home Administration (FmHA) or its successor agency under Public Law 103-354 Emergency (EM) loans. With respect to natural disasters, it sets forth the responsibility of the Secretary of Agriculture; the factors used in making a natural disaster determination; the relationship between FmHA or its successor agency under Public Law 103-354 and the Federal Emergency Management Agency (FEMA); the method for establishing and using Emergency Loan Support Teams (ELST) and Emergency Loan Assessment Teams (ELAT); the training of FmHA or its successor agency under Public Law 103-354 personnel; and disaster related public information functions. The natural disaster determinations/notifications made under this subpart do not apply to any program other than the FmHA or its successor agency under Public Law 103-354 EM loan program. FmHA or its successor agency under Public Law 103-354's policy is to make EM loans to any otherwise qualified applicant without regard to race, color, religion, sex, national origin, marital status, age, or physical/mental handicap (provided the applicant can execute a legal contract) as provided by law.		x	A, S	x			Secretary of Agriculture activates programs
Credit for income eligible to be deferred on sale of livestock due to weather-related conditions	Taxation	CRS 39-22-128 HB 02S-1010 August 12, 2002	Allows qualified livestock producers to defer taxes on livestock sold due to drought (with four years to replace livestock without reporting gains).		x	A	x			Tax benefit to the agricultural community
Colorado Noxious Weed Act	Department of Agriculture	CRS 35-5.5-1-2	This "Act" declares that certain undesirable plants constitute a present threat to the continued economic and environmental value of the lands of the state and if present in any area of the state must be managed. It is the intent of the general assembly that the advisory commissions appointed by counties and municipalities under this article, in developing undesirable plant management plans.				x			Noxious Weed Management Fund under the State Treasurer

*A=Agriculture

*E=Environment

*PHS=Public Health and Safety

*R=Recreation

*S=Socioeconomic

*WS=Water Supply

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Appendix E DEFINITIONS AND ACRONYMS

Definitions

Drought Types	<i>Meteorological drought</i> – a period of below-average precipitation.
	<i>Agricultural drought</i> – a period of inadequate water supply to meet the needs of the state’s crops and other agricultural operations such as livestock.
	<i>Hydrological drought</i> – deficiencies in surface and subsurface water supplies. Generally measured as streamflow, snowpack, and as lake, reservoir, and groundwater levels.
	<i>Socioeconomic drought</i> – occurs when drought impacts health, well-being, and quality of life, or when a drought starts to have an adverse economic impact on a region.
Drought Stages	Drought severity levels generally differentiated by pre-defined trigger points or thresholds.
Drought Indices	Assimilation of data on rainfall, snowpack, streamflow, and other water supply measurements into a comprehensible picture (NDMC website, “What Is Drought: Drought Indices,” Michael Hayes). Some examples of common drought indices are: Palmer Drought Severity Index, Crop Moisture Index, Surface Water Supply Index, and the Standardized Precipitation Index.
Drought Management Planning	
	Drought management planning includes drought mitigation and drought response planning. The main objective of drought management planning is to preserve essential public services and minimize the adverse effects of a water supply deficit on public health and safety, economic activity, natural resources and individual lifestyles.
Impact	Measured or observed effect of drought that could include social, economic, and environmental sectors.
Mitigation	Drought mitigation refers to actions taken in advance of a drought that reduce potential drought-related impacts when the event occurs. Measures taken in advance of a disaster aimed at decreasing or eliminating its impact on society and environment (U.N. 1992, 4). Examples of drought mitigation steps include community drought response plans, mutual aid agreements, and drought legislation. Advances in technology often result

in improved mitigation strategies, such as increasingly efficient techniques for irrigating crops.

Response Planning Drought response planning addresses the conditions under which a drought induced water supply shortage occurs and specifies the actions that should be taken in response.

Response Action Actions that will be carried out during a drought as various drought trigger points are reached. Response strategies can include anything from short-term emergency aid to government assistance programs and media relations.

Risk A combination of hazard, vulnerability, and exposure. The impact a hazard would have on people, services, facilities, and structures in a community and refers to the likelihood of a hazard event resulting in an adverse condition that causes injury or damage.

Vulnerability Being open to damage or attack (as defined by FEMA’s risk assessment guidance (FEMA 386-2). The likelihood that an area or sector will be negatively affected by environmental hazards (Bolin and Stanford, 1998).

Acronyms

AF	Acre-feet
AGO	Attorney General’s Office
AUM	Animal Unit Month
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BNDSS	Basin Needs Decision Support System
BRT	Basin Roundtable
CAA	Community Agriculture Alliance
CAH	Climate-Adjusted Hydrology
CAIC	Colorado Avalanche Information Center
CASA	Carnegie-Ames-Stanford Approach
C-BT	Colorado Big Thompson
CCA	Colorado Cattlemen’s Association

CCC	Colorado Climate Center
CDA	Colorado Department of Agriculture
CDBG	Community Development Block Grant
CDBG-DR	Community Development Block Grant – Disaster Recovery
CDC	Center for Disease Control
CDOC	Colorado Department of Corrections
CDPHE	Colorado Department of Public Health and Environment
CEAEP	Colorado Energy Assurance Emergency Plan
CEDMP	Colorado Equilibrium Displacement Mathematical Programming Model
CEO	Colorado Energy Office
CFWE	Colorado Foundation for Water Education
CGS	Colorado Geological Society
CIR	Crop Irrigation Requirement
CMI	Crop Moisture Index
CMPDI	Colorado Modified Palmer Drought Index
COAGMET	Colorado Agricultural Meteorological Network
CoCoRaHS	Community Collaborative Rain, Hail & Snow Network
CO WWC	CO Water Wise Council
CODOS	Colorado Dust-on-Snow program
COGCC	Colorado Oil and Gas Conservation Commission
COMaP	Colorado Ownership, Management, and Protection
CPW	Colorado Parks and Wildlife
CRC	Center for Resource Conservation

CROA	Colorado River Outfitters Association
CRP	Conservation Reserve Program
CRMI	Colorado Resource Monitoring Initiative
CRWA	Colorado Rural Water Association
CRWAS	Colorado River Water Availability Study
CSAS	Center for Snow and Avalanche Studies
CSCUSA	Colorado Ski Country USA
CSFS	Colorado State Forest Service
CSU Coop Ext	Colorado State University Cooperative Extension
CSU	Colorado State University
CSU-WRI	Colorado State University Water Research Institute
CU	University of Colorado
CWCB	Colorado Water Conservation Board
CWPP	Community Wildfire Protection Plan
CWR&PDA	Colorado Water Resources and Power Development Authority
DARE-CSU	Department of Agricultural and Resource Economics at Colorado State University
DART	Drought Assessment and Response Tools or Drought Assessment for Recreation and Tourism
DEWS	Drought Early Warning System
DHSEM	Colorado Division of Homeland Security and Emergency Management
DMA	Disaster Mitigation Act
DMRPC	Drought Mitigation and Response Planning Committee
DNR	Department of Natural Resources

DOI	Department of the Interior
DOLA	Department of Local Affairs
DOLA DLG	Division of Local Government
DOLA CRO	Colorado Resiliency Office
DORA-PUC	Department of Regulatory Agencies Public Utilities Commission
DOW	Division of Wildlife (merged with Colorado State Parks in 2012; currently Colorado Parks and Wildlife (CPW))
DPS	Department of Public Safety
DRMS	Division of Reclamation and Mining Safety
DTF	Drought Task Force
DWR	Division of Water Resources
DWRF	Drinking Water Revolving Fund
DWSA	Drought and Water Supply Assessment
DWSU	Drought and Water Supply Update
EDA	Economic Development Administration
EDDI	Evaporative Demand Drought Index
EHH	Extended Historical Hydrology
EHSB	Environmental Health Services Branch
EIA	Energy Information Administration
EMAP	Emergency Management Accreditation Program
EMPG	Emergency Management Performance Grant
EPA	Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
FEMA	Federal Emergency Management Agency

FSA	Farm Services Agency
FTAP	Flood Technical Assistance Partnership
FWS	Fish and Wildlife Service
GAR	Governor’s Appointed Representative
GCM	Global Climate Model; General Circulation Model
GCSAA	Golf Course Superintendents Association of America
GIS	Geographic Information Systems
GOCO	Great Outdoors Colorado
GreenCo	Green Industries of Colorado
GW	Groundwater
HMA	Hazard Mitigation Assistance grant program
HMGP	Hazard Mitigation Grant Program
HSIP	Homeland Security Infrastructure Program
HSPA	Health Professional Shortage Area
HVAC	Heating, Ventilating and Air Conditioning
IBCC	Interbasin Compact Committee
IP&Ps	Identified Projects and Processes
IPCC	International Panel on Climate Change
IRP	Integrated Resource Planning
ISFDSS	Instream Flow Decision Support System
ITF	Impact Task Force
JFRCCVS	Joint Front Range Climate Change Vulnerability Study
KBDI	Keetch-Byram Drought Index
LMIC	Livestock Marketing Information Center

L-PDM	Legislative Pre-Disaster Mitigation Program
M&I	Municipal and Industrial
MODIS	Moderate Resolution Imaging Spectroradiometer
MWTF	Municipal Water Task Force
NASA	National Aeronautics and Space Administration
NASA ASO	NASA Airborne Snow Observatory
NASS	National Agriculture Statistics Service
NCAR	National Center for Atmospheric Research
NCNA	Non-Consumptive Needs Assessment
NCWCD	Northern Colorado Water Conservancy District
NDIS	Natural Diversity Information Source
NDMC	National Drought Mitigation Center
NETL	National Energy Technology Laboratory
NHD	National Hydrography Dataset
NHMP	Natural Hazard Mitigation Plan
NIDIS	National Integrated Drought Information System
NDIS	Natural Diversity Information Source
NIMS	National Incident Management System
NIMSCAST	National Incident Management System Capability Assessment Support Tool
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Agency
NPS	National Park Service
NRCS	National Resource Conservation Service

NREL	Natural Resource Ecology Laboratory
NRF	National Response Framework
NSAA	National Ski Areas Association
NTU	Nephelometric Turbidity Units
NWS	National Weather Service
NWS RFC	National Weather Service – River Forecast Center
OEDIT	Office of Economic Development and International Trade
OSPB	Governor’s Office of State Planning and Budgeting
OWDCP	Office of Water Conservation and Drought Planning
PA	Public Assistance
PDM	Pre-Disaster Mitigation Program
PEPO	Public Education, Participation, and Outreach
PR	Public Relations
QWEL	Qualified Water Efficient Landscaper
RAD	EPA’s Reach Address Database
RMA	Risk Management Agency
RW	Reservoir Water
SAP	Simplified Acquisition Procedures
SBA	Small Business Administration
SCS	Soil Conservation Service
SEO	State Engineer’s Office
SHMO	State Hazard Mitigation Officer
SHMP	State of Colorado Hazard Mitigation Plan
SLB	State Land Board

SM	Soil Moisture
SNOTEL	Snow Telemetry Network
SPEI	Standardized Precipitation – Evapotranspiration Index
SPI	Standardized Precipitation Index
ST	Streamflow
SWSI 2010 update	Statewide Water Supply Initiative 2010 update
SWSI	Statewide Water Supply Initiative
SWSI	Surface Water Supply Index
SWSP	Substitute Water Supply Plans
TABOR	Taxpayer Bill of Rights
THM	Trihalomethane
TMDL	Total maximum daily load
TNC	The Nature Conservancy
TRT	Technical Roundtable
UCAR	University Corporation for Atmospheric Research
UCRB	Upper Colorado River Basin
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USDM	United States Drought Monitor
USDOI	United States Department of Interior
USDOT	United States Department of Transportation
USFS	United State Forest Service
USFWS	United States Fish and Wildlife Service

USGS	United States Geological Survey
VAT	Vulnerability Assessment Tool
VIC	Variable Infiltration Capacity
WATF	Water Availability Task Force
WCD	Water Conservation District
WECC	Western Electricity Coordinating Council
WISE	Water Infrastructure and Supply Efficiency
WPA	Western Area Power Authority
WPCRF	Water Pollution Control Revolving Fund
WQCC	Water Quality Control Commission
WQCD	Water Quality Control Division
WRA	Western Resource Advocates
WRF	Water Research Foundation
WWA	Western Water Assessment