DROUGHT VULNERABILITY ASSESSMENT TECHNICAL INFORMATION

ANNEX B TO THE COLORADO DROUGHT MITIGATION AND RESPONSE PLAN

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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 (Risk = Hazard x 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	• 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	• 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	• 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	• 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.
	• 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	• 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	• 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	• 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

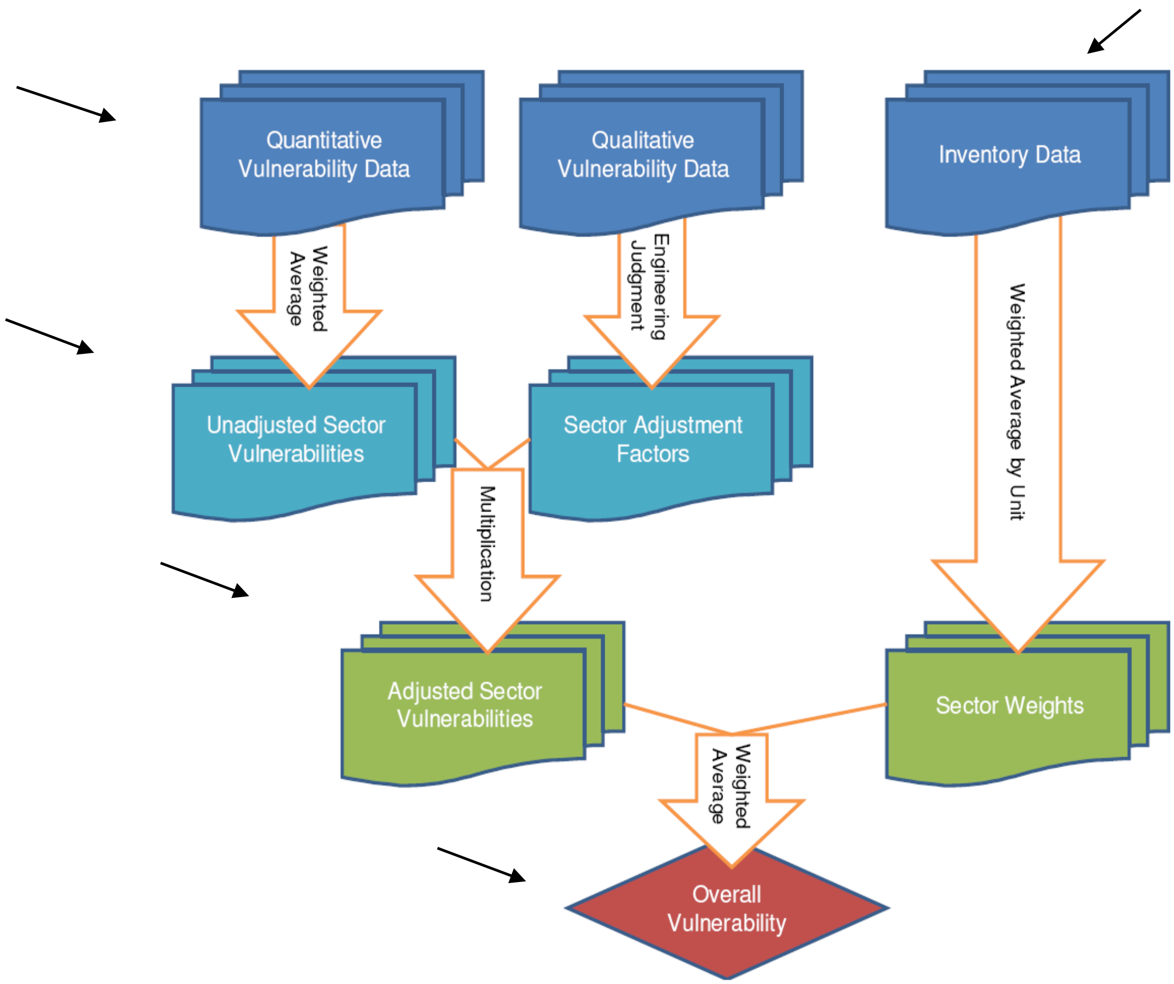
3.1 General Approach

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

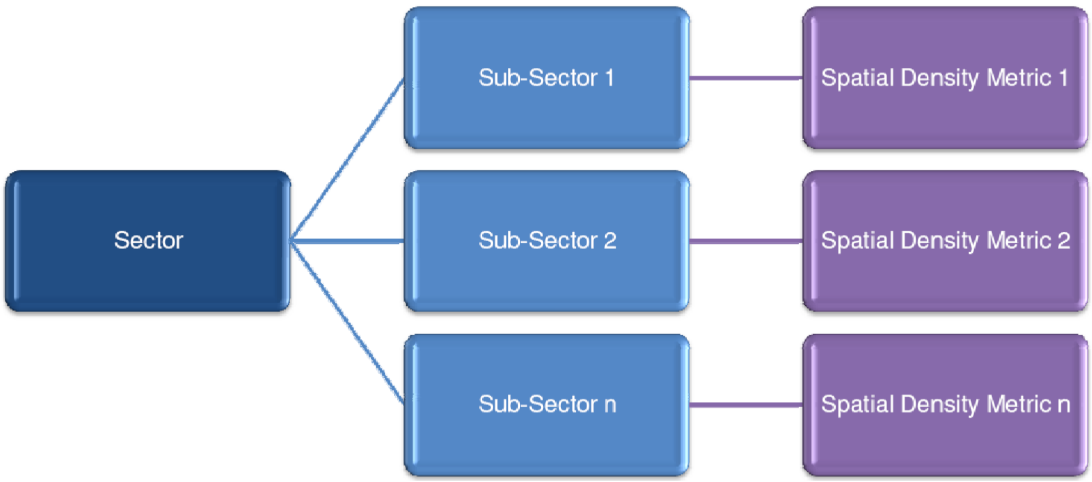
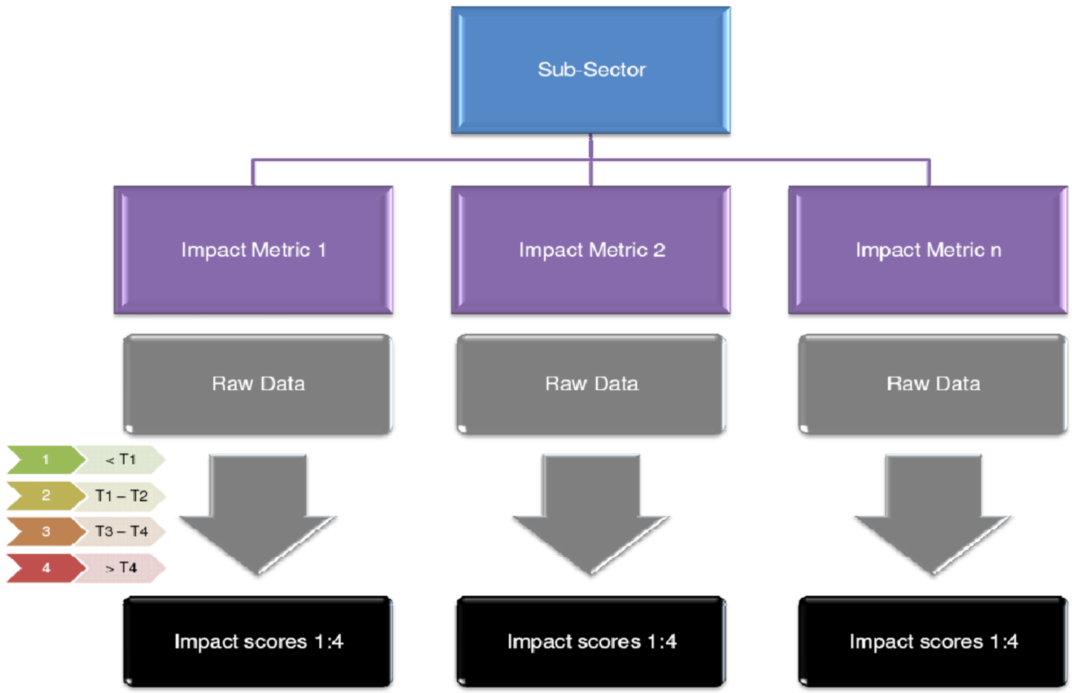


Figure 3.2 outlines the process of assigning spatial density metrics to sectors. Sub-sectors, also referred to as impact groups, are defined when the sources of vulnerability within a sector are sufficiently diverse to warrant separate consideration. For example, the Energy Sector covers power providers 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

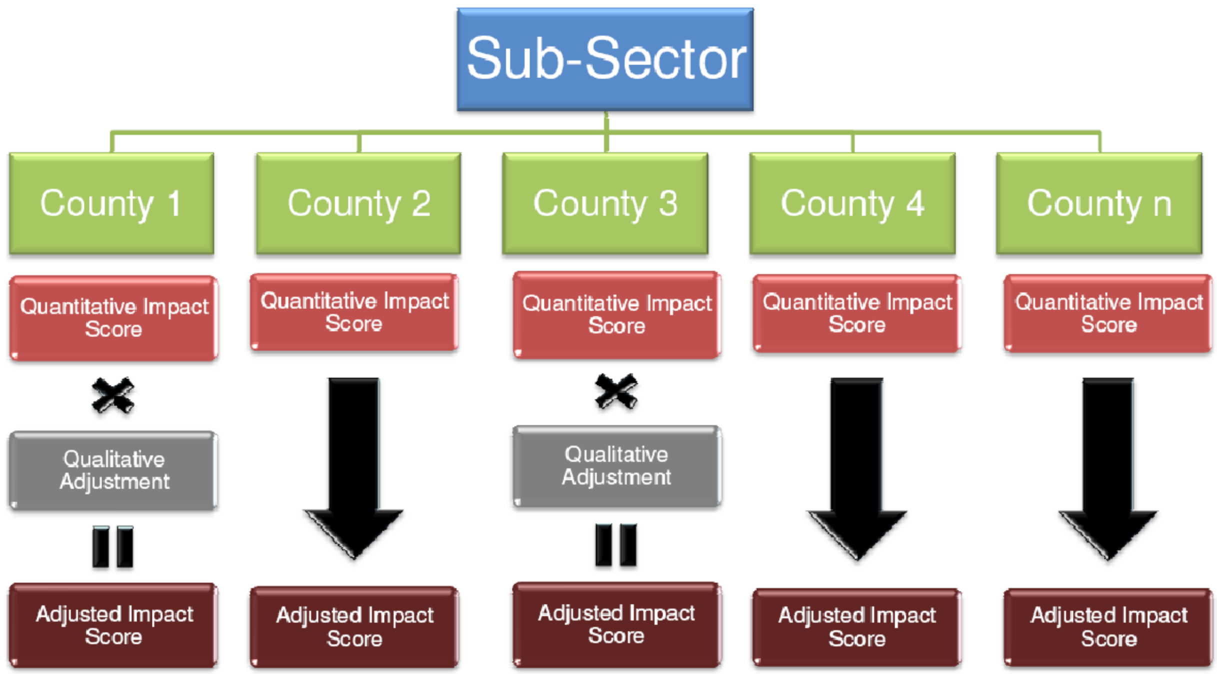
Figure 3.4 Quantitative Impact Calculations

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

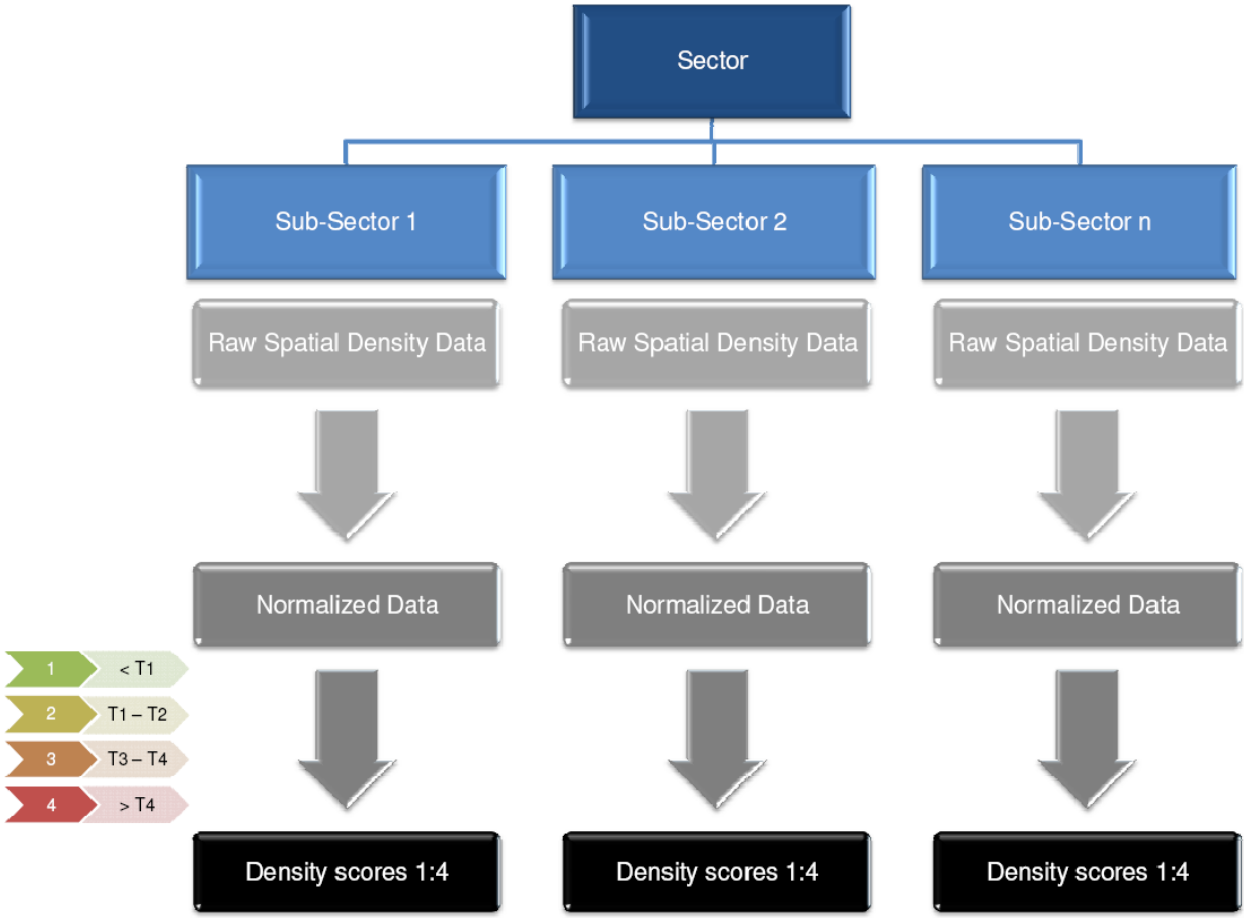
Qualitative Adjustment Description	Numerical Scaling
Highly adaptive	50%
Somewhat adaptive	25%
Somewhat greater impact	125%
Much greater impact	150%

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.

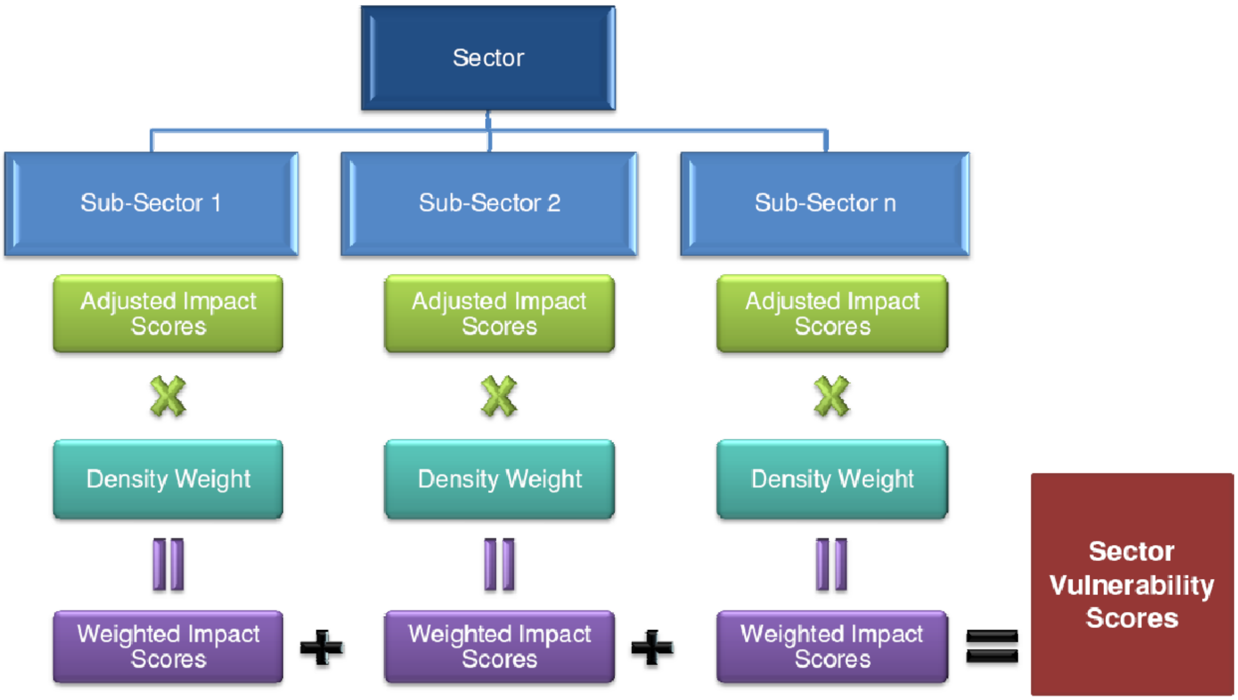
Figure 3.6 Spatial Density Score Calculation (T=Threshold)



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, t 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.

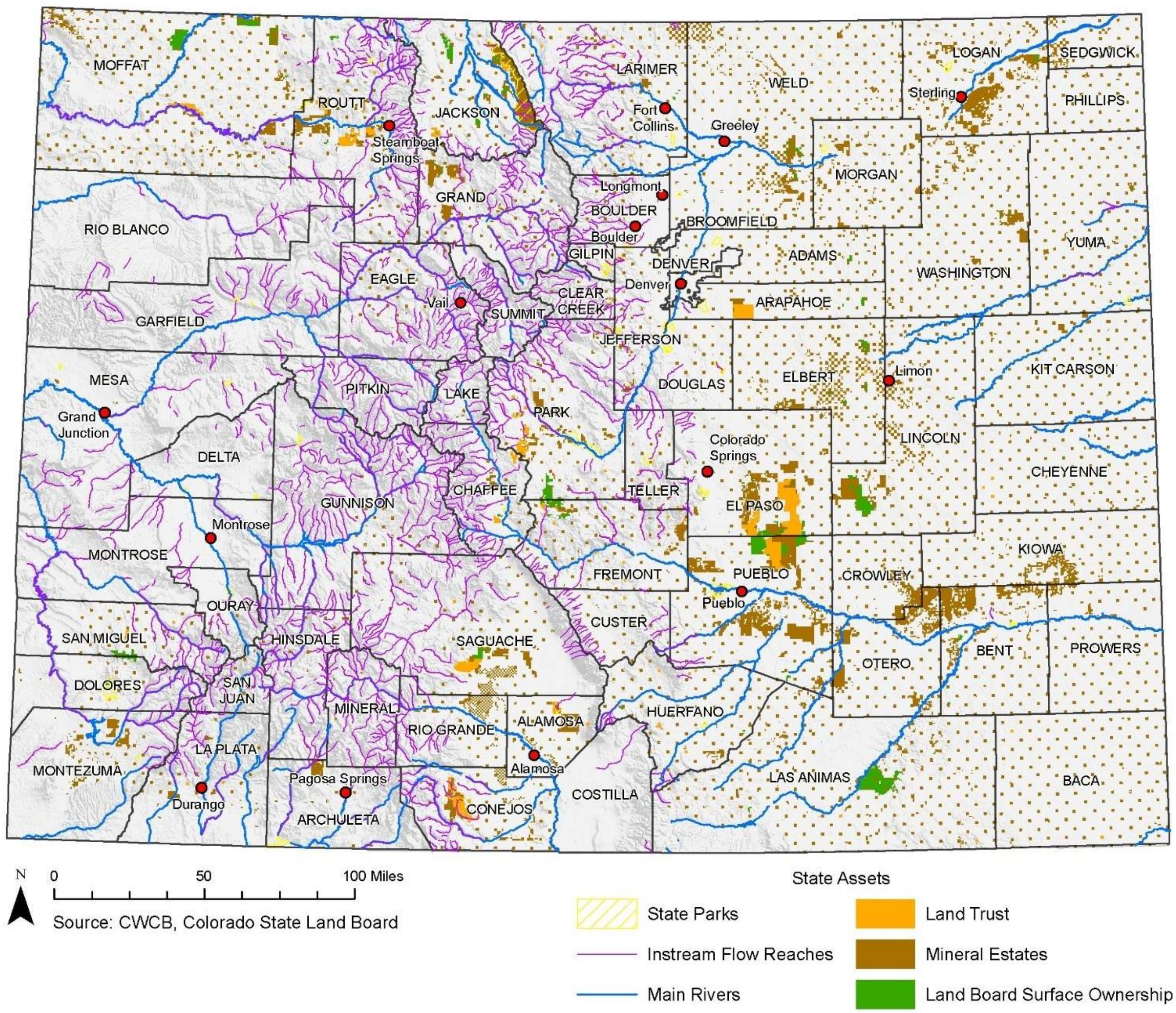
- In many cases vulnerability data are not available consistently statewide. Section 5.6.2 outlines future data gathering tasks for each impact category.

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	• Damage due to wildfires • Loss of landscaping • Damage to structure as a result of soil drying	• Invest in less water intensive landscaping • Make a drought plan
Critical Infrastructure	• 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	• Budget for additional maintenance and oversight during and following a drought • Take advantage of low water levels to maintain and repair structures
Land Board	• Damage to rangeland and agricultural areas • Loss of agricultural lease revenue	• Offer lease discounts in return for less intensive land use
Parks and Wildlife	• 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	• 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	• Inability to maintain instream flow rights resulting in impacts to fisheries and aquatic habitat	• 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.

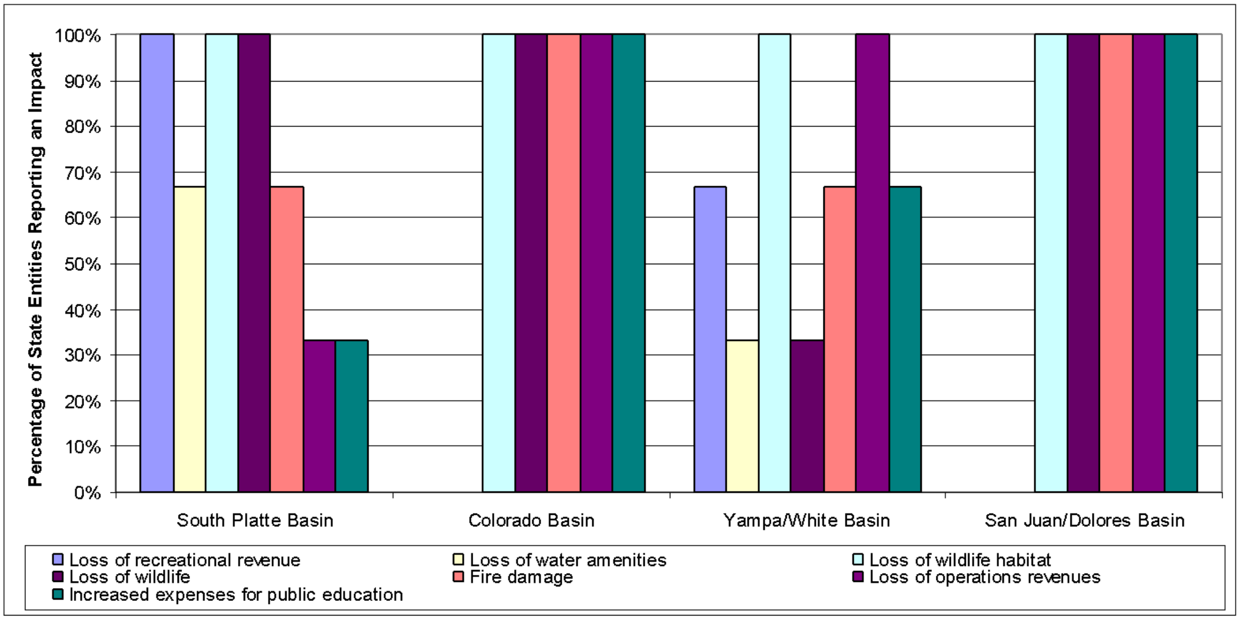
Figure 5.2 provides the percentage of surveyed State entities that experienced the impacts listed at the bottom of the figure. State entities surveyed included the Division of Water Resources (DWR), Colorado State University (CSU) Cooperative Extension, CSFS, Land Board, Steamboat Lake State Park, Department of Corrections, CPW[1], 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

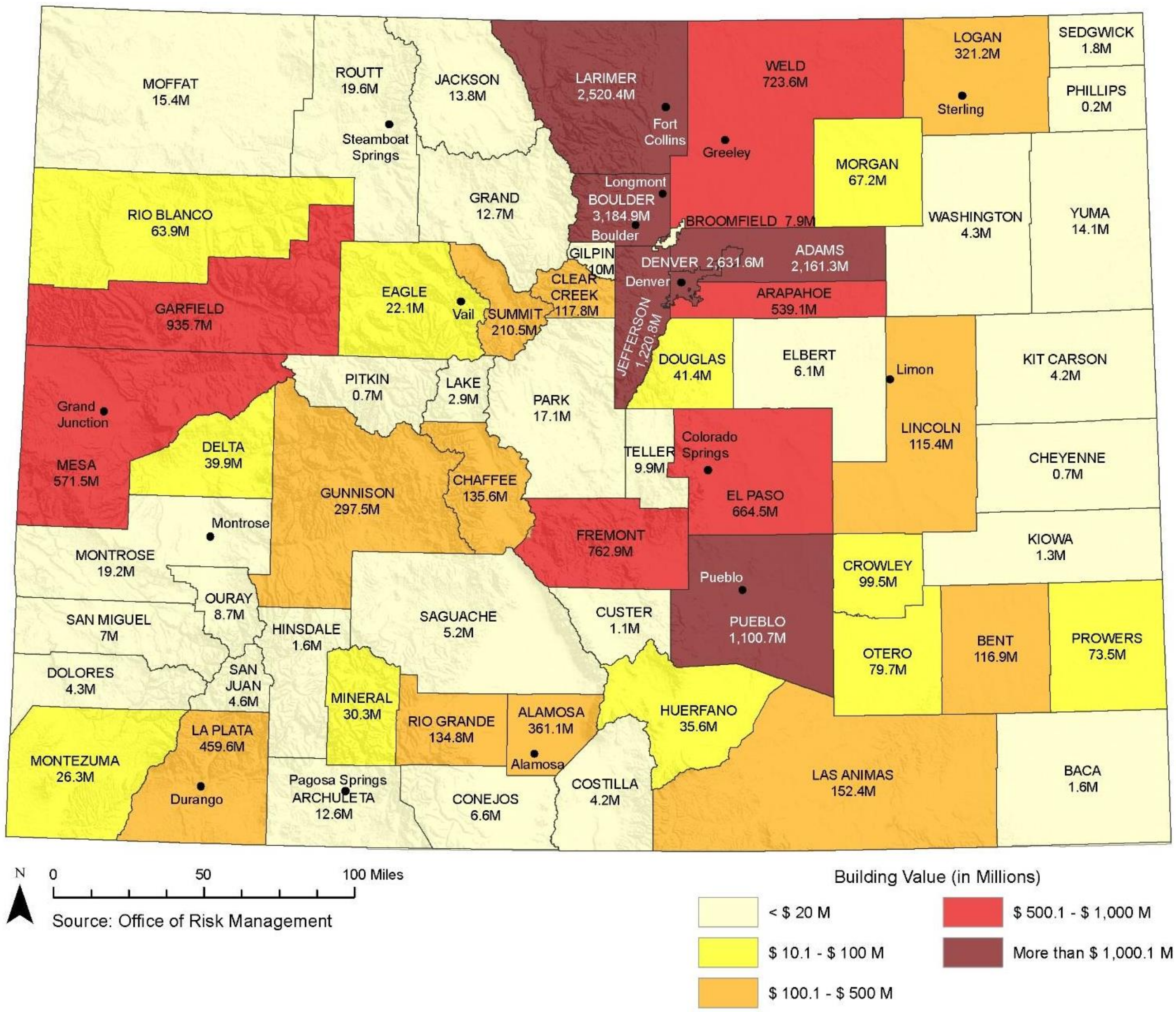


Figure revised 2018

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	• 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	• 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	• 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	• 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

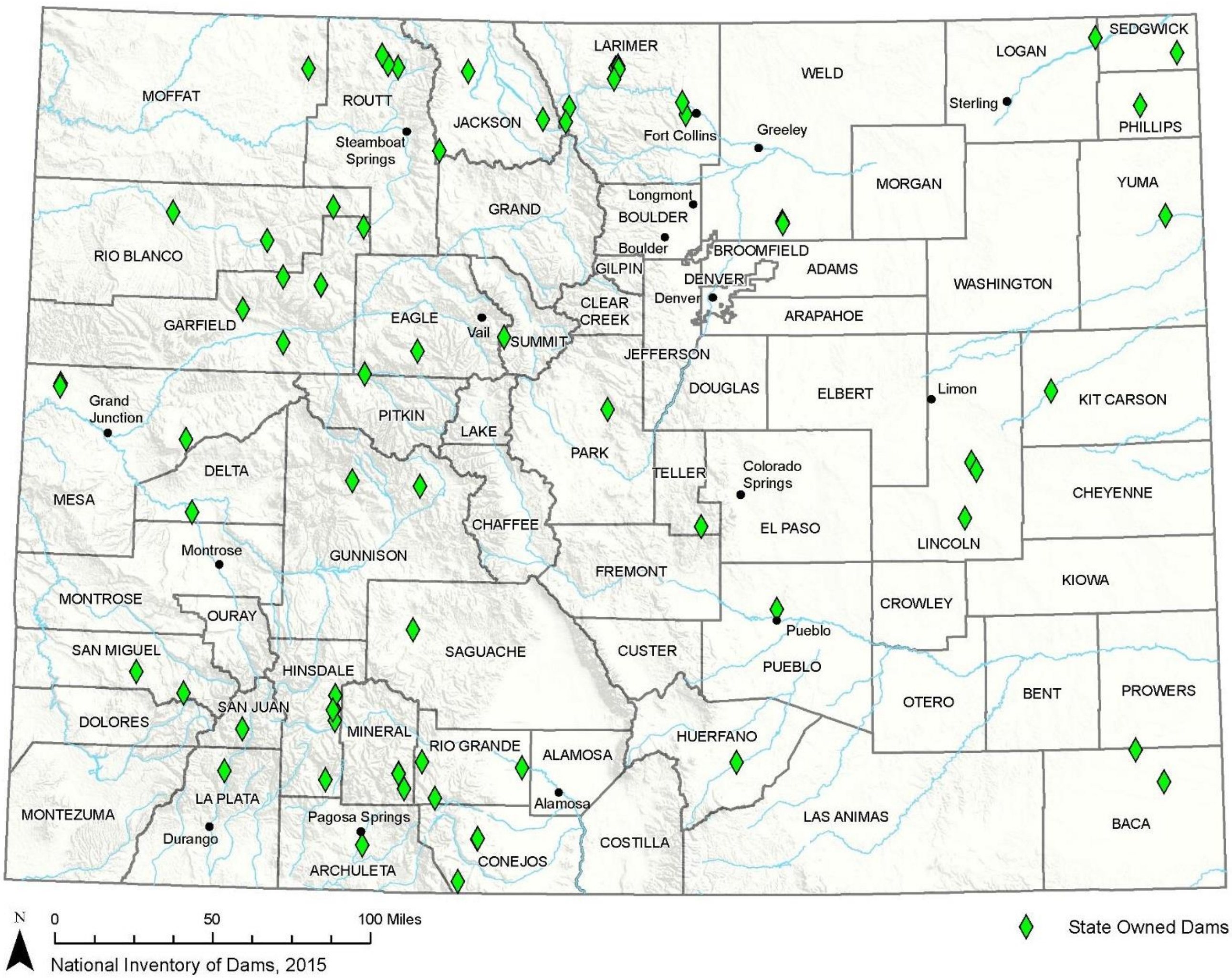
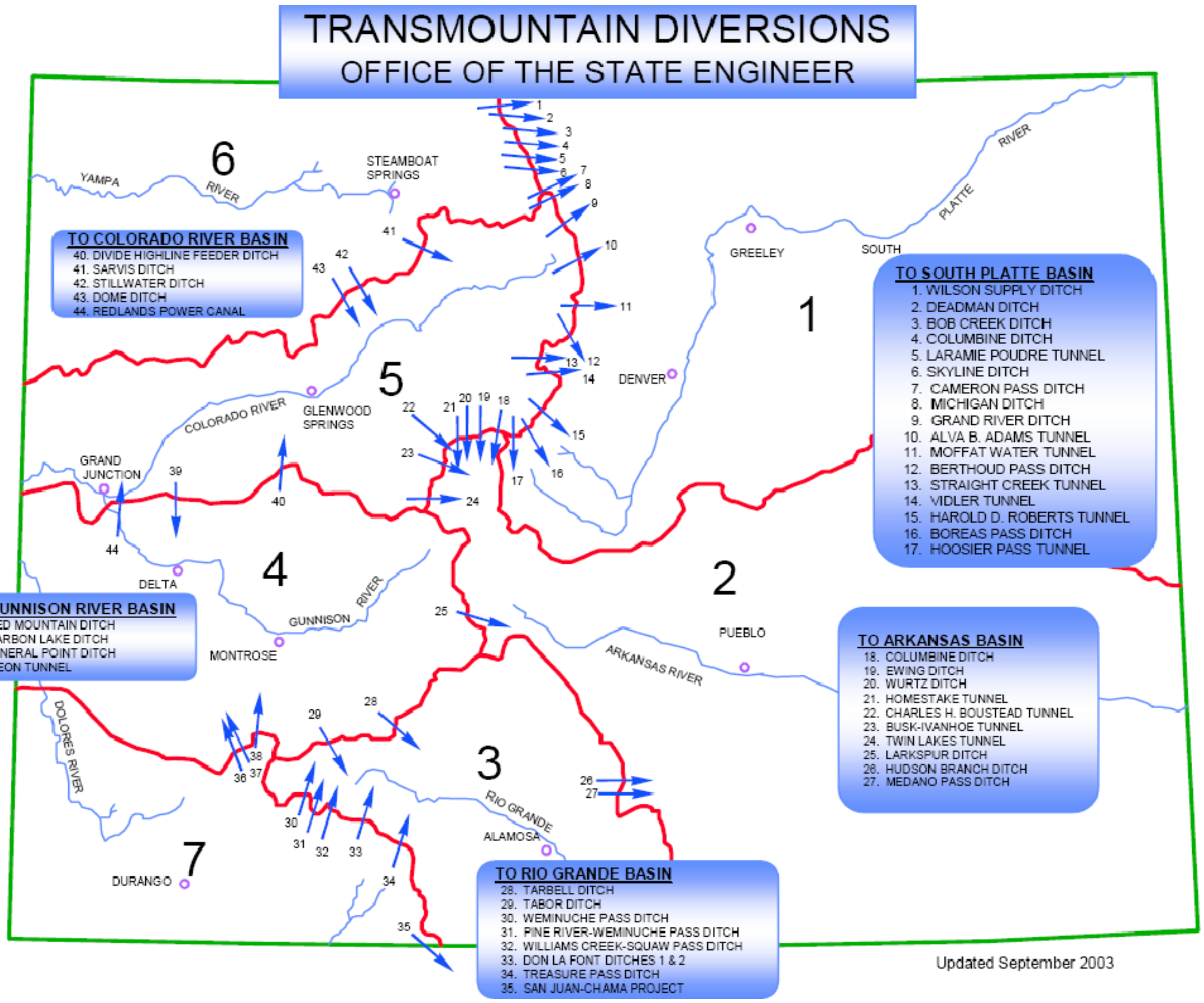


Figure revised 2018

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.

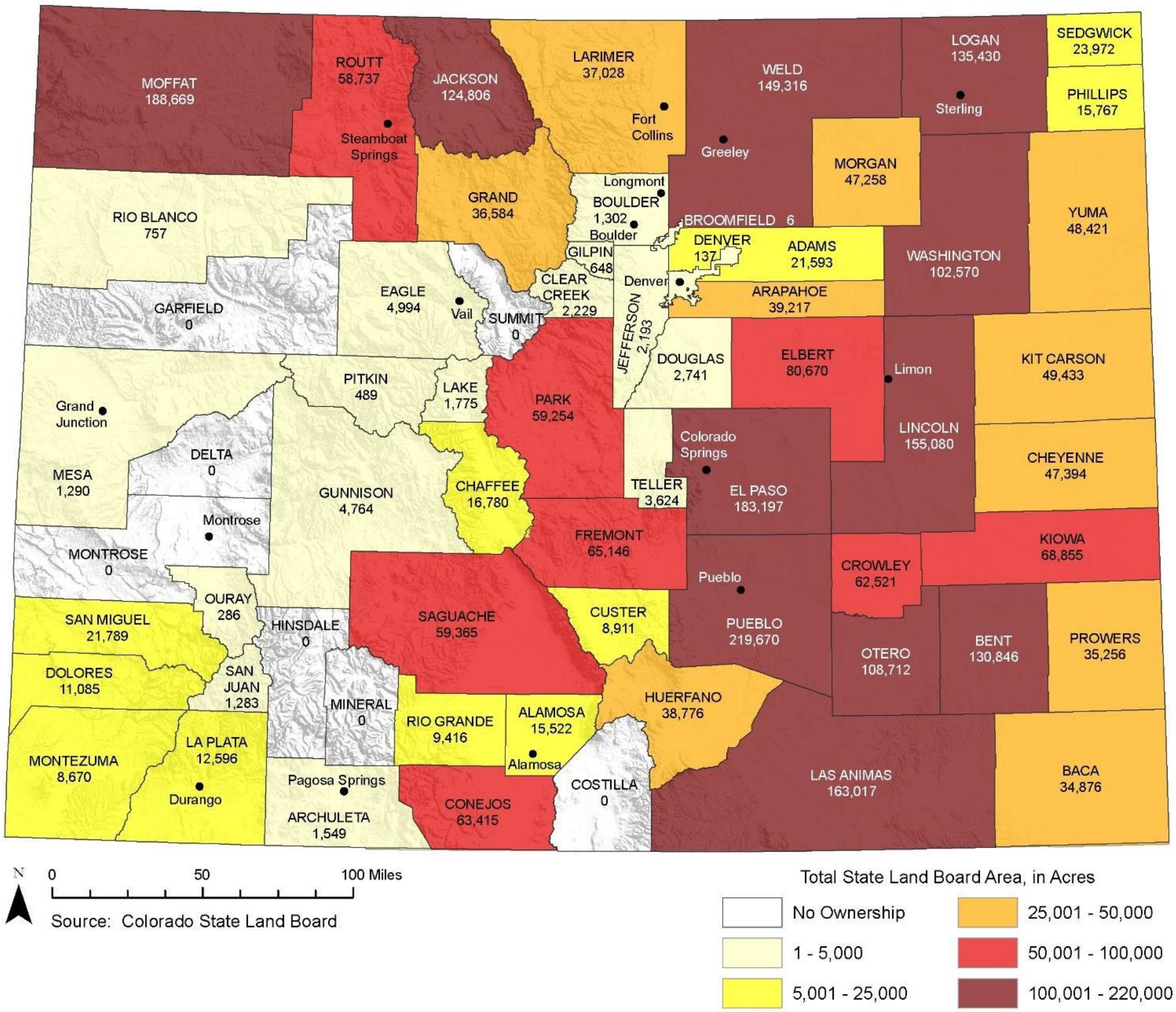
Table 5.3 Critical Infrastructure Impacts and Adaptive Capacities

Key Impacts to State Buildings	Key Adaptive Capacities or Mitigation Strategies
Decreased water levels in dams can cause structural damage	• Take advantage of low water levels to conduct maintenance
Dry ditches can be damaged by animal holes and increased vegetative growth	• Budget for additional ditch maintenance following drought
High sediment loading resulting from low reservoir levels or wildfires can damage structures.	• Pre-emptive fire management in key supply basins • Focused beetle kill management in key supply basins
Flash flooding following wildfires can damage structures	• 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

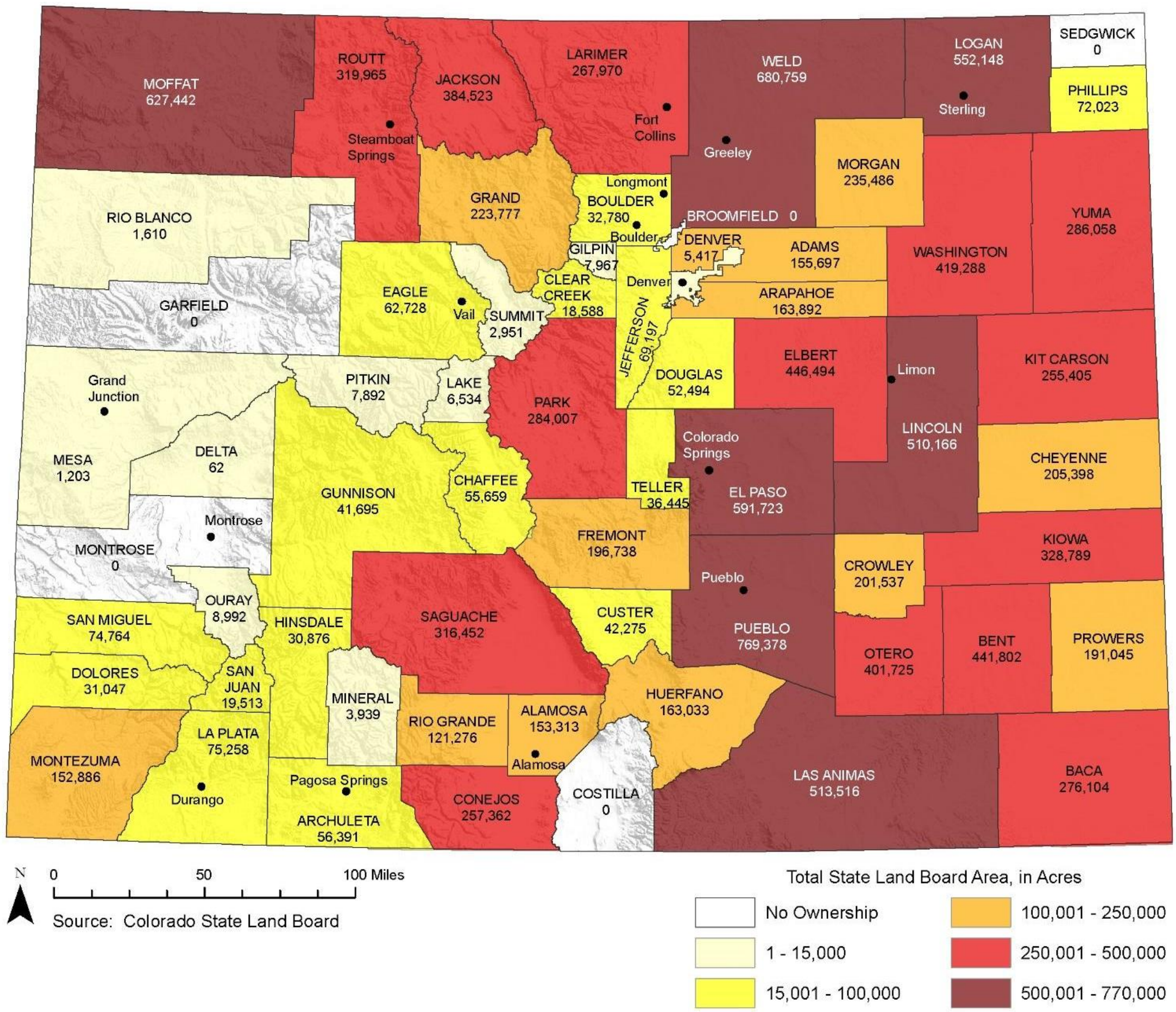


Figure revised 2018

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

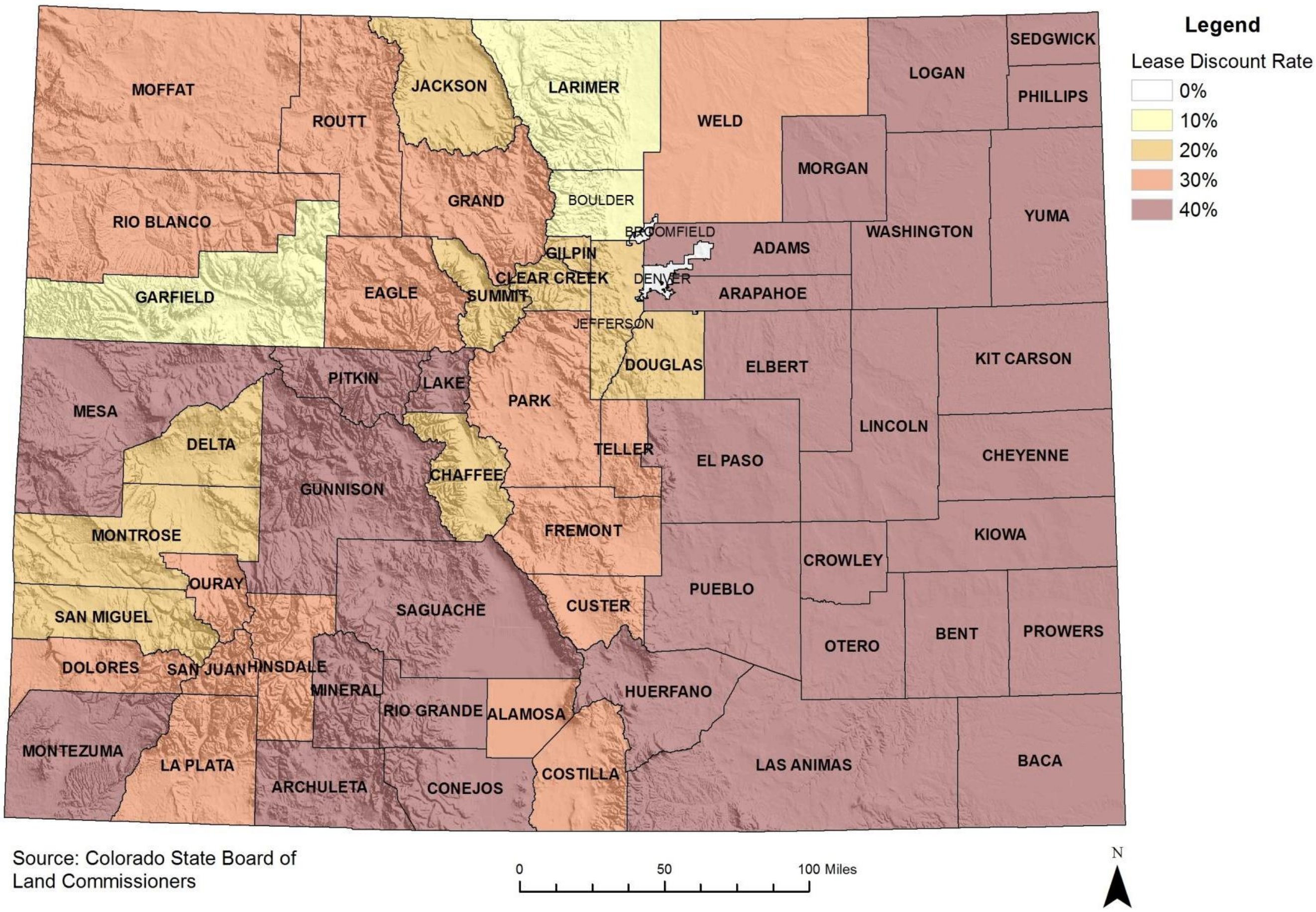


Figure from 2013

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	• Offer agricultural leases at discounted rates in return for decreased intensity of land use.
Decreased mining activity if water is not available for production	• 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.

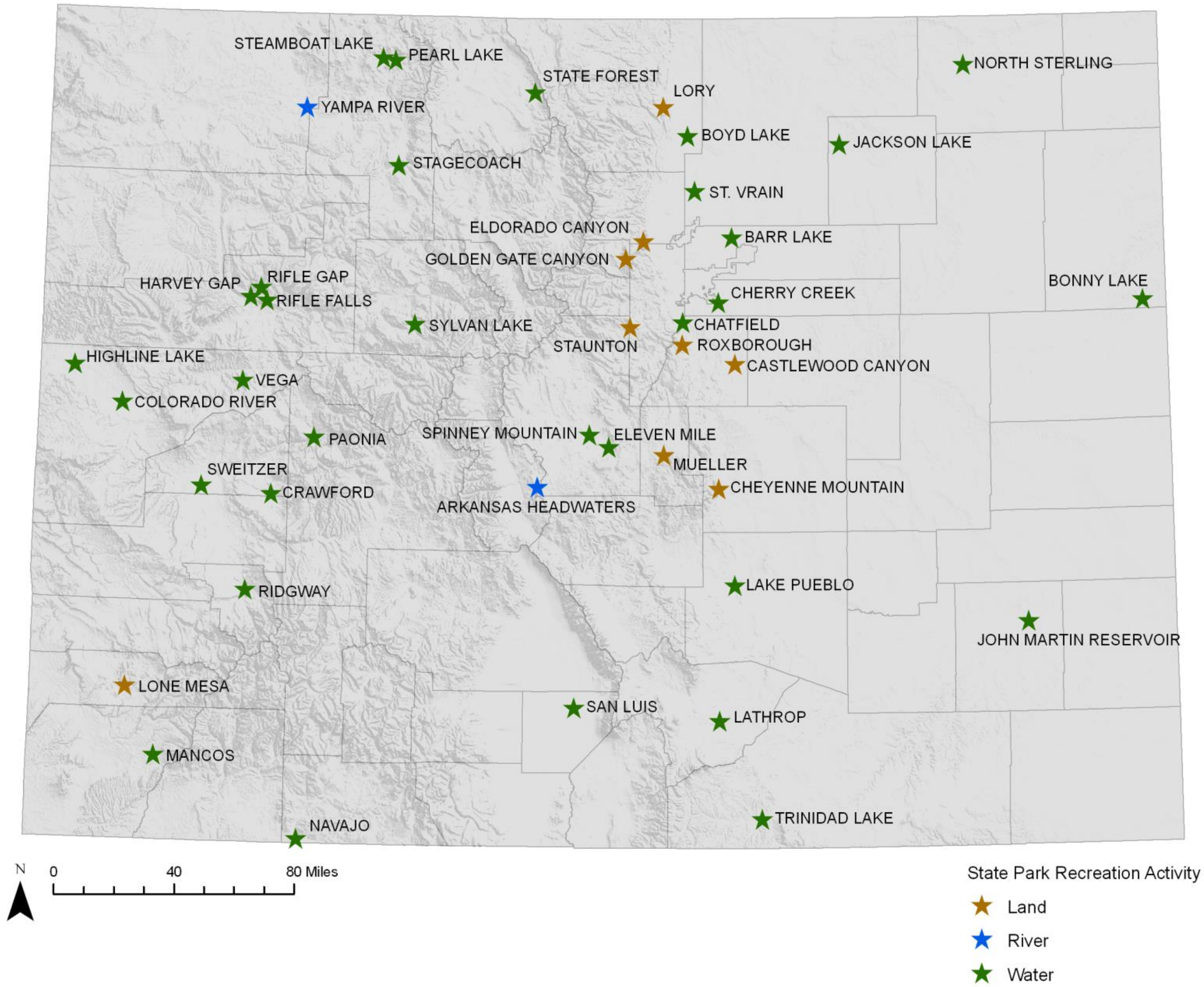
Table 5.7 CPW Funding 2016-2017

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

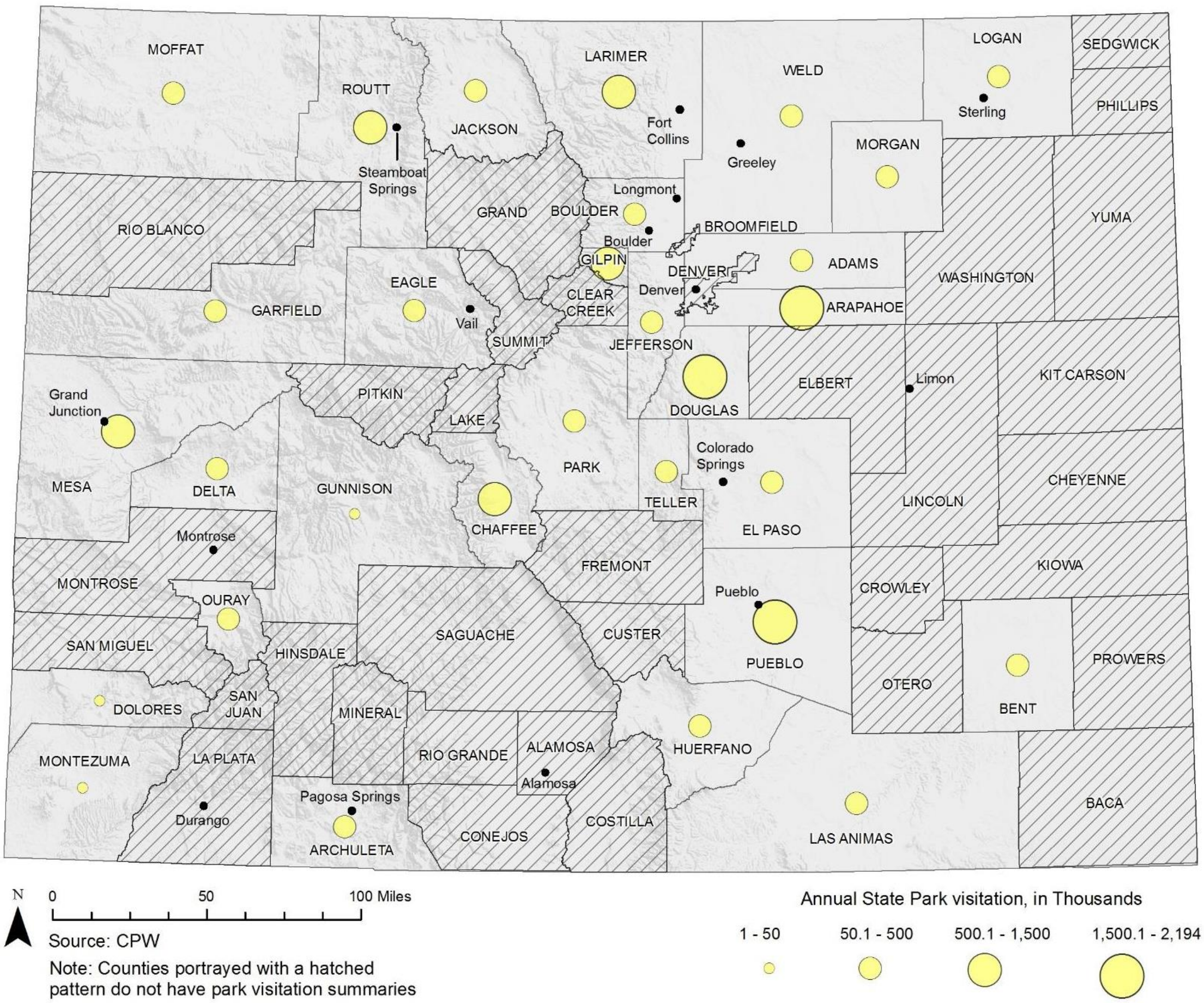
The CPW construction budget, which is different than the operating budget, is funded primarily by lottery money and by the GOCO fund. These funds are less variable and not reliant on visitation numbers. Based on conversations with CPW employees, the operating budget is much more drought vulnerable than 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



Source: CPW

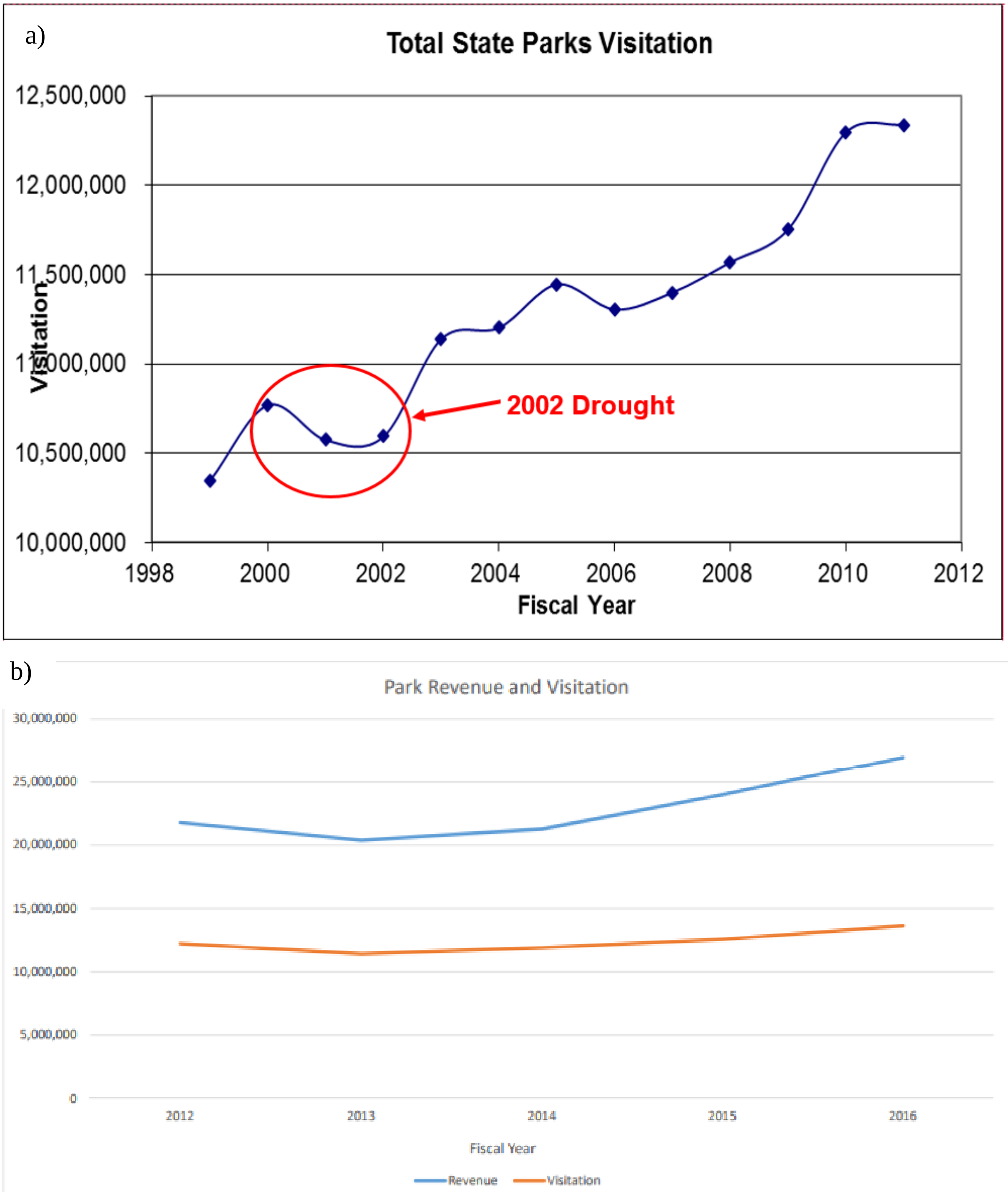
Note: Counties portrayed with a hatched pattern do not have park visitation summaries

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

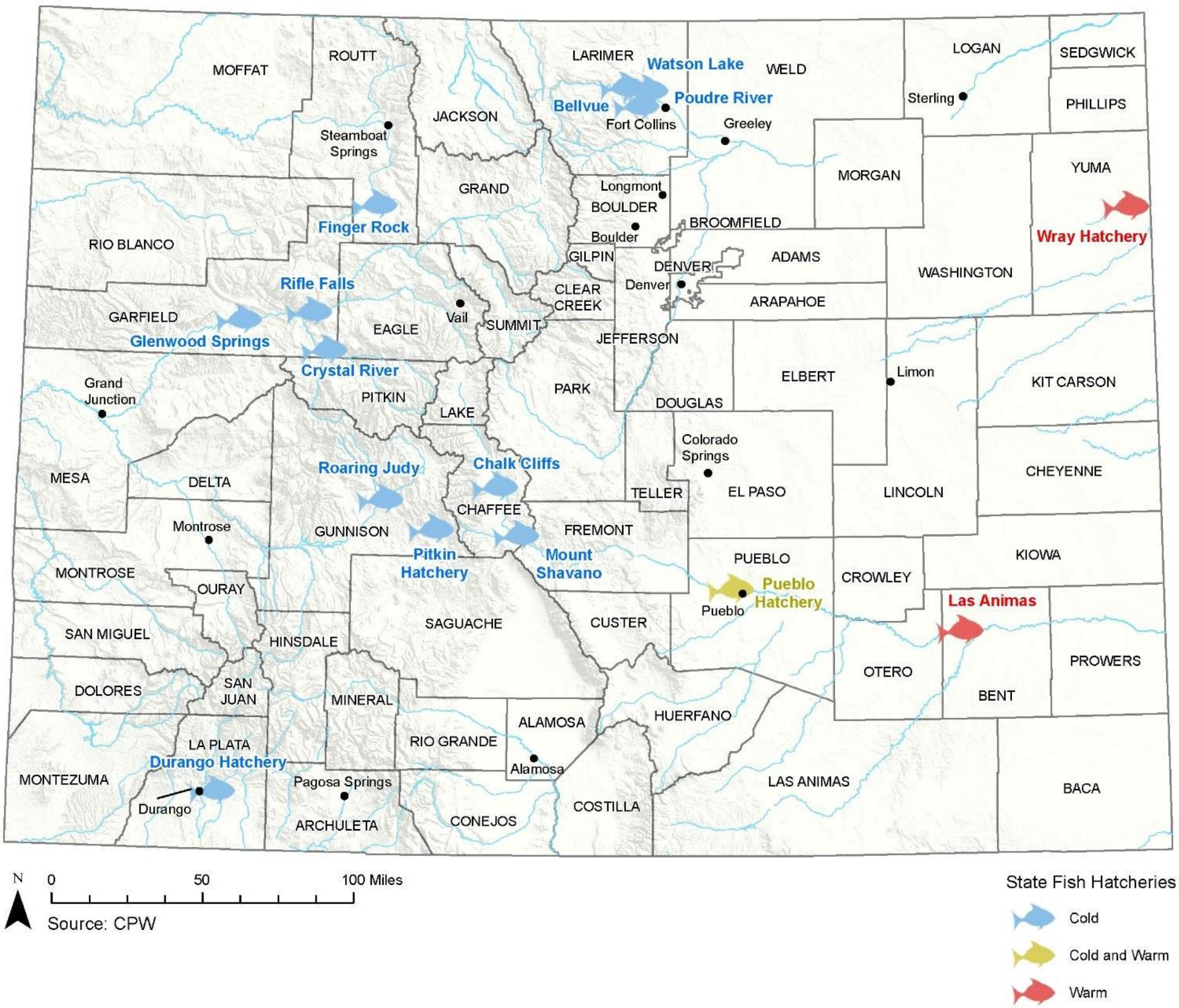
[4] For more information on beetle kill and drought refer to the Environmental Sector

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.

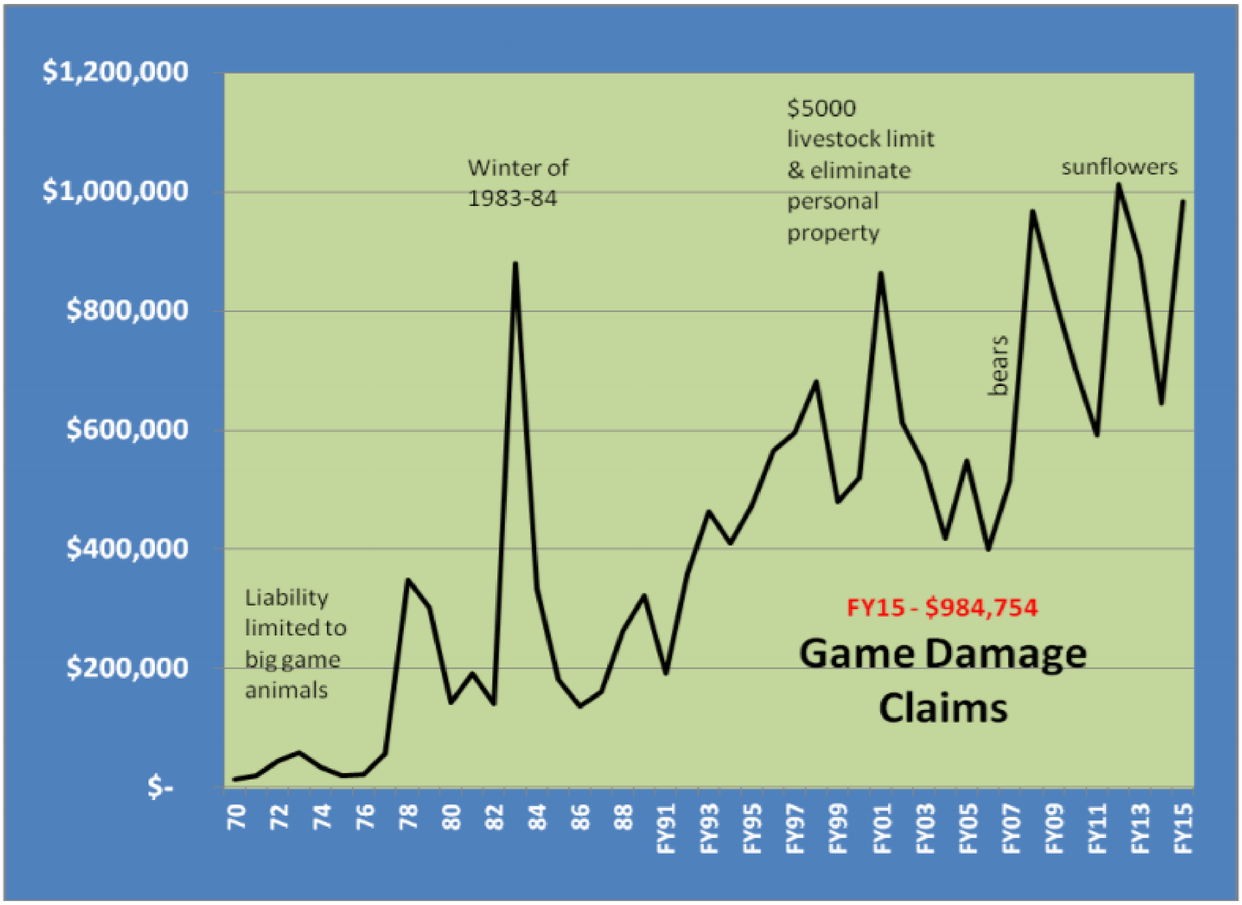
The potential impact of any land acquisition would be highly dependent on the planned land use and its location.

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).

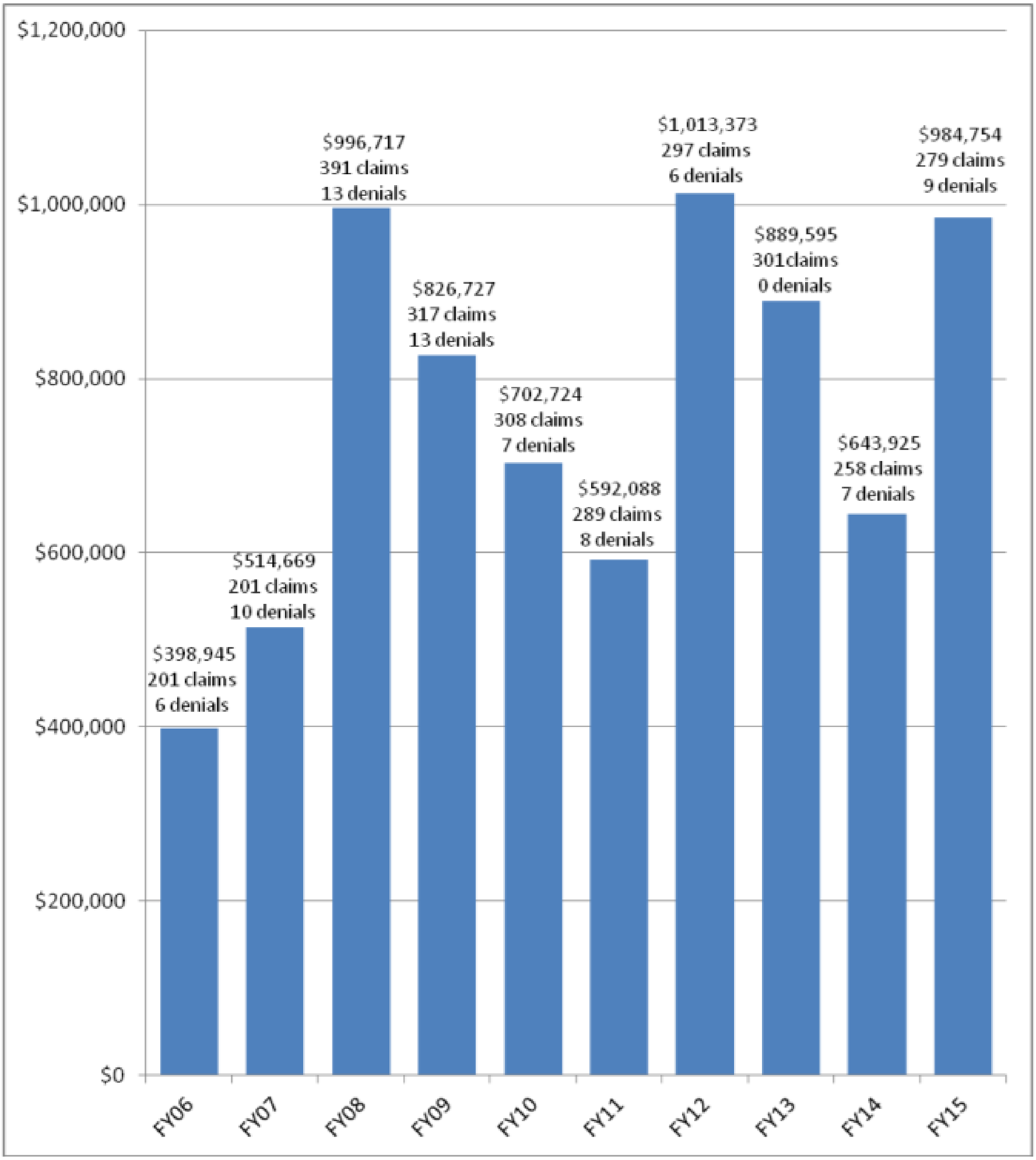
CPW pays damage claims when big game animals (e.g., elk, deer, bear, mountain lion, pronghorn antelope, moose and bighorn sheep) damage private property. Figure 5.14 shows the total annual big game damage claims from 1970 to 2015. Figure 5.14 summarizes the 2006-2015 years with specific claim totals 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

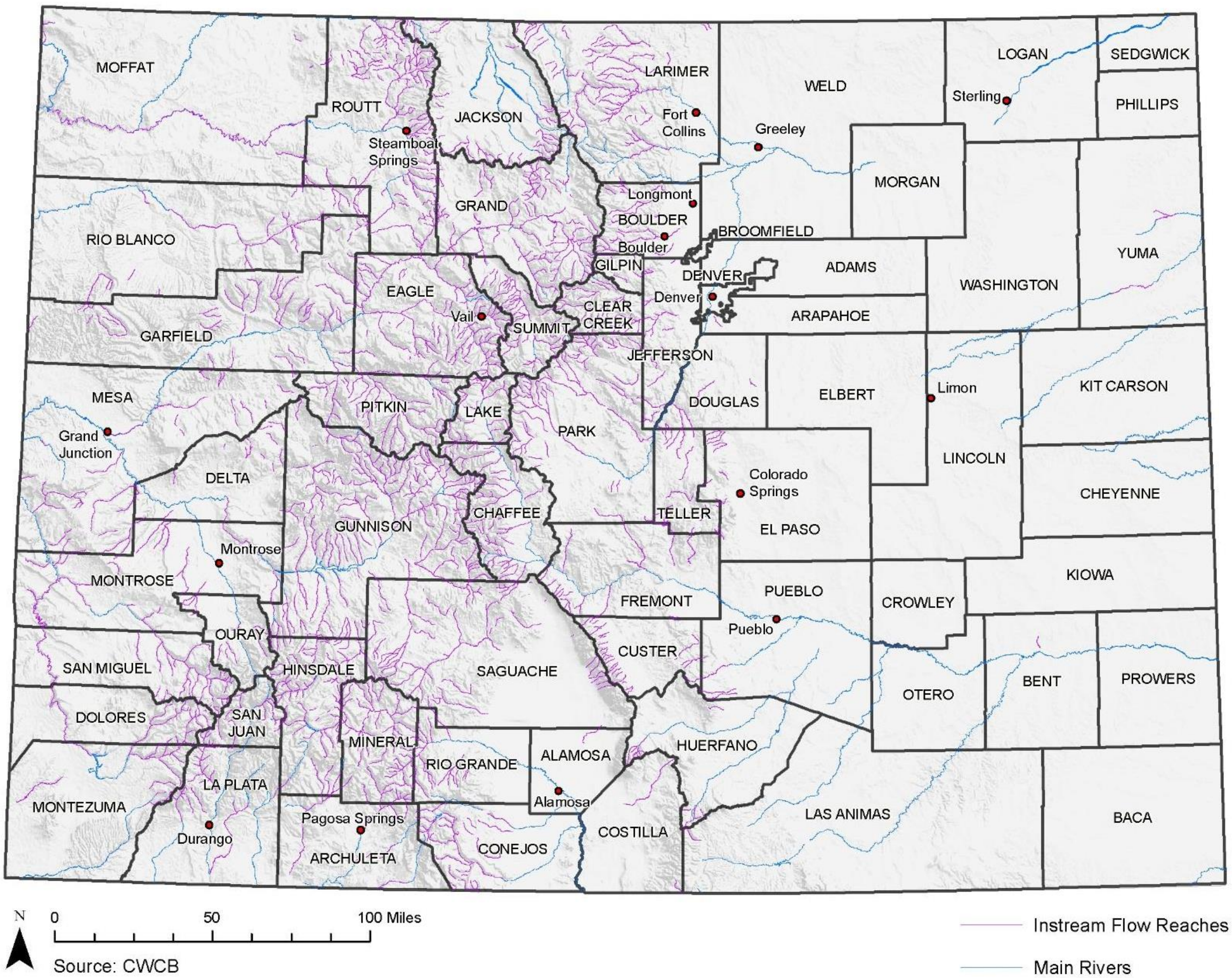
Key Impacts to CPW	Key Adaptive Capacities or Mitigation Strategies
Lower reservoir and stream levels can impact water based recreation	• Lengthen boat ramps to accommodate lower water levels • PR campaign to educate the public about alternative activities to boating/fishing • Implement monitoring programs, 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	• Communicate with media to emphasize which state parks are still open and which counties don't have campfire restrictions
Negative media portrayal	• 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	• Cut operating costs by decreasing seasonal staff
Lower (surrounding) land values	• Opportunities for expansion and to acquire more habitat for protected species
Impacts to fish populations	• 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	• 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	• 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.

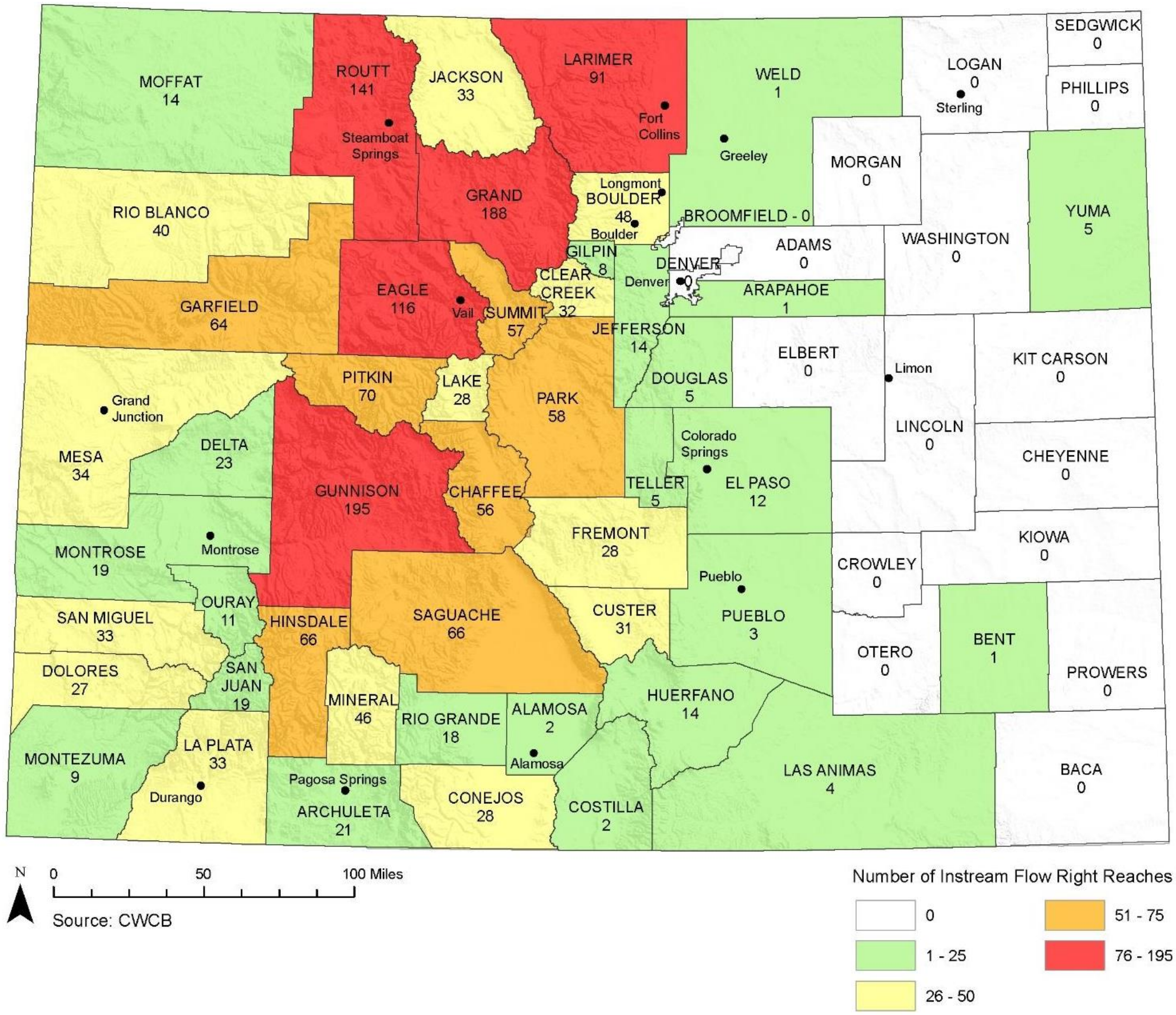
Instream flow rights are considered assets, not only in an environmental sense but as real property. However, the water rights market is highly variable and not well documented. Therefore, tabulating the existing value of CWCB water rights would not be practical from a logistical as well as a value-added 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



Source: CWCB, data current as of 2018

Figure 5.16 Number of Instream Flow Rights by County



Data current as of 2018. Counts do not include pending rights.

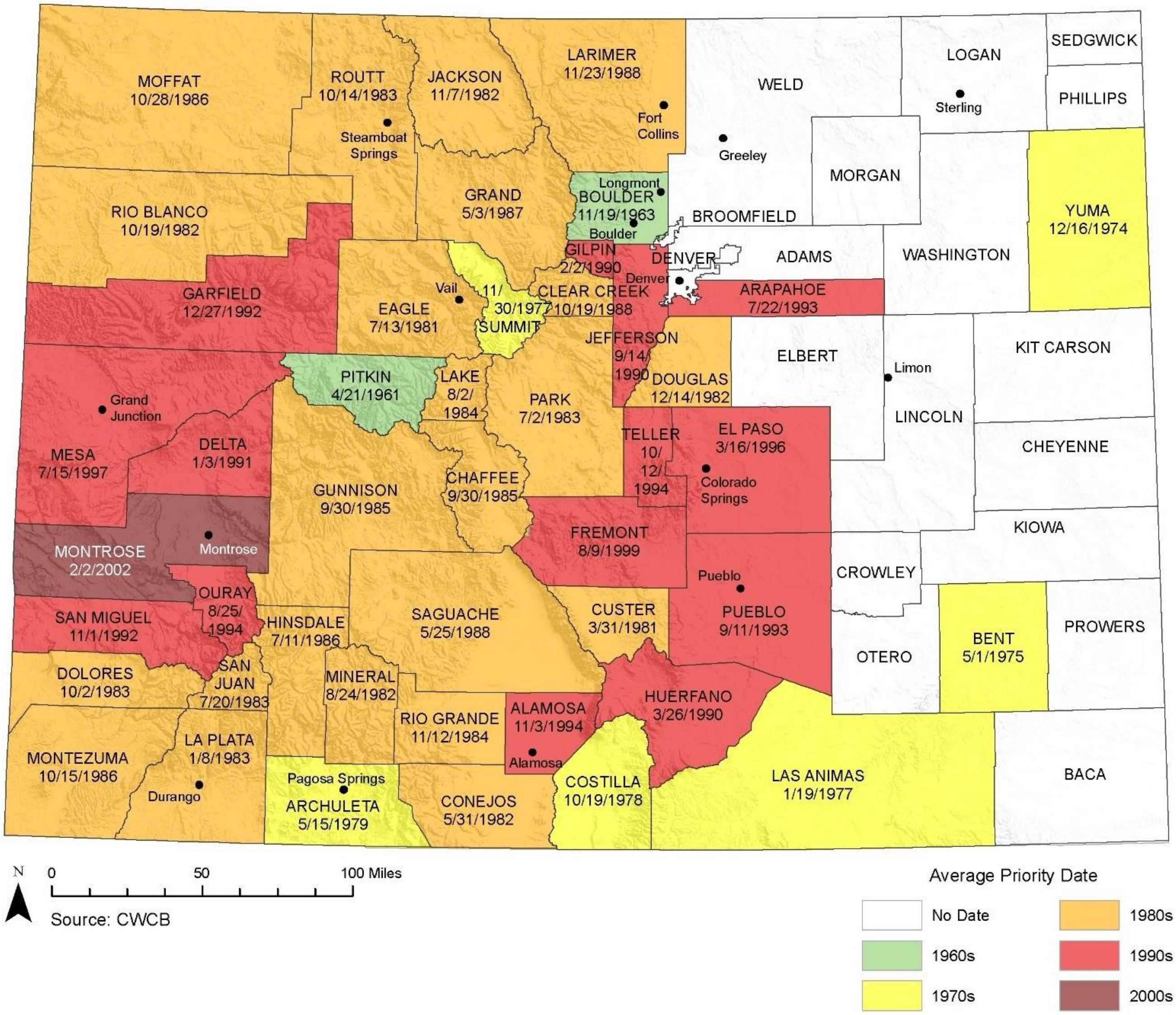
Instream flows are administered as any other water right in Colorado according to the Doctrine of Prior Appropriations. During a drought, it is possible that instream flow rights would be out of priority and therefore non-functioning. This could potentially leave habitat unprotected in the most stressful (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	• 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 on 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

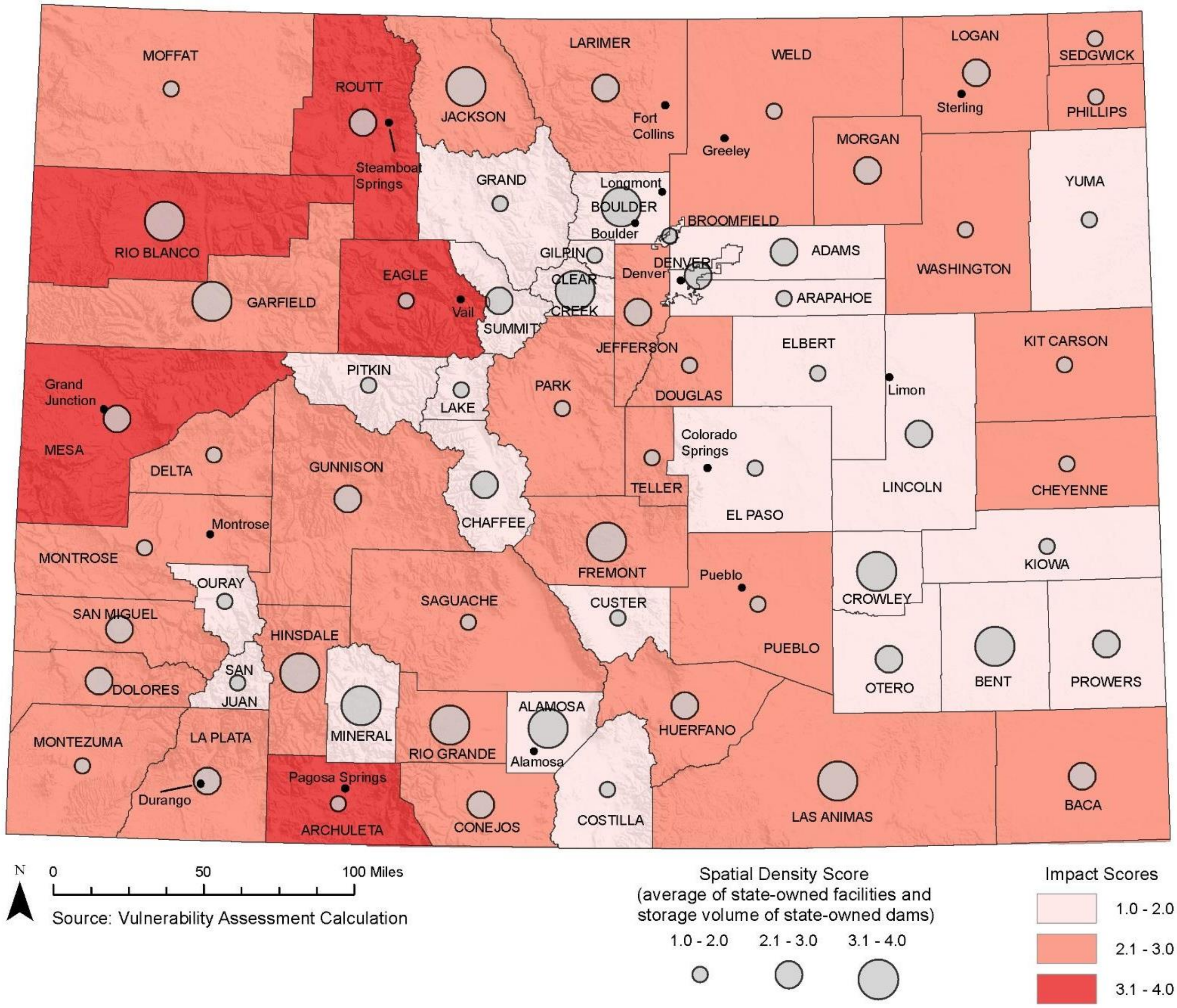
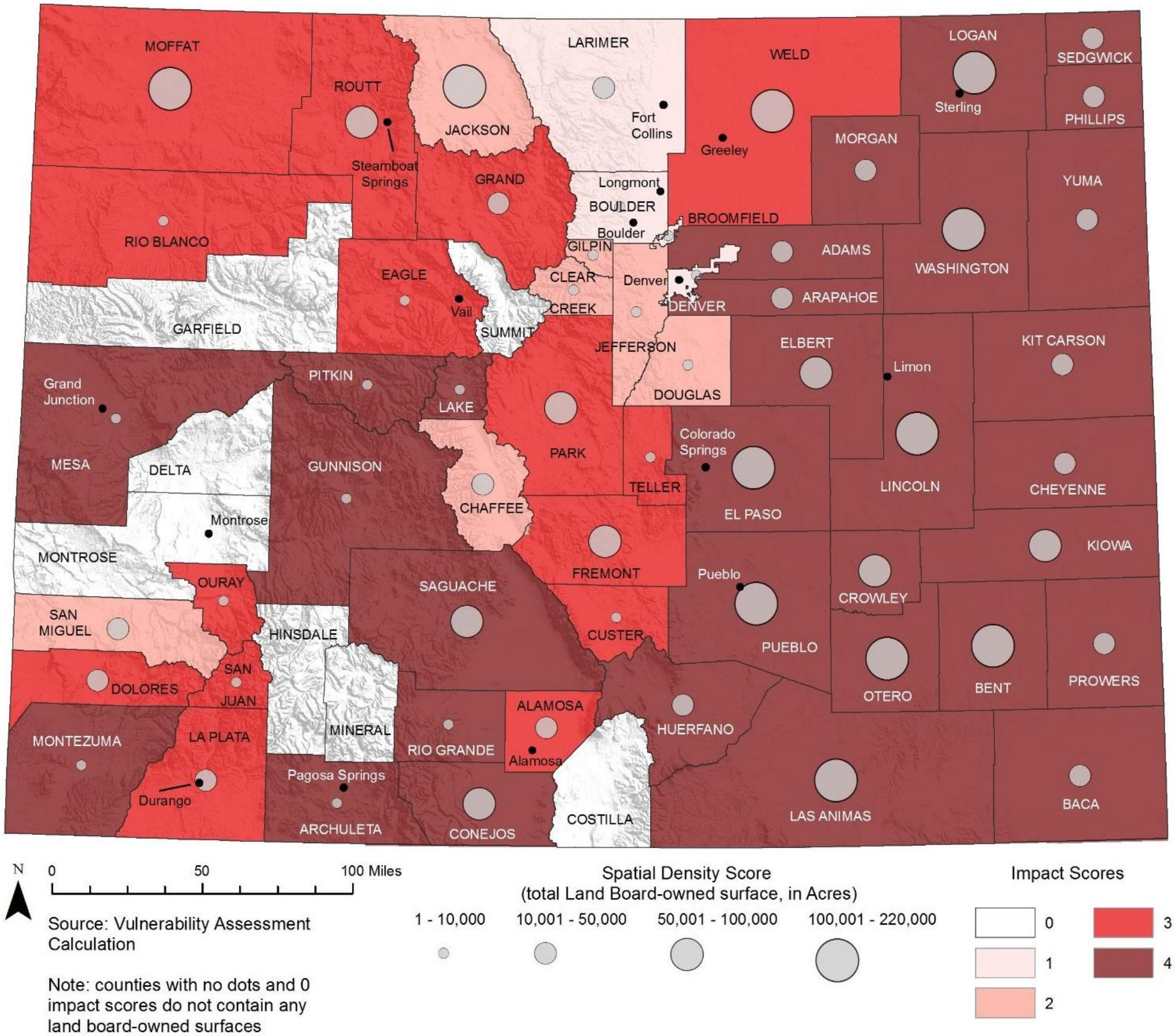


Figure 5.19 Land Board Impacts and Spatial Density Metrics by County



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

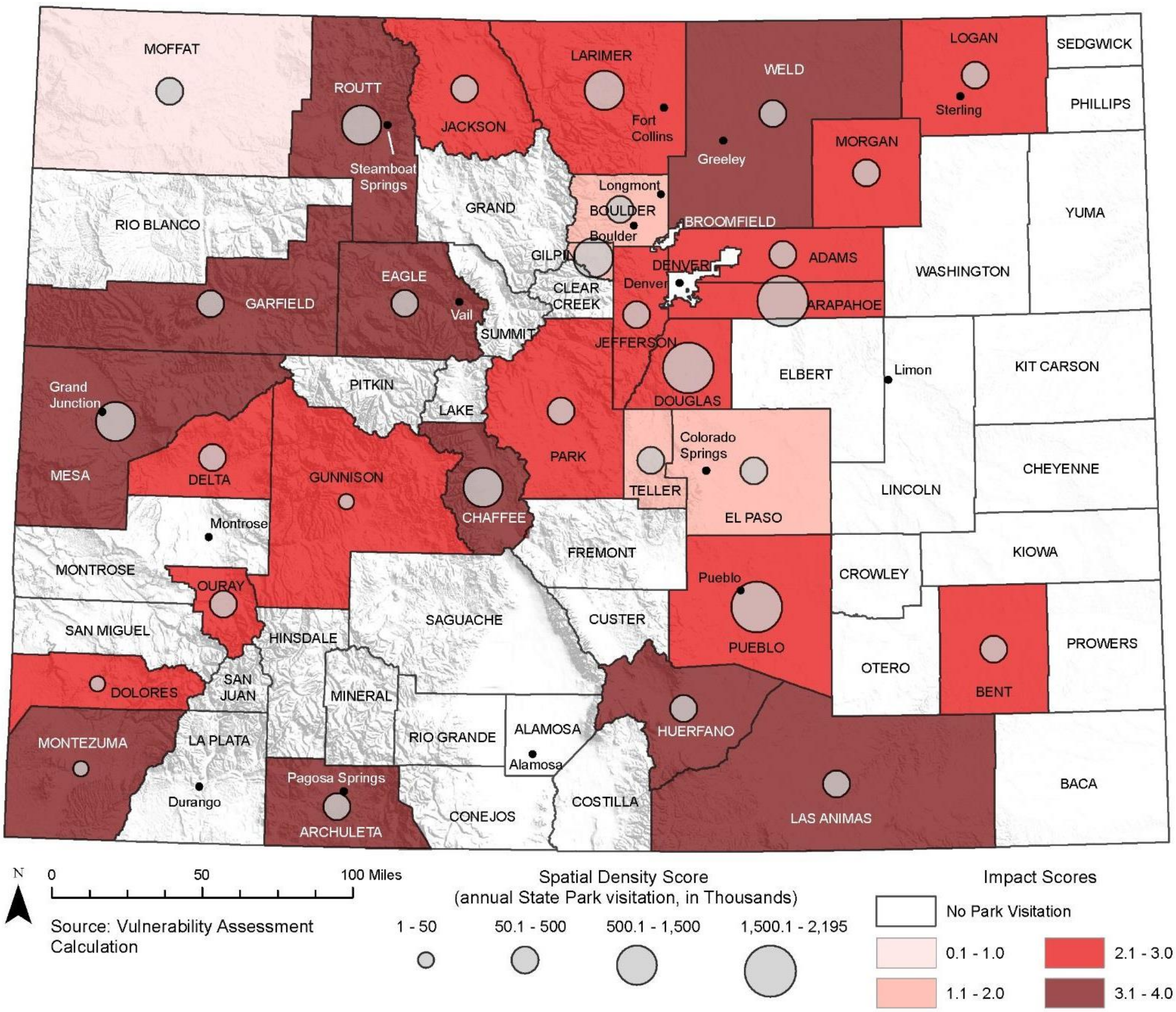


Figure 5.21 Impacts to State Fisheries, with Spatial Density Metrics by County

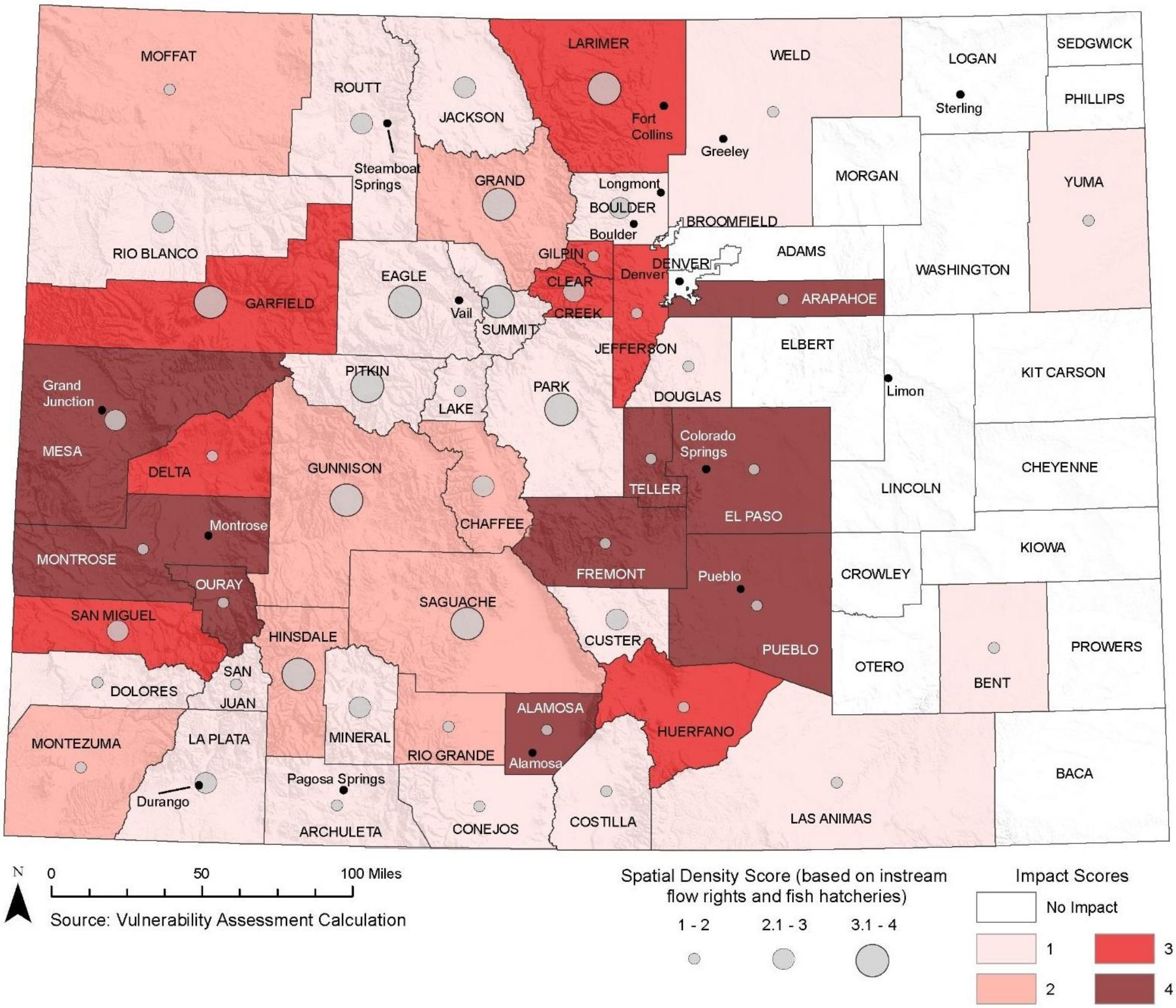


Figure 5.22 State-Owned Protected Areas by County

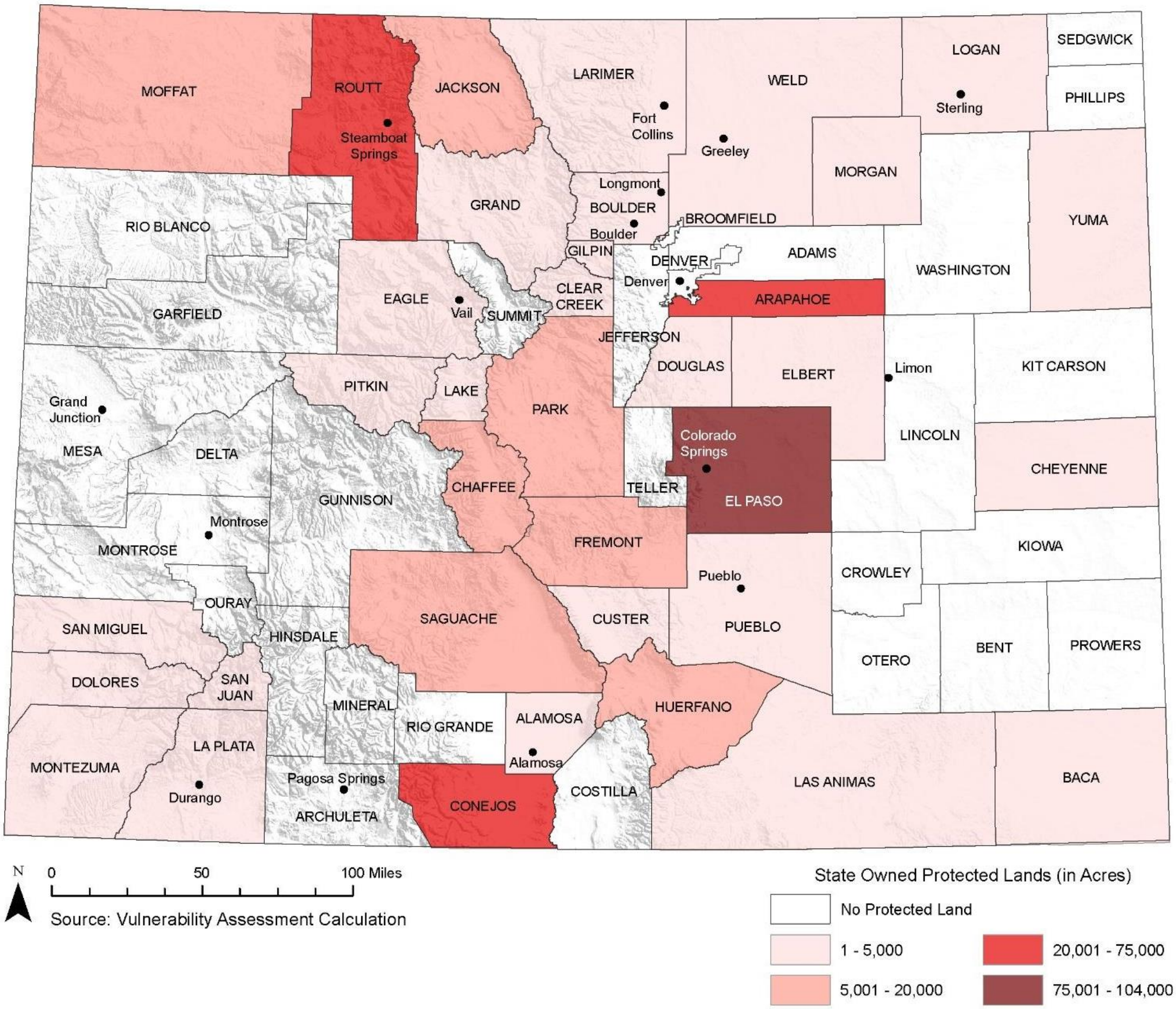
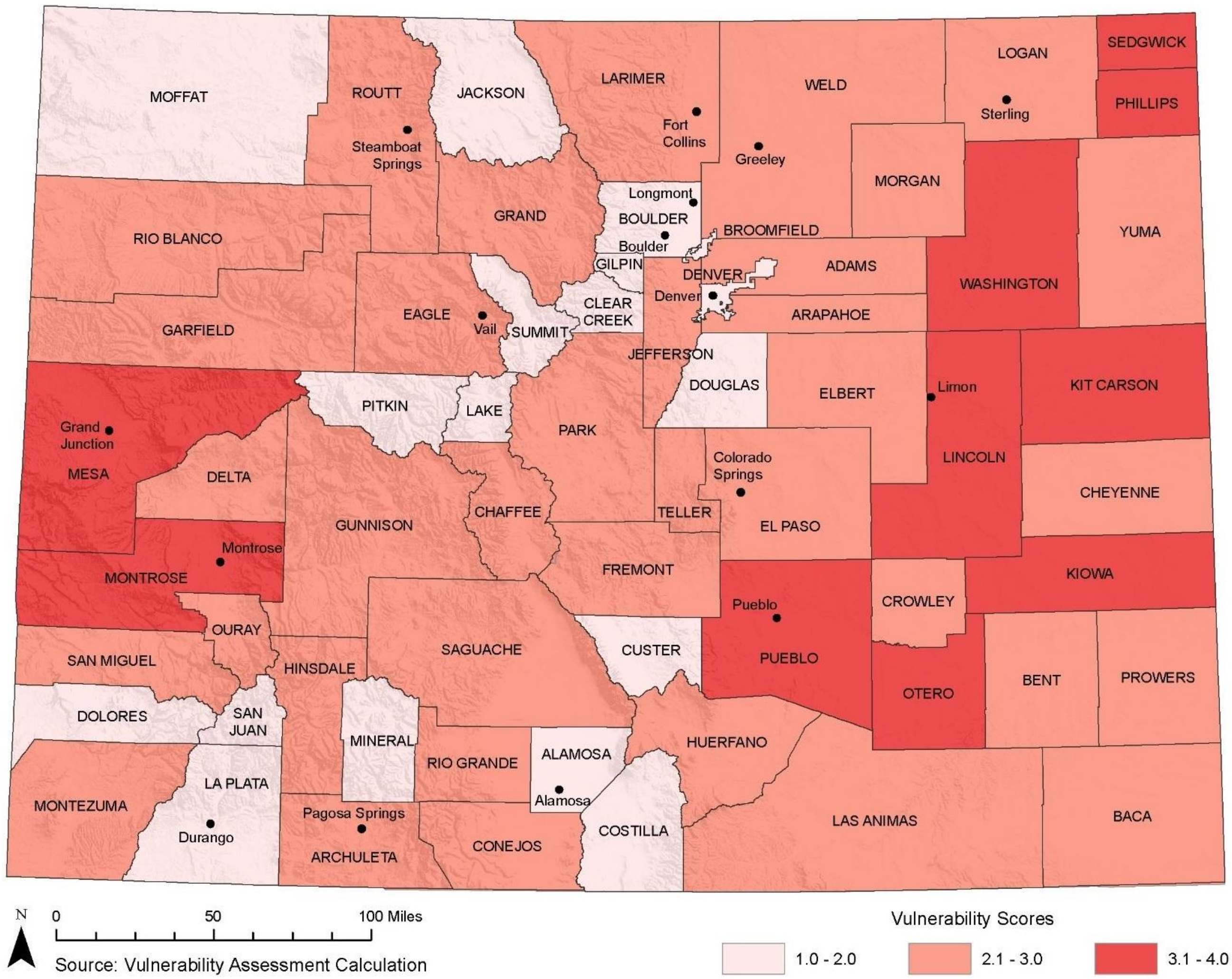


Figure 5.23 Overall Vulnerability Rankings in the State Assets Sector, by County



Source: Vulnerability Assessment Calculation

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 industry[7] 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 whole[8], 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.

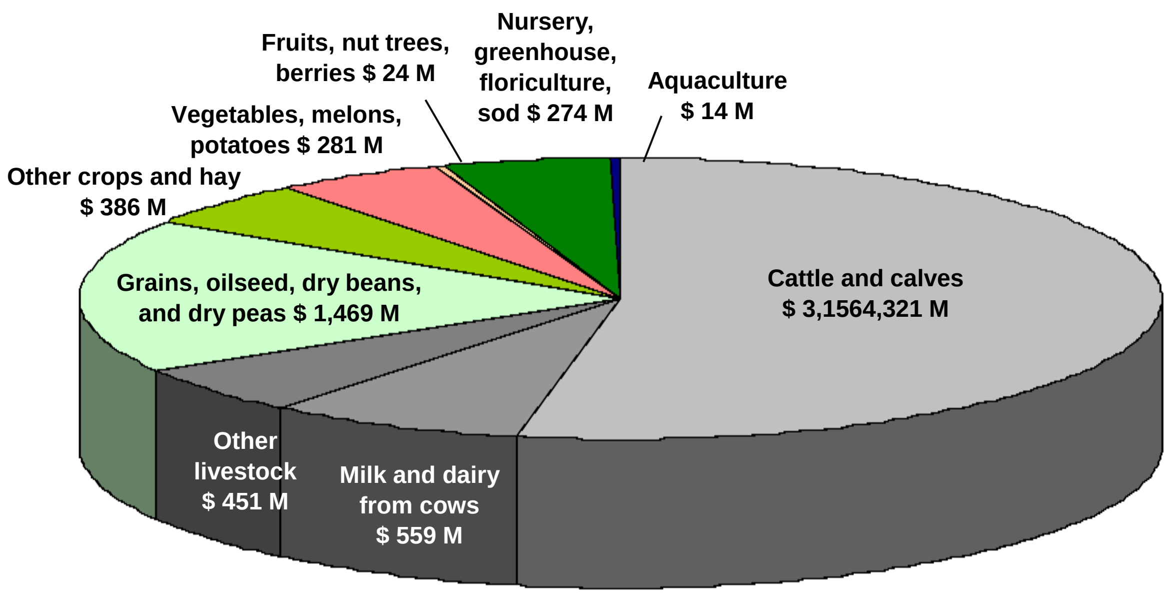
Key Recommendations

- 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 sector[1] (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	• Successful crop depends on precipitation in the fall to start plant germination, and in the spring to develop the grain (McKee et al., 2000).	• Water is required for adequate soil moisture to germinate and grow.

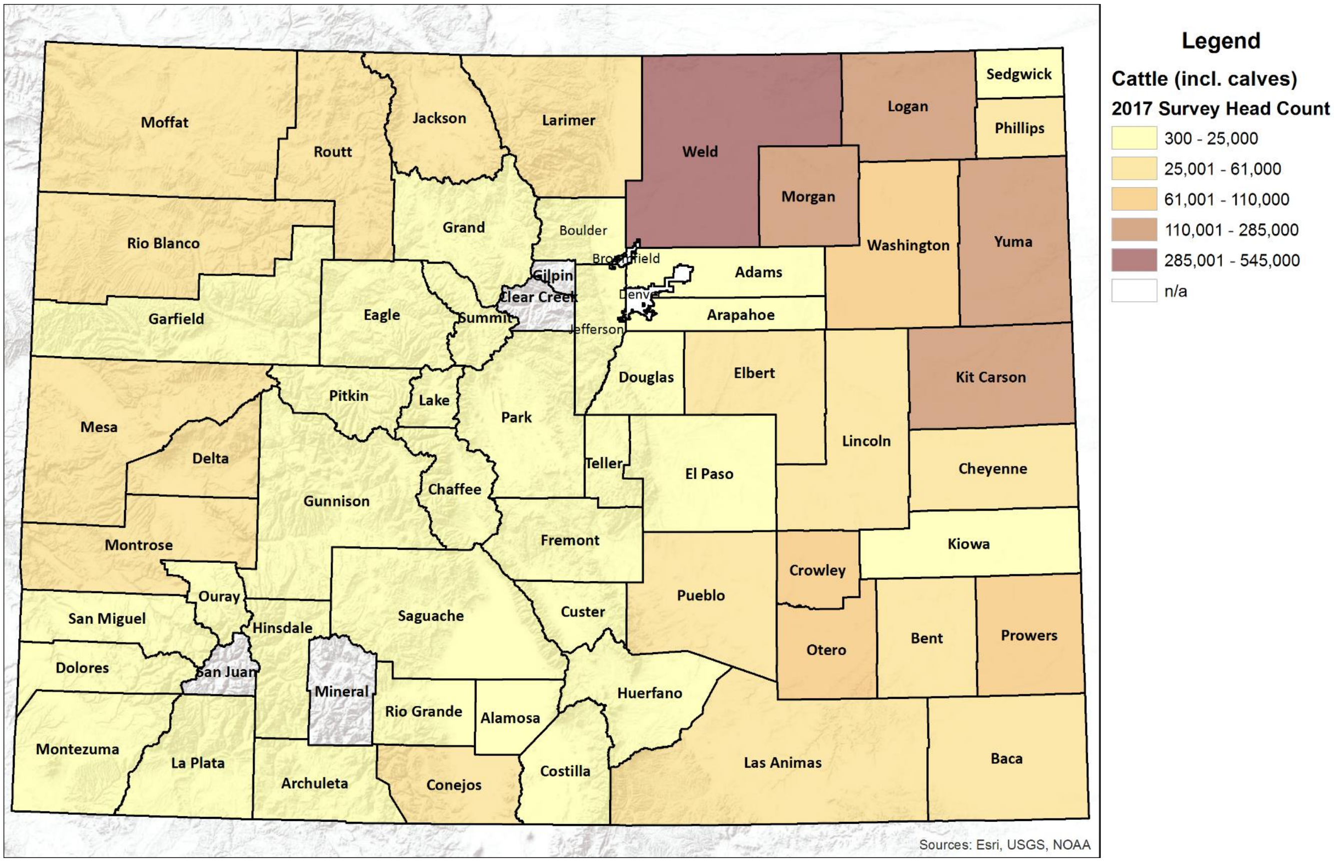
Sub-sector	Season	Water Use
	● Winter wheat, the prominent dryland crop in Colorado, is generally planted on a 2-year rotating basis to allow the soil to accumulate enough moisture to support it.	● These crops are entirely dependent on precipitation.
Crops: irrigated	● Water demands for most irrigated crops begin increasing in late April, peak in early July, and drop off into late October (McKee et al., 2000).	● Irrigation water is used to supplement natural precipitation and ensure the crop has adequate moisture to grow and produce the desired yield.
Livestock	● Cattle released to grazing pasture in early summer, return around the time of the first snowfall.	● 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	● 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).	● 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).

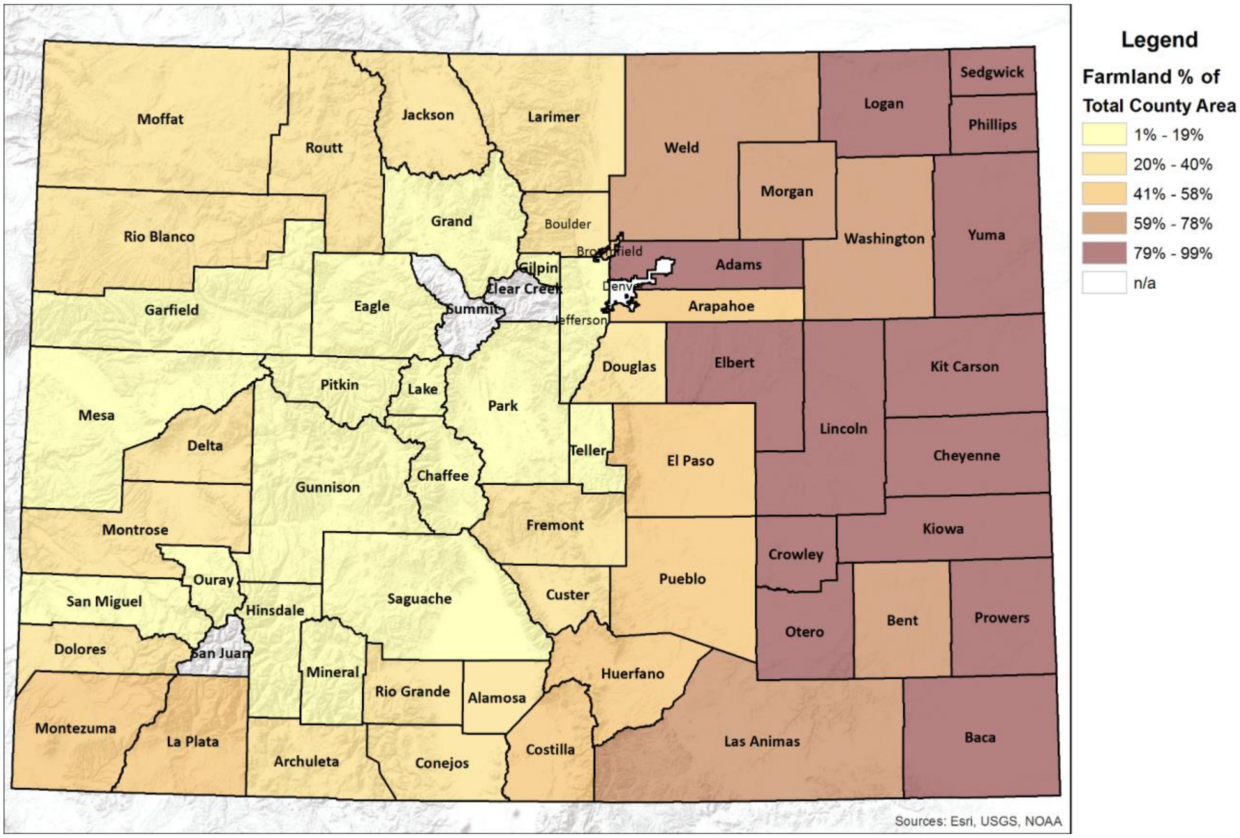
The following sections discuss aspects of vulnerability to drought in the Agriculture Sector, and cover adaptive capacities used to mitigate the impacts. For a general description of the vulnerability assessment approach refer to Chapter 2 of Annex B.

Figure 6.2 Cattle Head Count per County



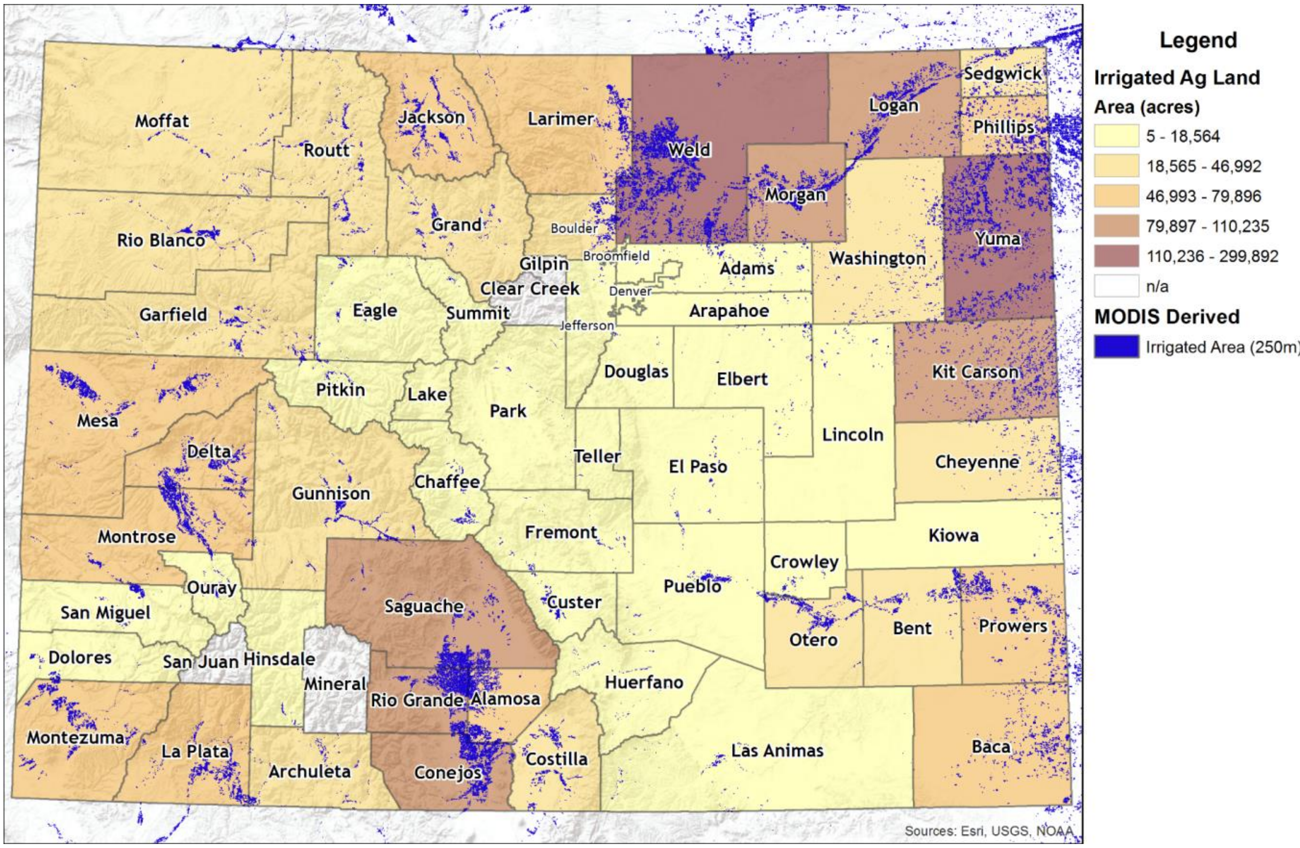
Data Source: NASS, 2017

Figure 6.3 Percentage of Total County Area Dedicated to Farmland



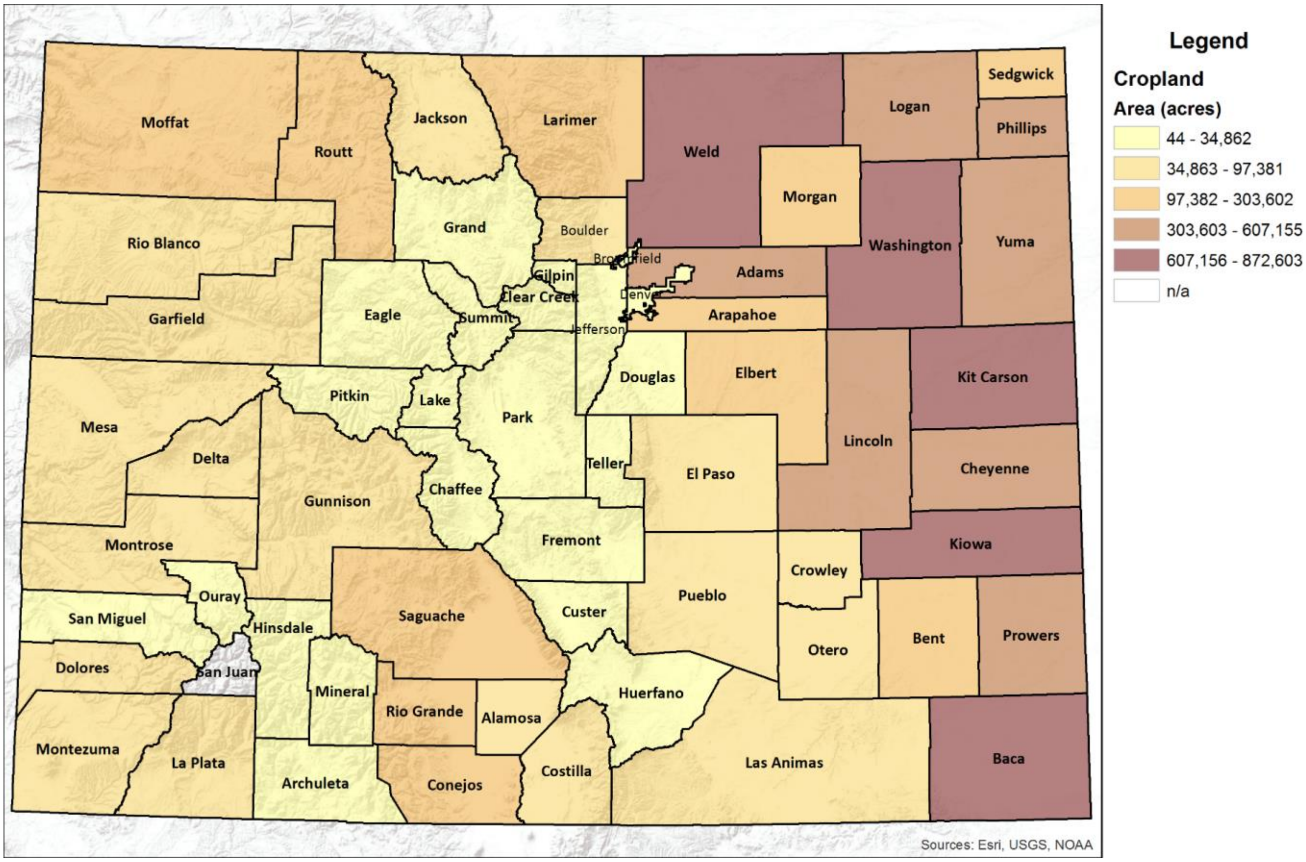
Data Source: NASS, 2012

Figure 6.4 Total Agricultural Land Area with Irrigation



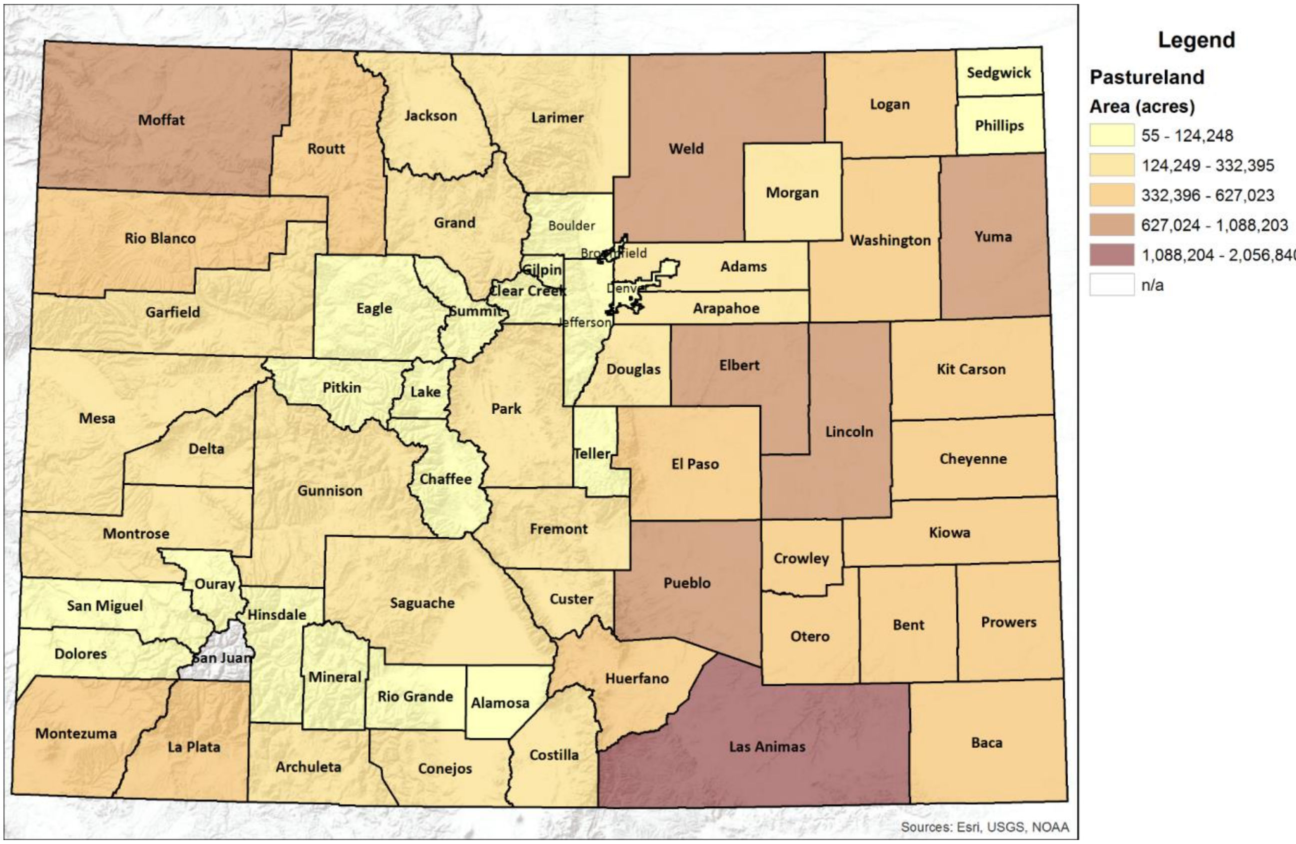
Data Source: NASS, 2012

Figure 6.5 Total Area Dedicated to Cropland Agriculture



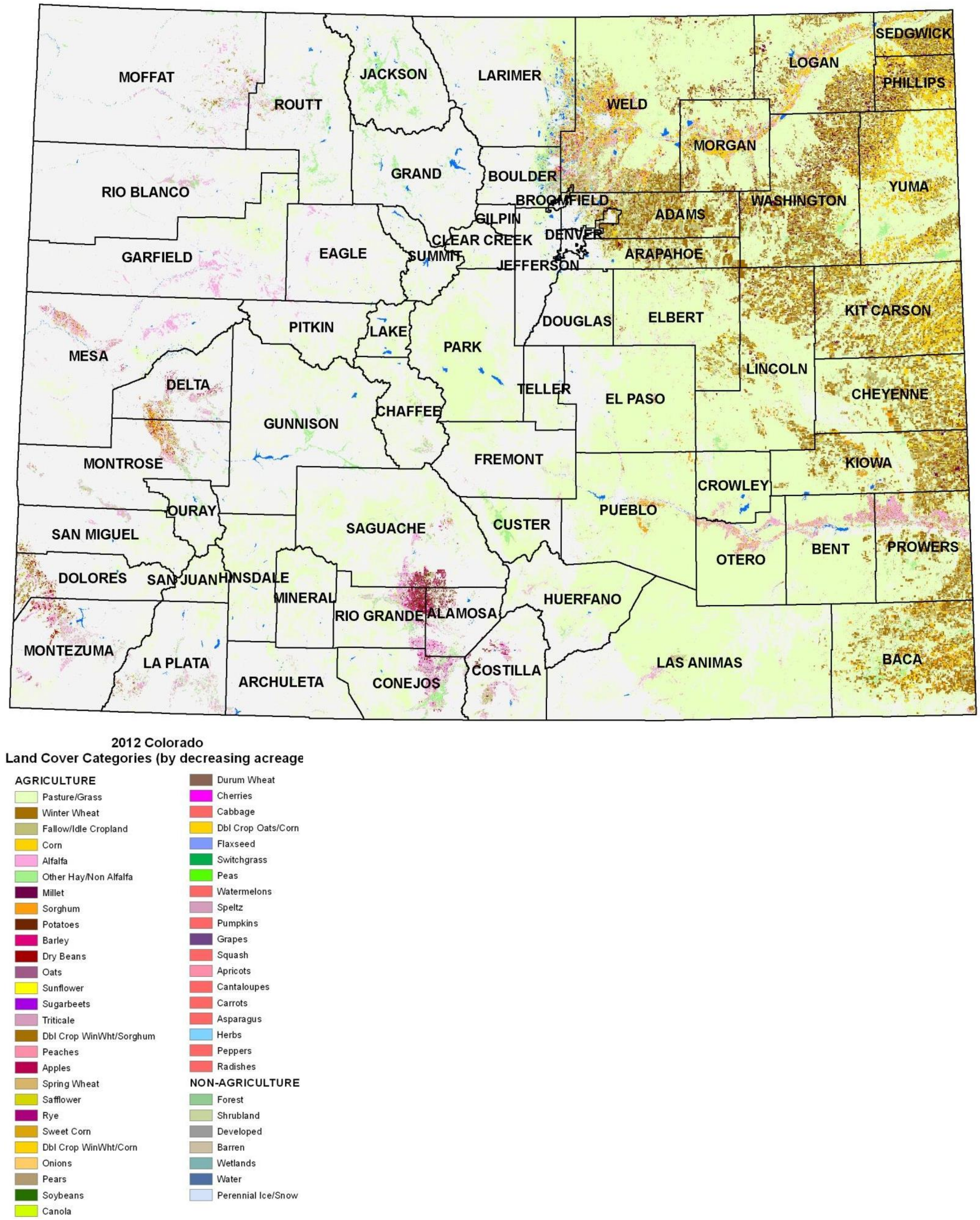
Data Source: NASS, 2012

Figure 6.6 Total Area Dedicated to Pastureland



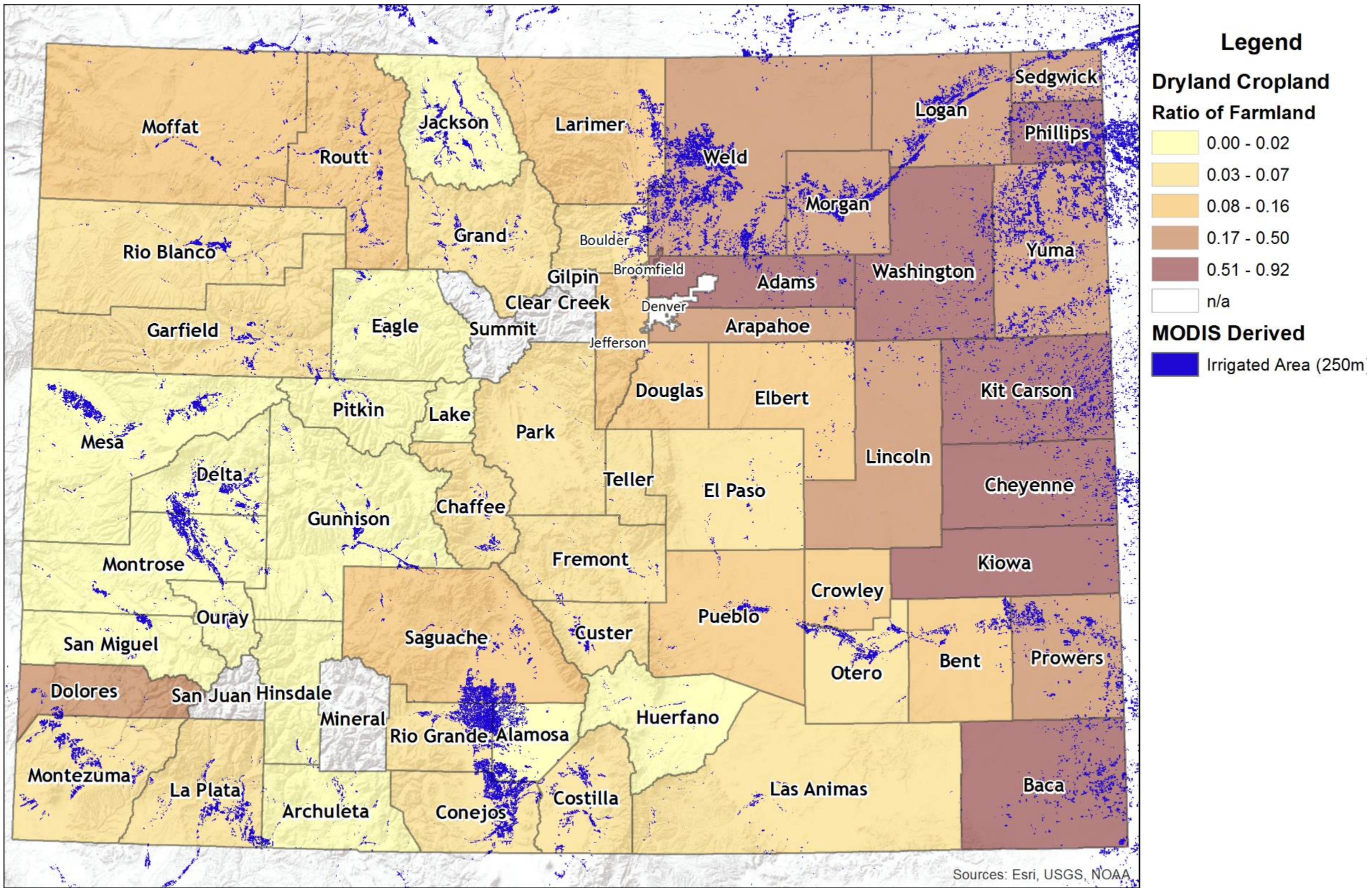
Data Source: NASS, 2012

Figure 6.7 Crop Types Across Colorado



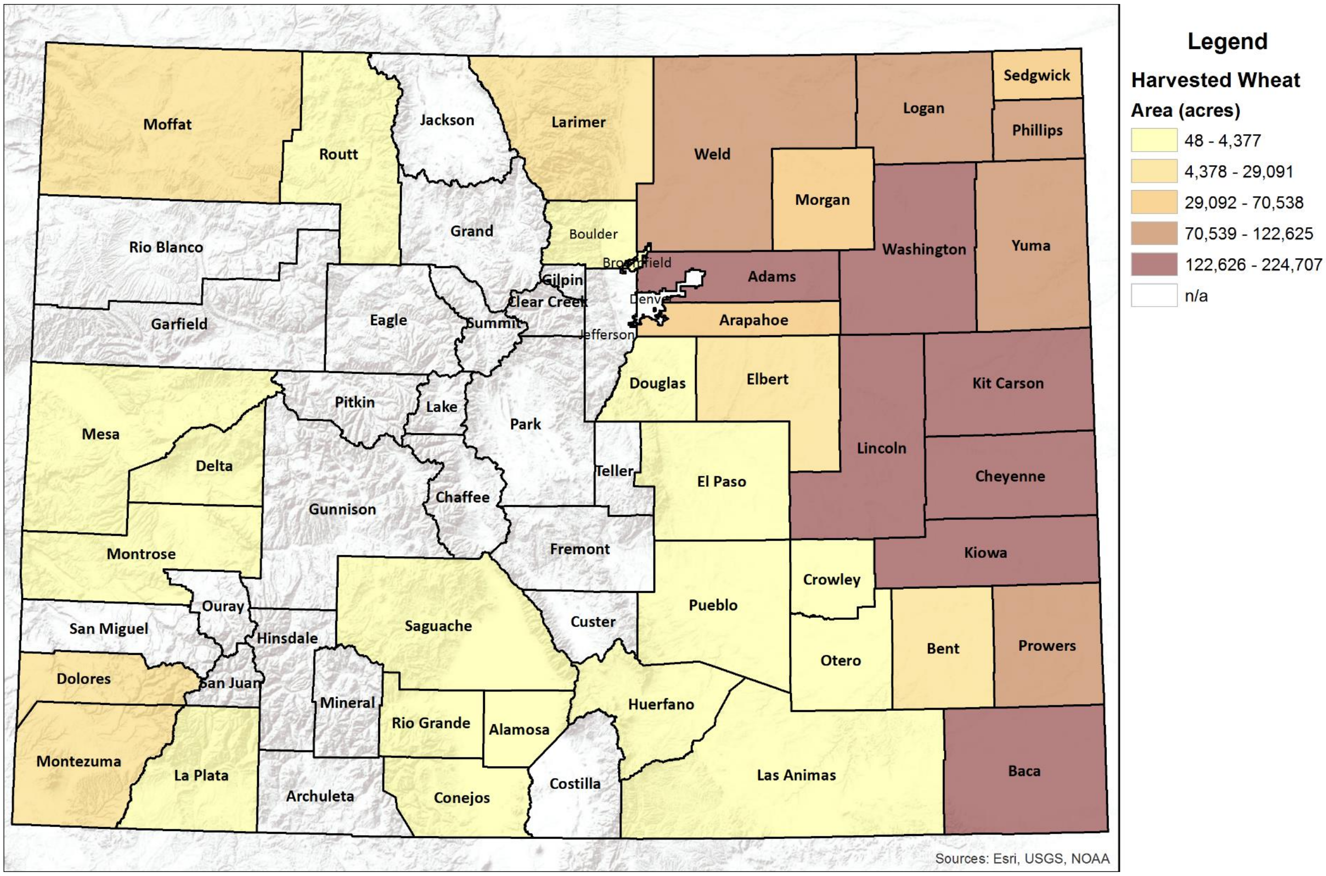
Data Source: USDA, NASS Crop Data Layer Program, 2012

Figure 6.8 Ratio of Farmland Area Consisting of Dryland Crops



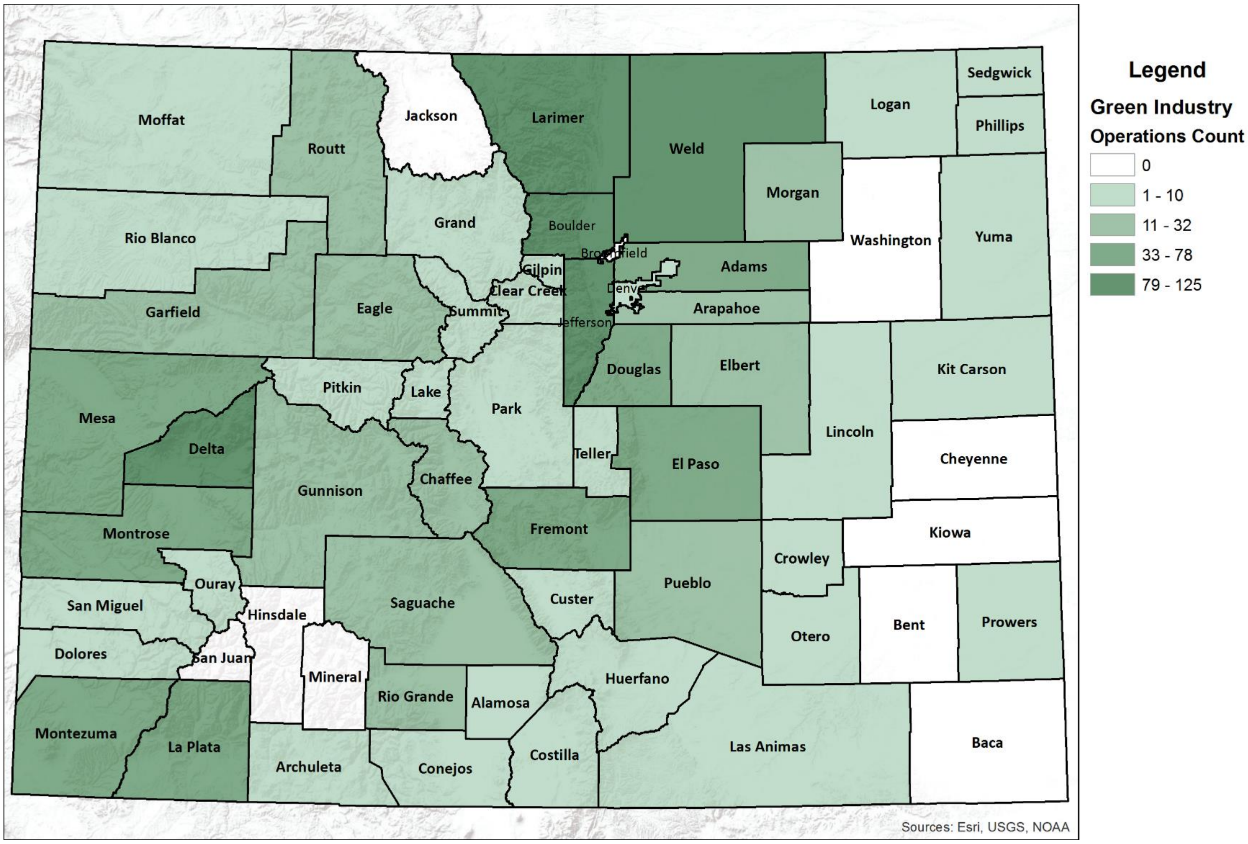
Data Source: NASS, 2012

Figure 6.9 Harvested Wheat Area



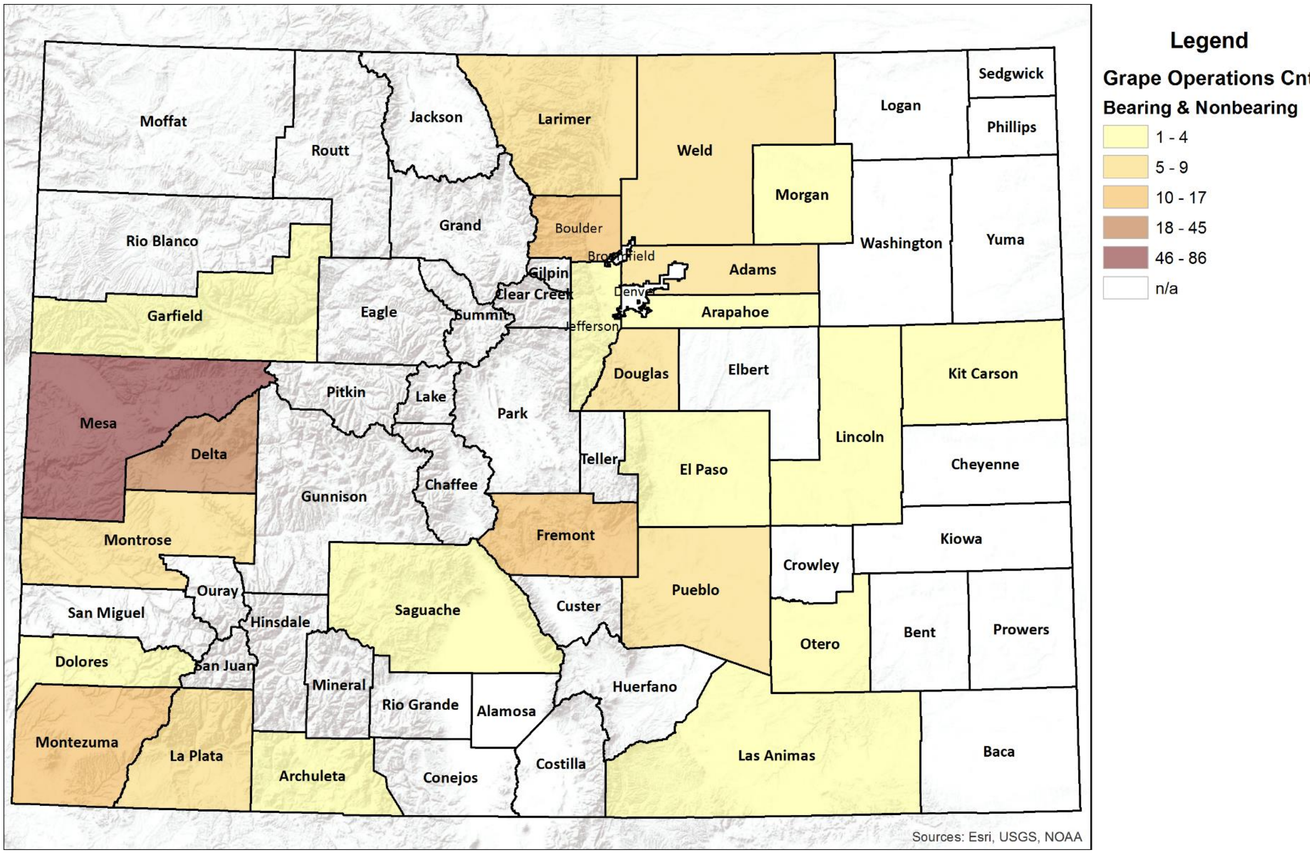
Data Source: NASS, 2012

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 CWCB'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 ECw*			
	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 Import 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

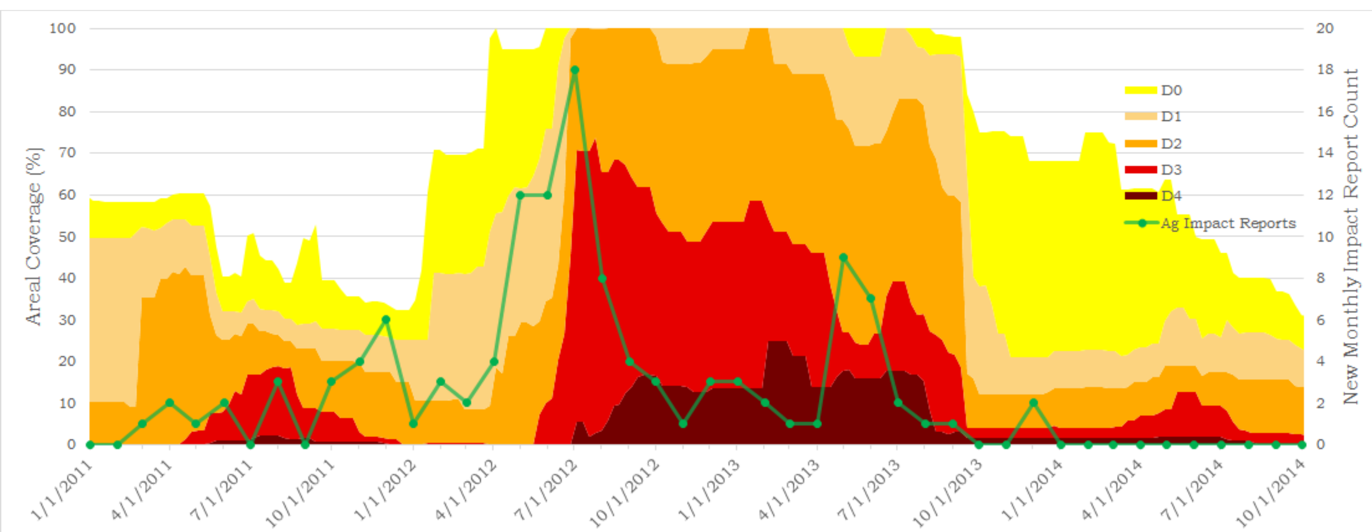


Table 6.4 Previously Reported Agricultural Impacts

Sub-sector	Previously reported impacts	Sources
Livestock	• 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.	Luecke et al., 2003 DWSA 2004 Christensen 2002 Nelson et al., 2012 Gunter et al., 2012 Pritchett et al., 2013 Pritchett et al., 2013 LMIC, 2013
Crops - dryland	• 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 • •	Luecke et al., 2003 Christensen 2002 Gunter et al., 2012Gunter et al., 2012

Sub-sector	Previously reported impacts	Sources
	• 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	• 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	• 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

	Rio Grande			Arkansas		
Crop	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.

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[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.

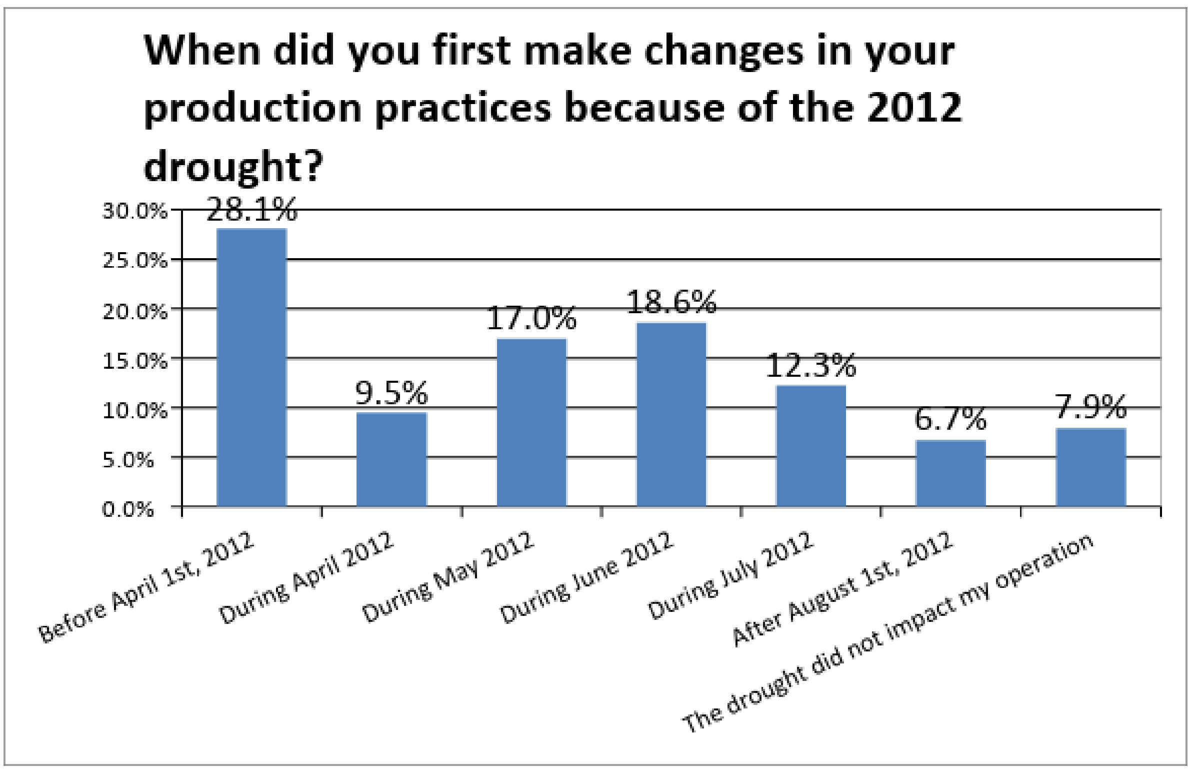
This impact to forage and feed production was felt in cow and calf production rates. The overall number of cows decreased 48% from normal with a culling rate of 21% (meaning roughly 1 out of every 5 cows was removed from the herd for one reason or another). Overall cow health was also affected by the 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).

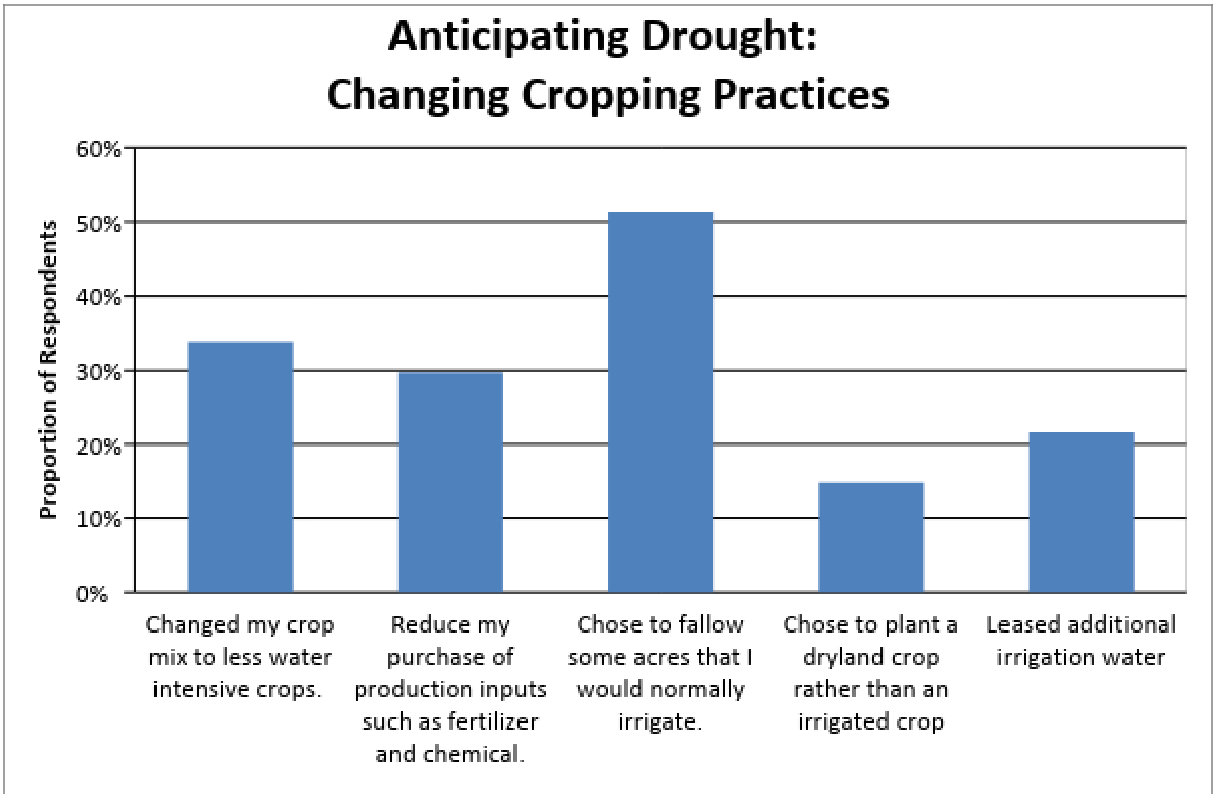
Figure 6.13 below shows when respondents chose to alter their operations in response to drought. Over 90% of respondents took action at some point during the 2012 season, with nearly 30% acting before April 1st. Figure 6.14 shows what those actions included for crop operations. The most common response 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

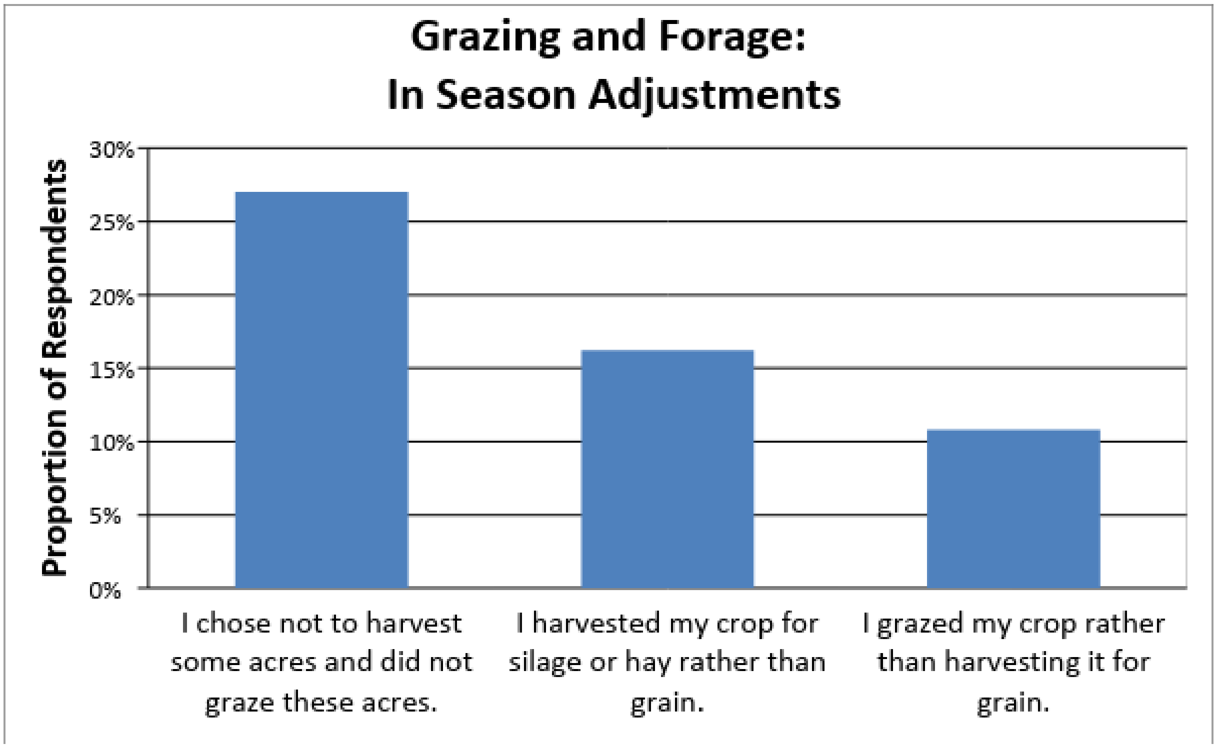
Figure 6.14 Crop Respondent Actions Taken During the 2012 drought



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%.

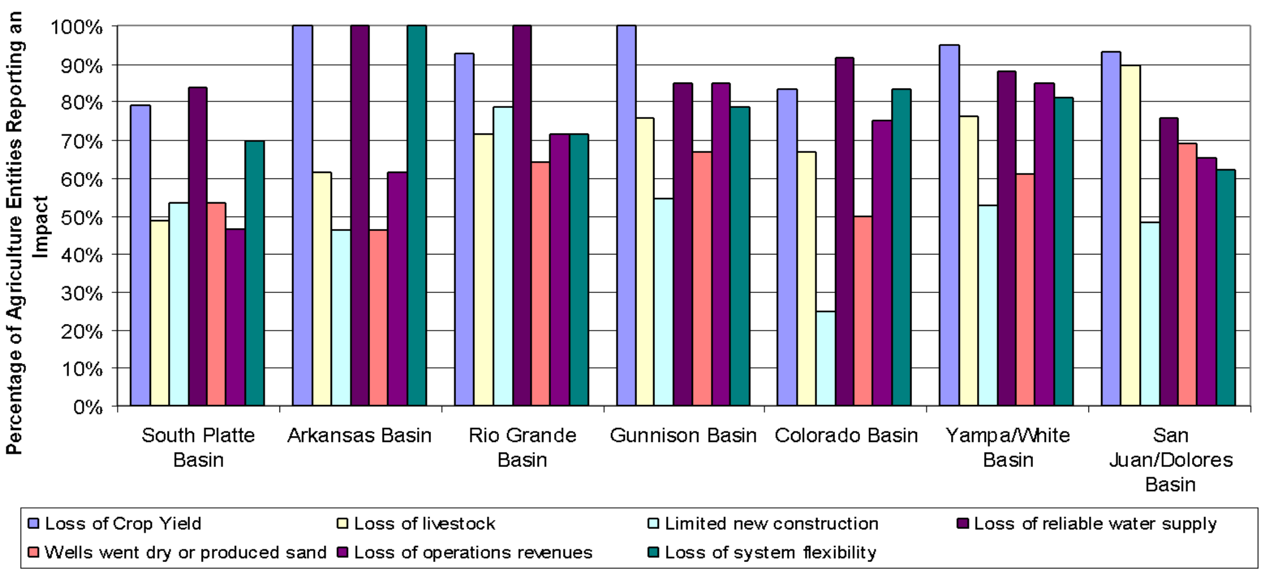
Drought Water Supply Assessment

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	• 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	• 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	• 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	• 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.

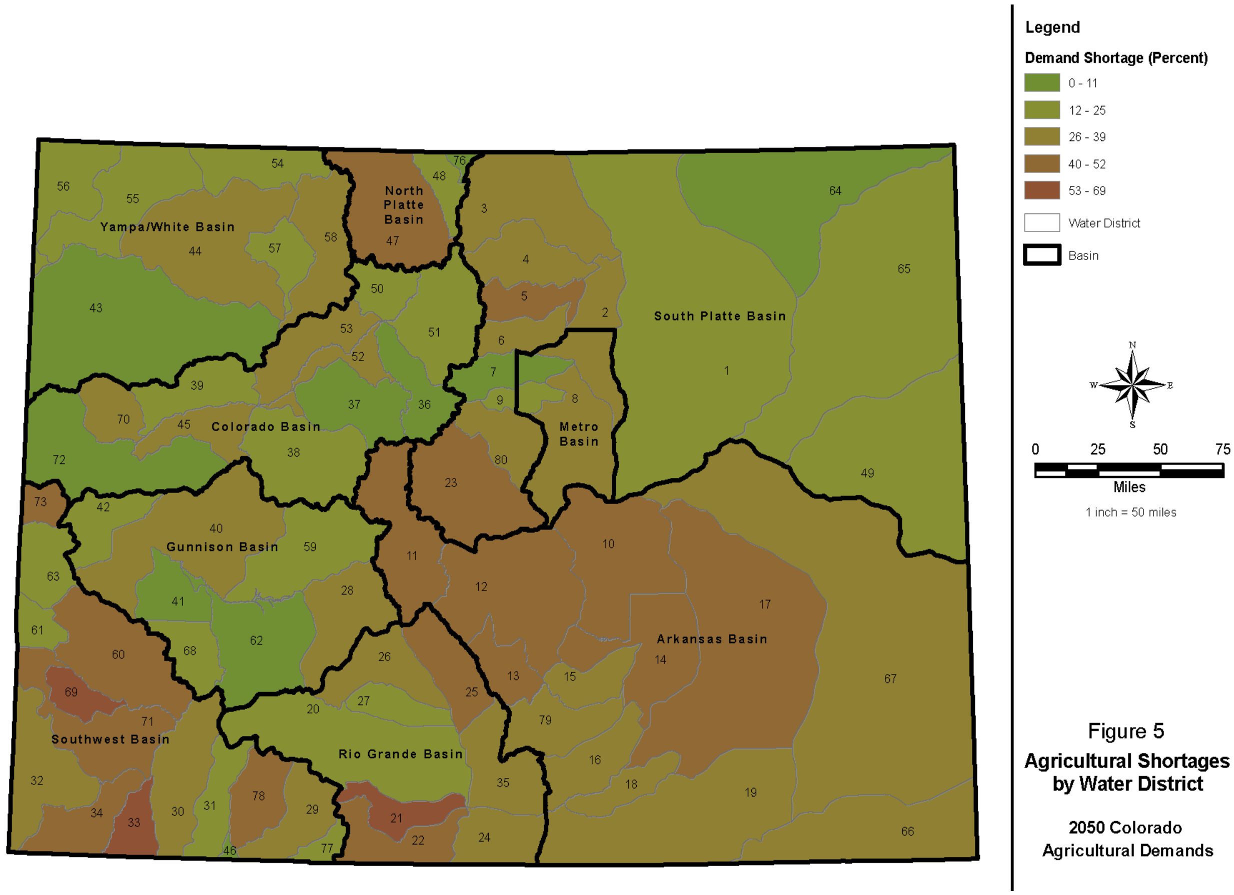
SWSI also discussed how conservation may benefit the Agricultural Sector in times of drought. Examples of efficiency measures include ditch lining, conversion of flood irrigation to gated pipe, and sprinkler or drip system installation. These measures may assist agricultural water users by, extending 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 CWCB in the form of current and 2050 agricultural demands projections further the exchange of ideas.

Figure 6.17 Projected 2050 Agricultural Demand Shortages

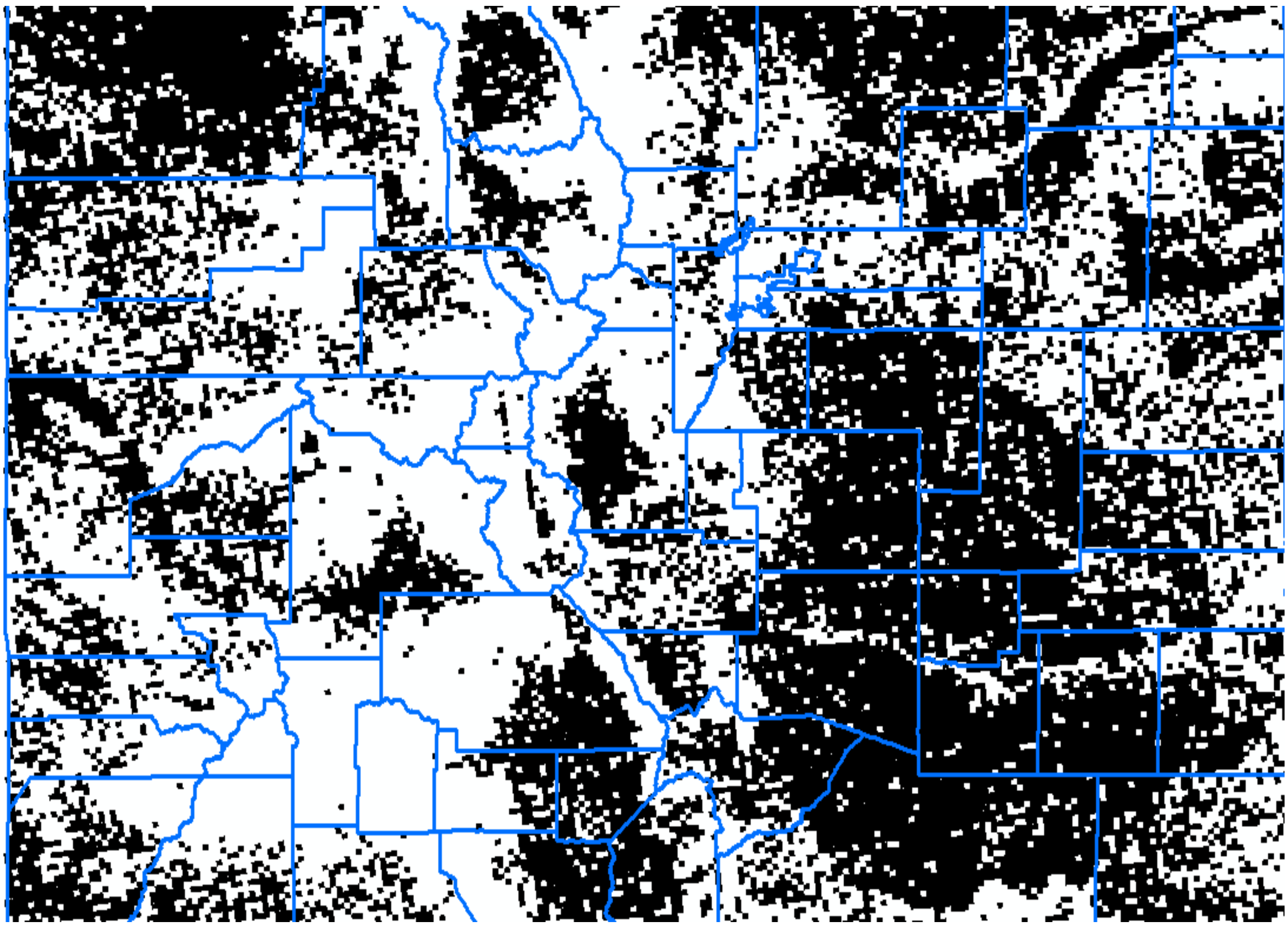


Source: CWCB-SWSI 2010

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

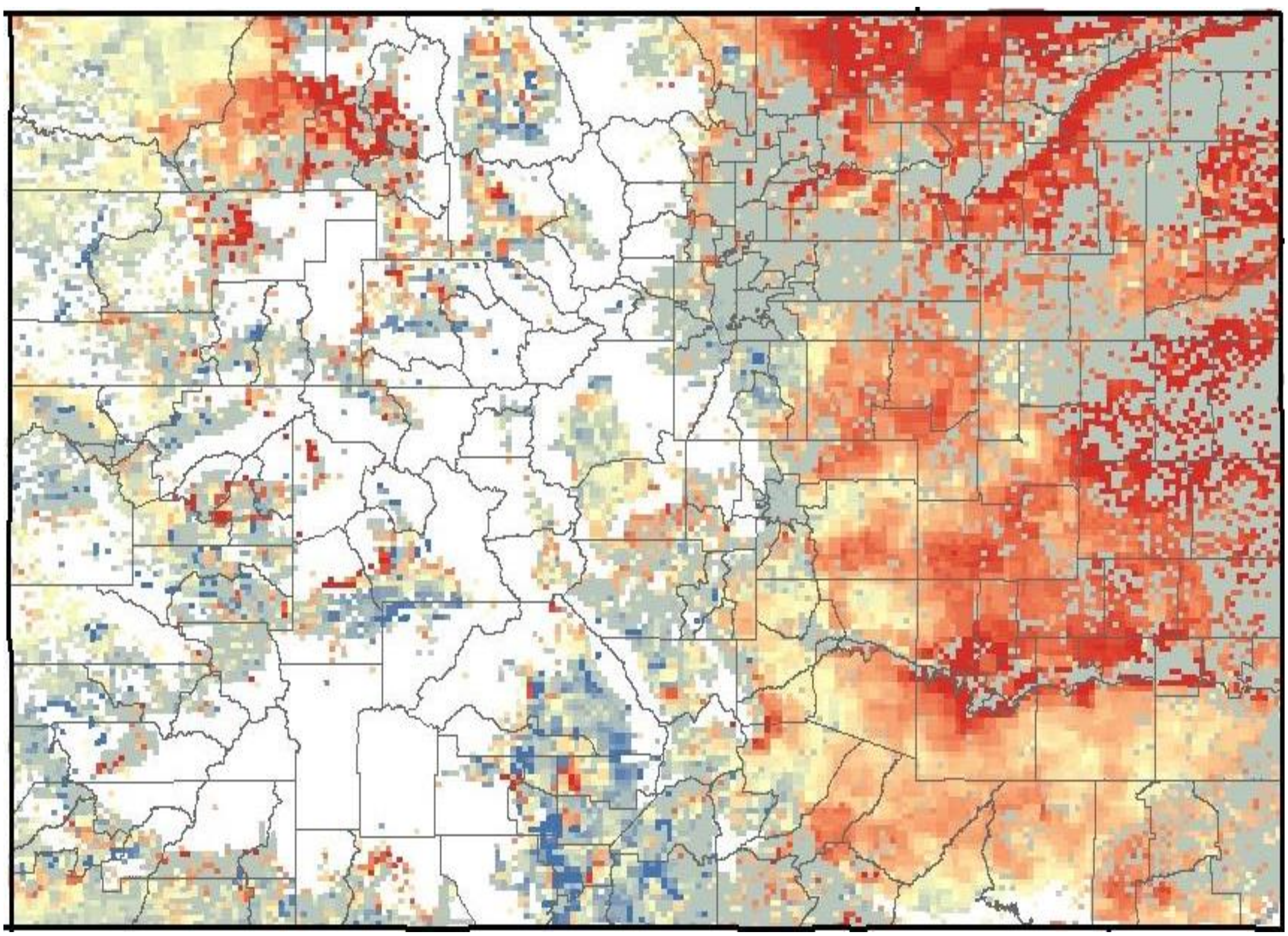


Figure 6.20 CASA Results Aggregated to the County Scale, Showing Net Total Change in Biomass

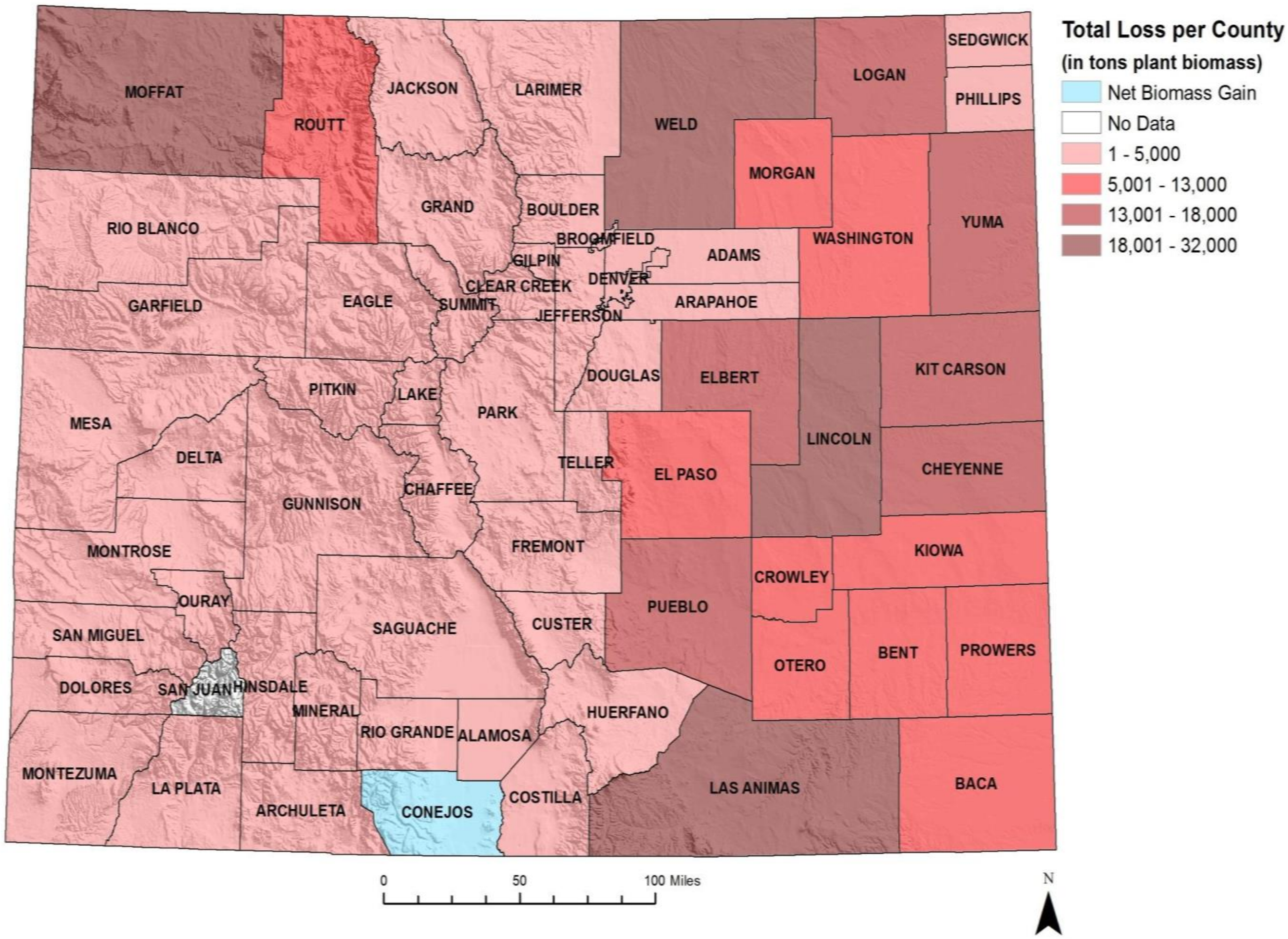
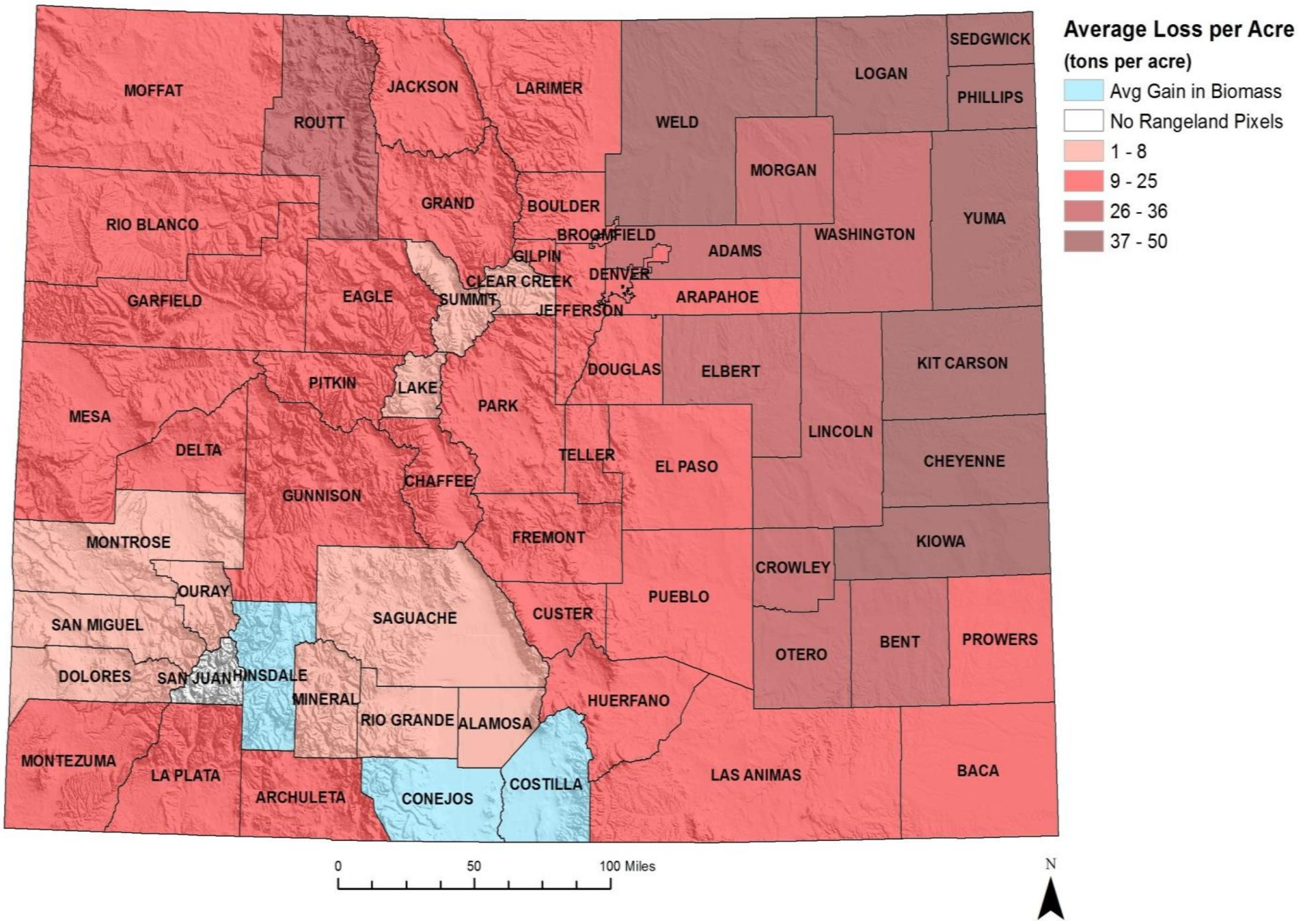


Figure 6.21 CASA Results Aggregated to the County Level, Showing Mean Biomass Change per Acre



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	• 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	• 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	• 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	• 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.

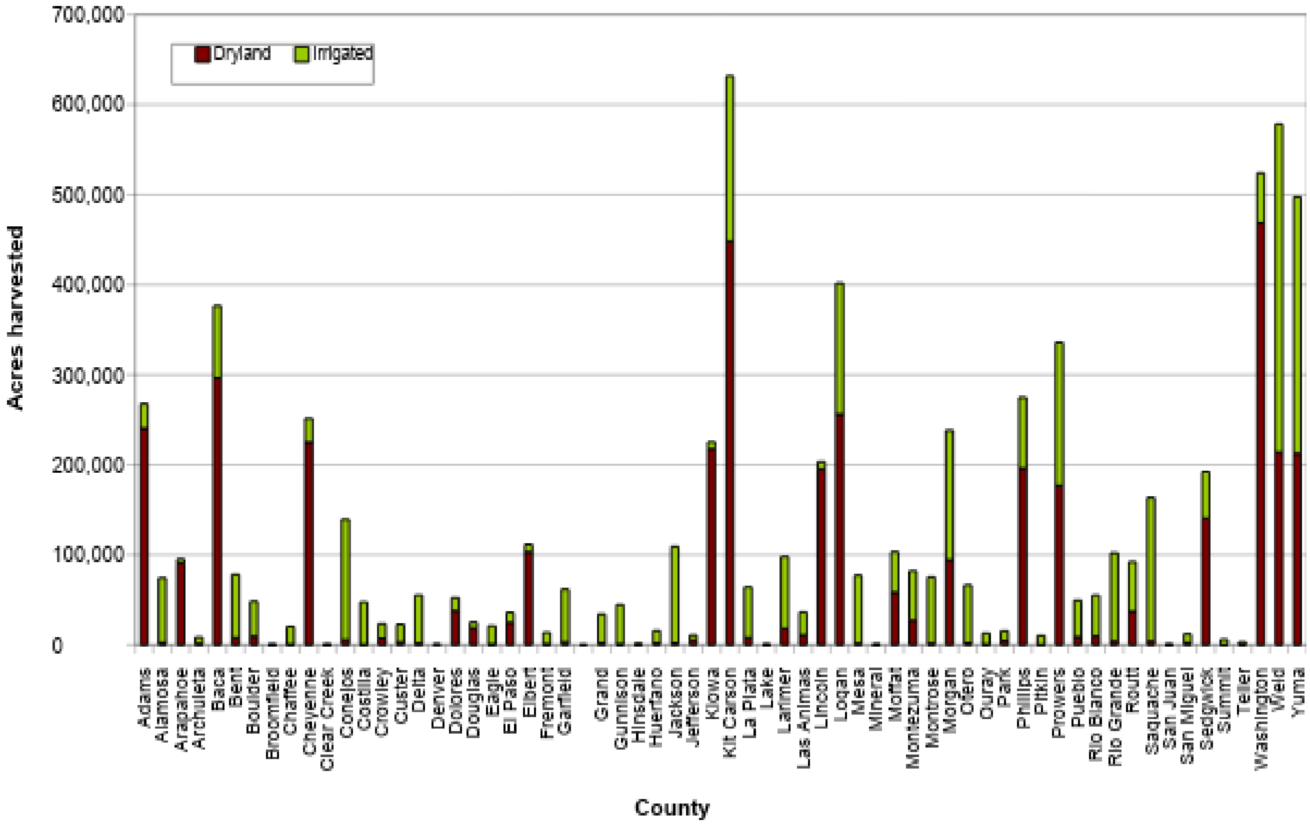
Figure 6.22 depicts the total harvested acreage per county separated by dryland and irrigated crops and averaged for 10 years (1999-2008). Harvested acreage is actual yield. The other data type in the NASS database are "planted" acreage, which measures the total acreage the farmer planted but might not 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).

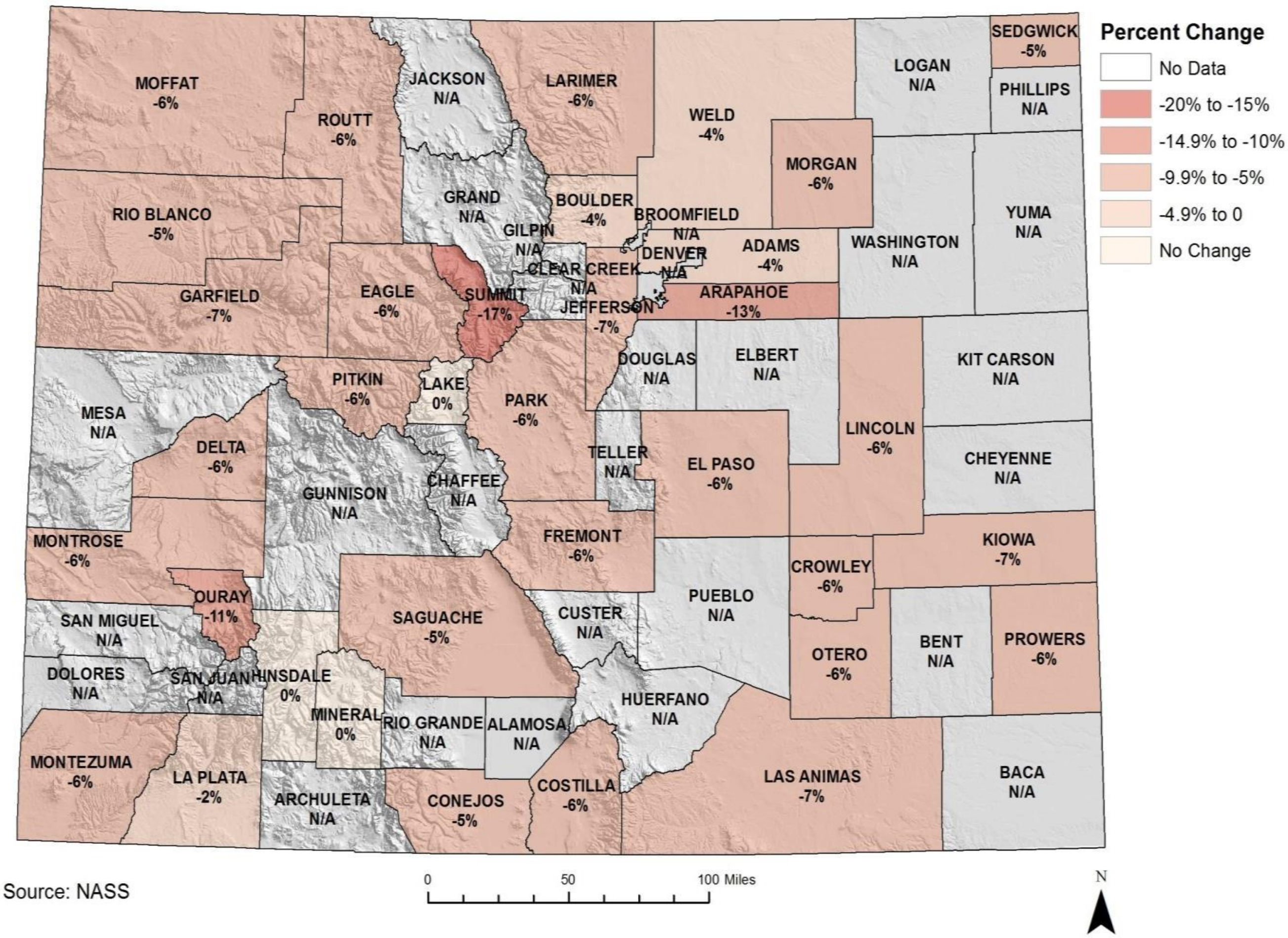
Data showing drought-related decreases in cattle is sparse, but the NASS database provides estimated annual numbers. By querying the database for beef cows, the percentage decrease from 2012 to 2013 for many counties in Colorado can be seen (Figure 6.23As this data is the result of a survey effort, numbers 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



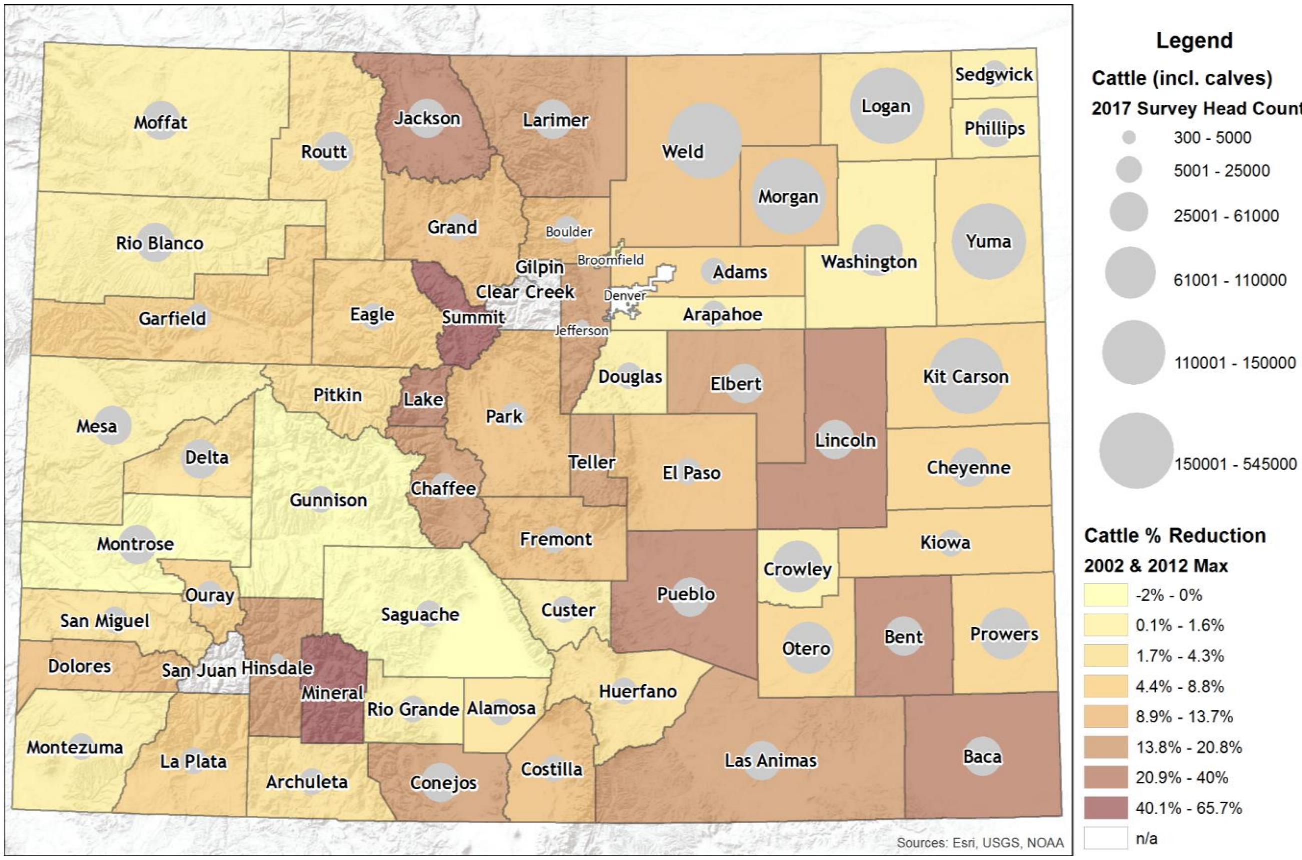
Source: NASS, 2010

Figure 6.23 Percentage decrease in the number of beef cows per county between 2012 and 2013



Source: NASS

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)	**1. Use stored feed.** **<u>Pros</u>** ● Enables the herd to stay intact. **<u>Cons</u>** ● 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. **2. Change operation, move herd or lease grazing fields in another area.** **<u>Pros</u>** ● If operational change is possible, enables herd to stay intact. **<u>Cons</u>** ● 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. **3. Sell portion or all of herd.** **<u>Pros</u>** ● Short-term monetary gain for rancher. **<u>Cons</u>** ● 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. **4. Avoid growing the herd above a certain limit, leave some flexibility for the next drought.** **<u>Pros</u>** ● A management practice that does not require any investment of funds, just advance planning. **<u>Cons</u>** ● Rancher could miss out on possible monetary gains in years with ample water and forage supply.
Crops - dryland	● 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). **1. Apply for crop insurance.** **<u>Pros</u>** ● Ensures a payment if the crop fails due to drought.

Sub-sector	Adaptive Capacities, Pros and Cons
	<u>Cons</u> ● Insurance may not be available for all crops in all areas.
Crops - irrigated	**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).** **<u>Pros</u>** ● Provides an income to the farmer even when growing crops is not practical or possible. **<u>Cons</u>** ● Requires agreements between multiple parties **2. In principal, growers could significantly reduce water use by switching between crops (Frisvold 2009).** **<u>Pros</u>** ● 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. **<u>Cons</u>** ● May not be practical in some instances. ● It assumes the farmer is sufficiently diversified for new crop to be successful. **3. Practice deficit irrigation.** **<u>Pros</u>** ● A way to produce a crop with less irrigation. **<u>Cons</u>** ● 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. **4. Apply for crop insurance.** **<u>Pros</u>** ● Ensures a payment if the crop fails due to drought. **<u>Cons</u>** ● Insurance may not be available for all crops in all areas. **5. Reallocate irrigation water to higher-value crops.** **<u>Pros</u>** ● If possible, allows the farmer to prioritize crop irrigation and still receive an income. **<u>Cons</u>** ● 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	**1. Focus on edibles (e.g., vegetables, fruit trees, and berries), native, and drought-tolerant plants (Haight 2010).** **<u>Pros</u>** ● Demand for these products is generally strong. **<u>Cons</u>** ● 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
	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). **Pros** ● Diversifying services can help insulate against major drought impacts to one specific market. **Cons** ● 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

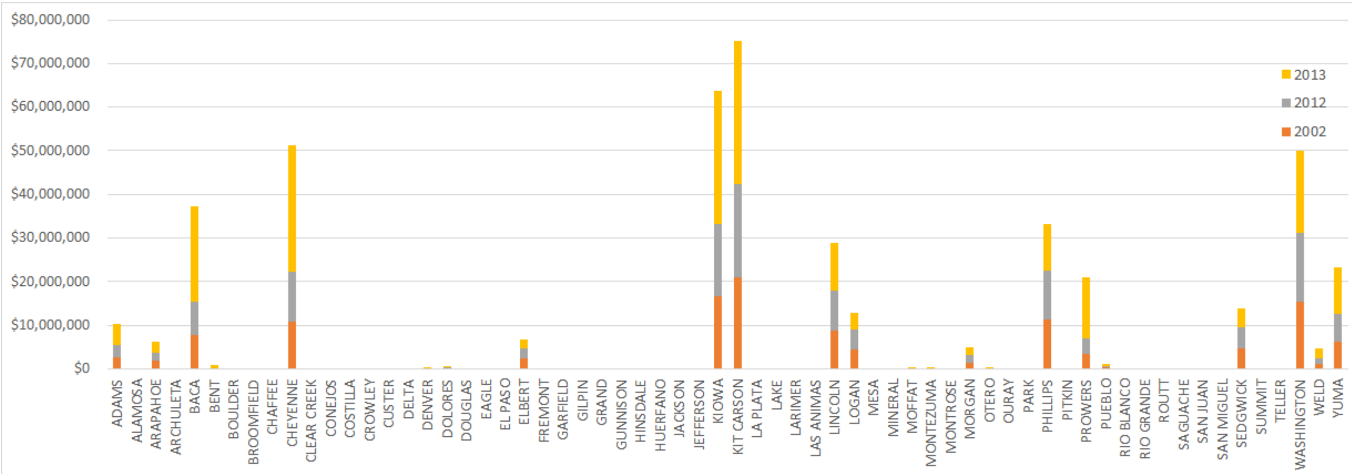
Percent dryland acreage out of total acreage, 2012

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

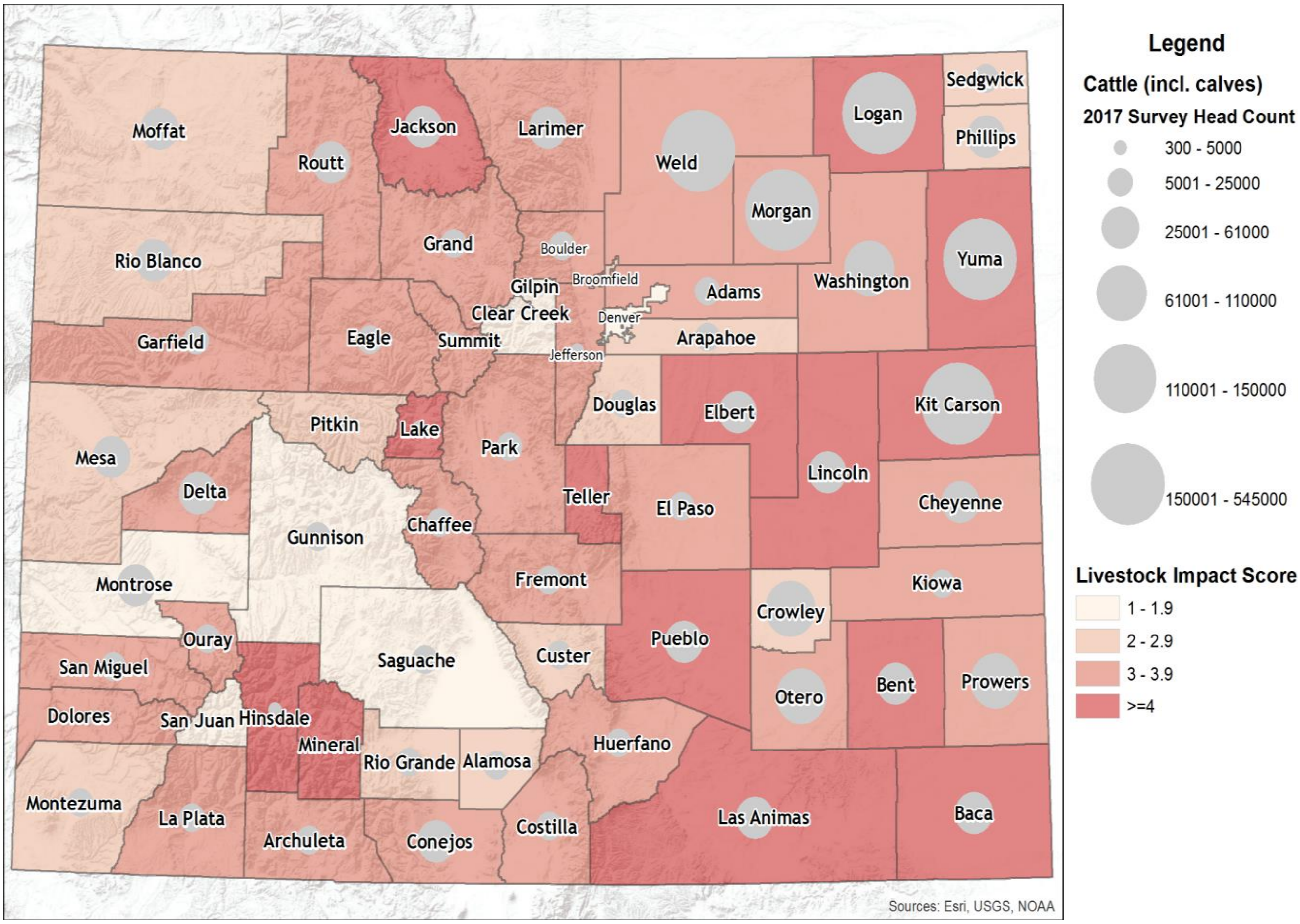


Figure updated 2017.

Figure 6.27 Crop Inventory and Vulnerability Ranking

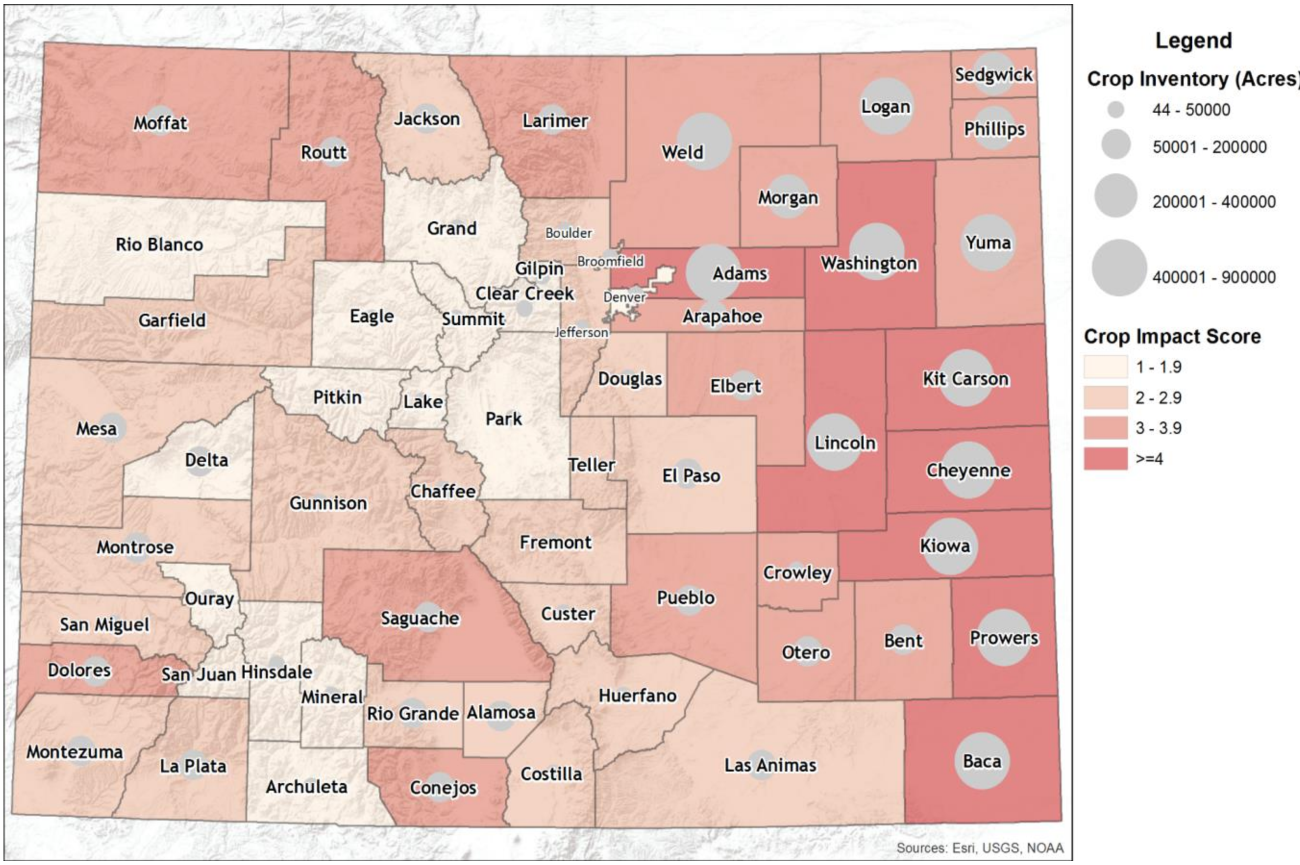


Figure updated 2017.

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 general, the eastern portion of the state is ranked more vulnerable to drought than the west due to the presence of dryland crops and, to a lesser degree, large numbers of cattle. The western half of the state does have agricultural activity, but it is more often irrigated and therefore is not as immediately vulnerable to drought as the dryland producers. Qualitative adjustments were applied to counties in the San Luis Valley. Vulnerability scores were increased to indicate a greater expected impact due to the existence of agricultural activity that was not reflected in the dryland crop metric. Other counties receiving the same qualitative adjustments include Montrose, Gunnison, and Delta, due to the presence of orchards and other irrigated crops in these counties. For detailed information on the qualitative adjustment methodology refer to Chapter 3. Counties that are mountainous and/or sparsely populated (e.g., Clear Creek, Gunnison, Mineral, etc.) and counties largely made up of urbanized areas (e.g. Denver) produced the lowest rankings because these counties contain a smaller proportion of agricultural activity compared to the rest of the state.

Figure 6.28 Overall Agriculture Impact Vulnerability Ranking

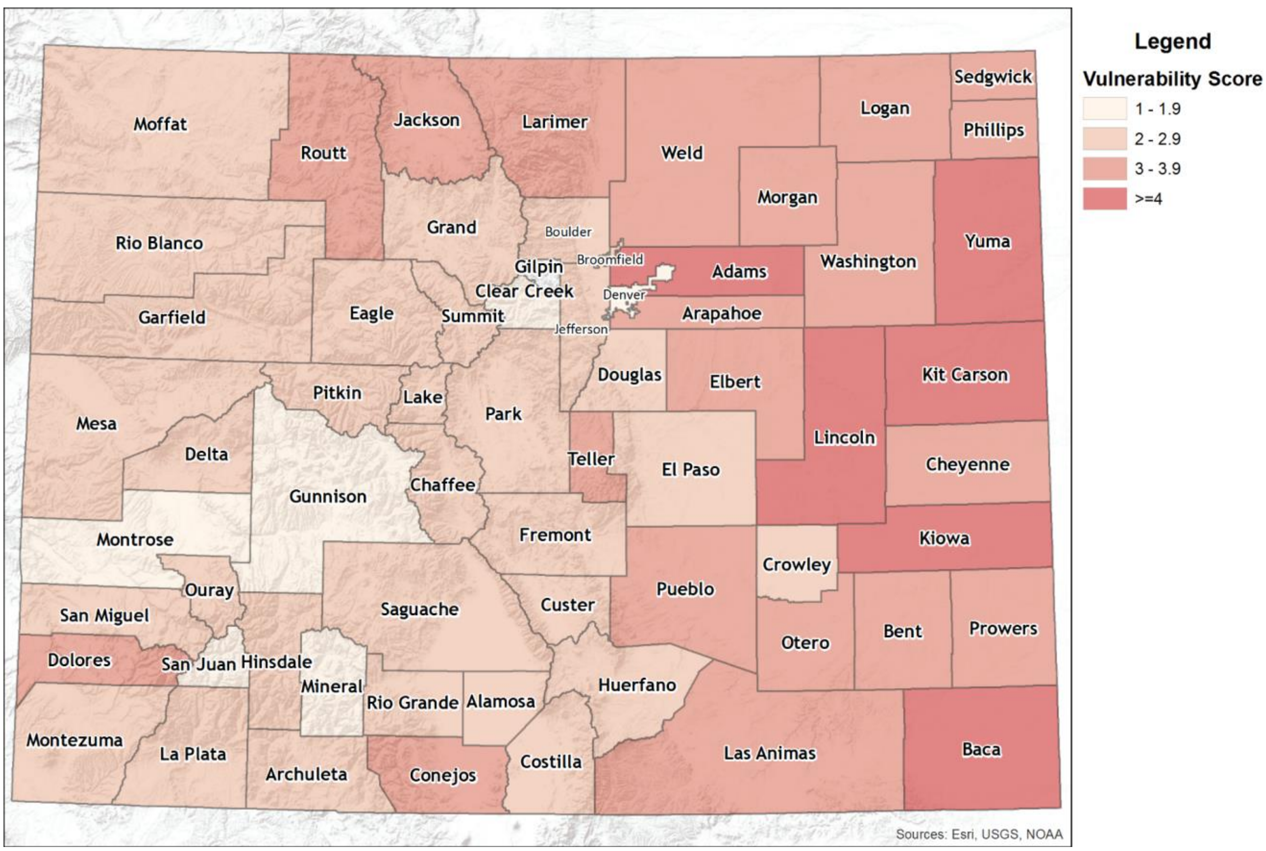


Figure 6.29 Overall Impact Vulnerability Ranking Change (2017 Scores – 2010 Scores)

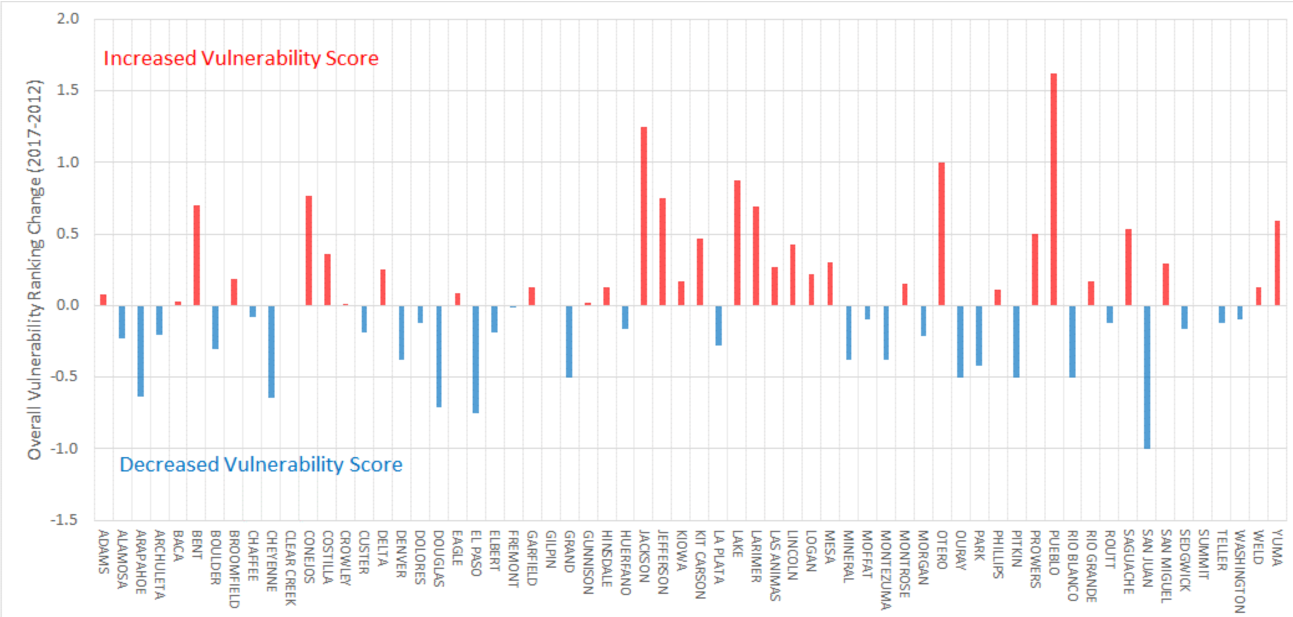
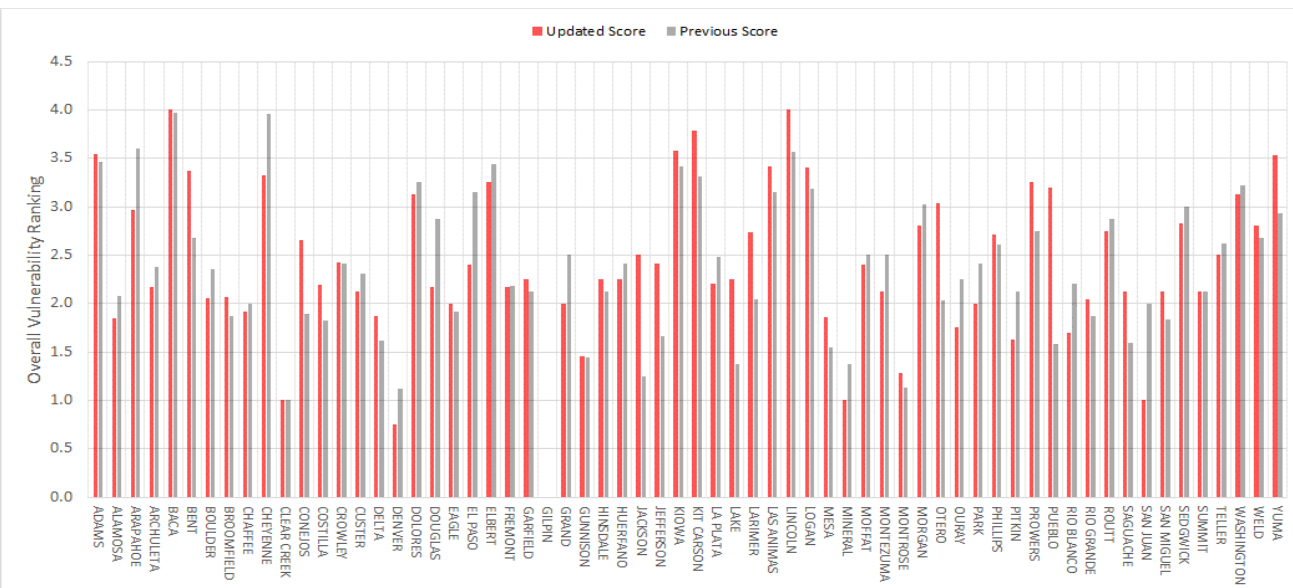


Figure 6.30 Drought Impact Vulnerability Comparison (Previous vs. Updated Scores)



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 indirect 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.

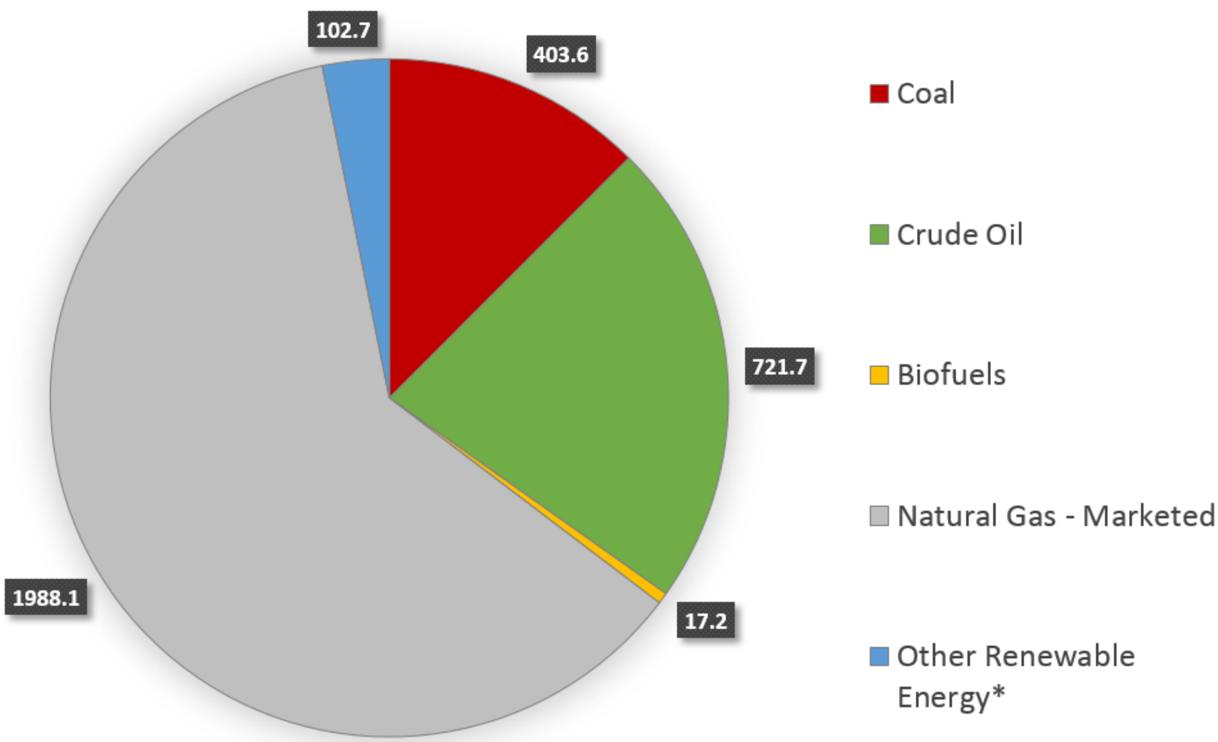
7.1 Introduction to Sector

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)



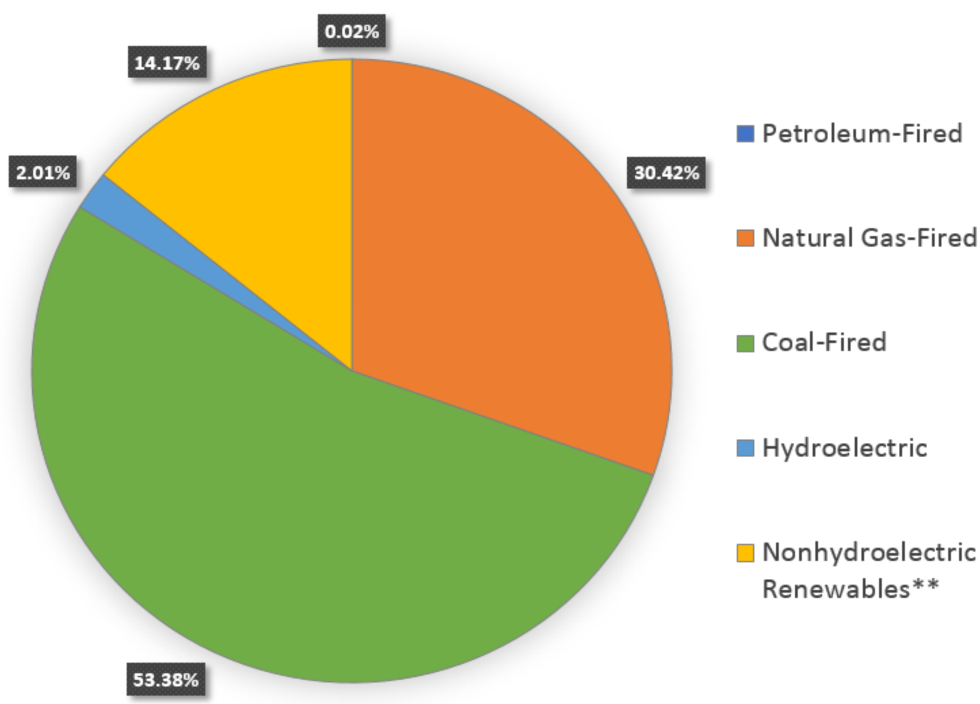
*Other Renewable Energy sources include: wood, black liquor, other wood waste, biogenic municipal solid waste, landfill gas, sludge waste, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind.
Source: U.S. Energy Information Administration, Figure revised in 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

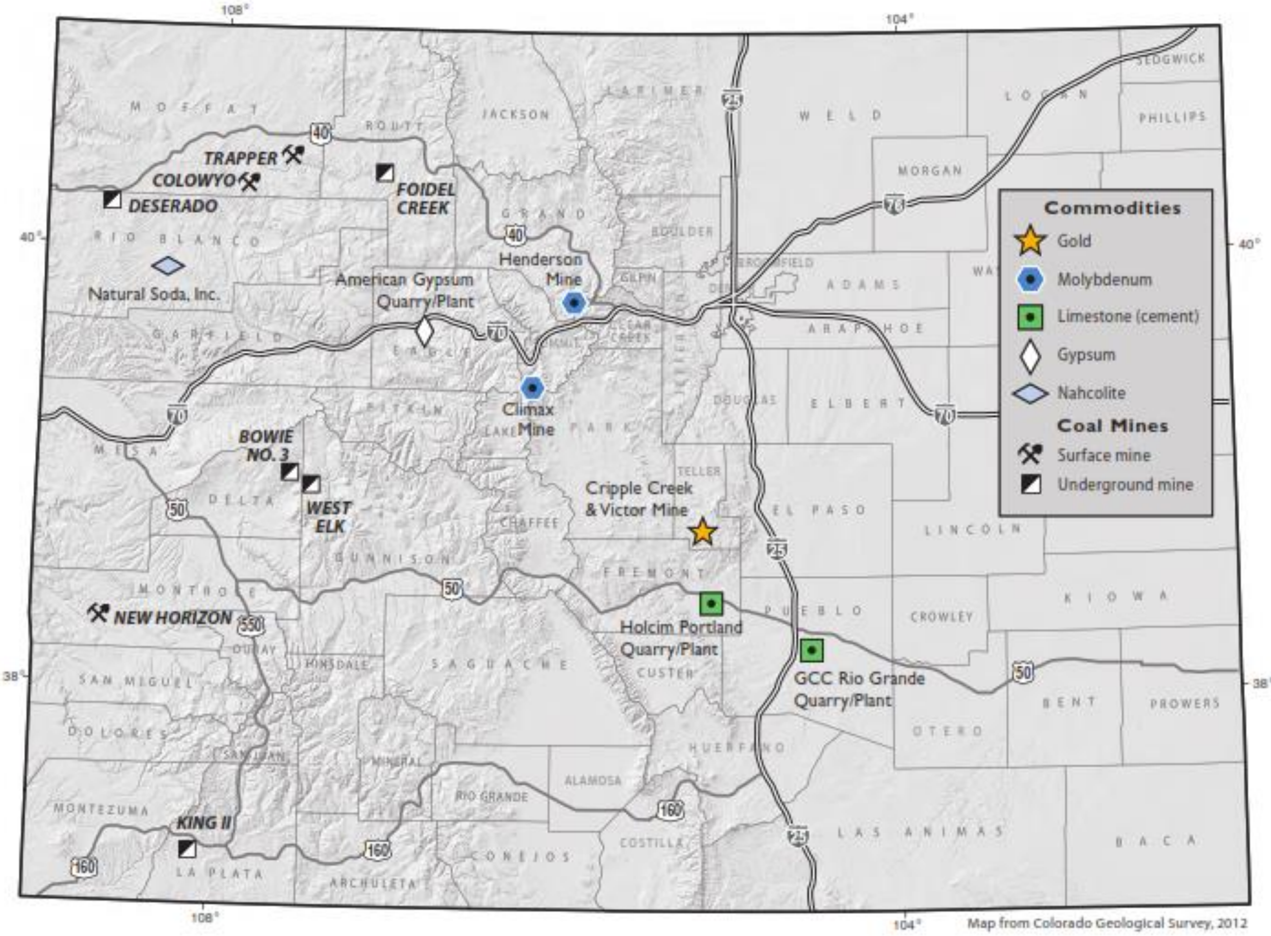
Energy Element	Connection Water Quantity	Connection to Water Quality
Hydroelectric	Reservoirs lose large quantities to evaporation	Can impact water temperatures, quality, ecology
Solar PV and Wind	None during operation; minimal water use for panel and blade washing	None during operation; minimal water 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.

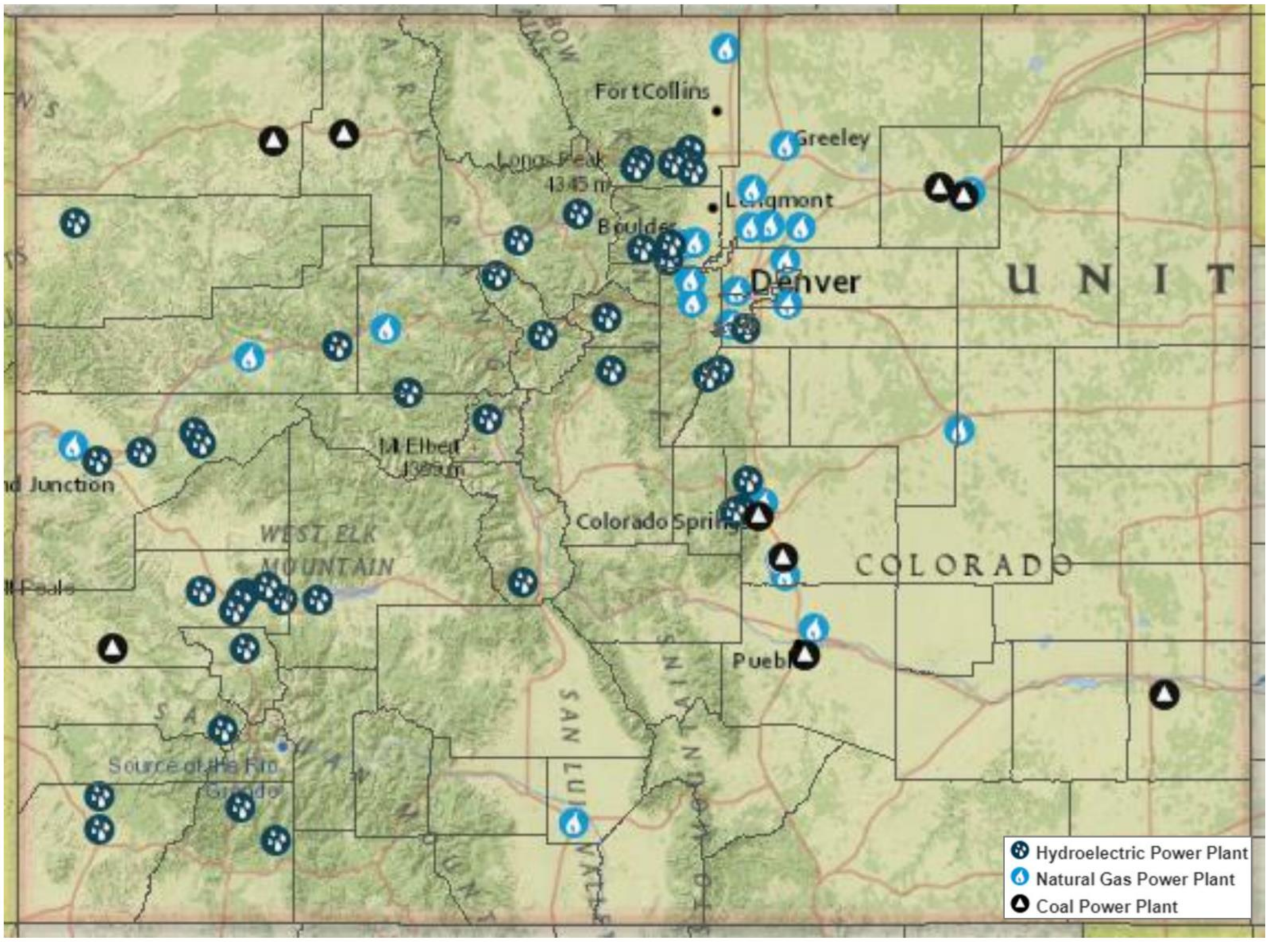
The Energy Sector is distributed across the State but more concentrated in the western half. The following figures illustrate the spatial distribution of mining activities and water intensive power production across the State. Figure 7.3 shows the distribution of major industrial mineral mines across 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

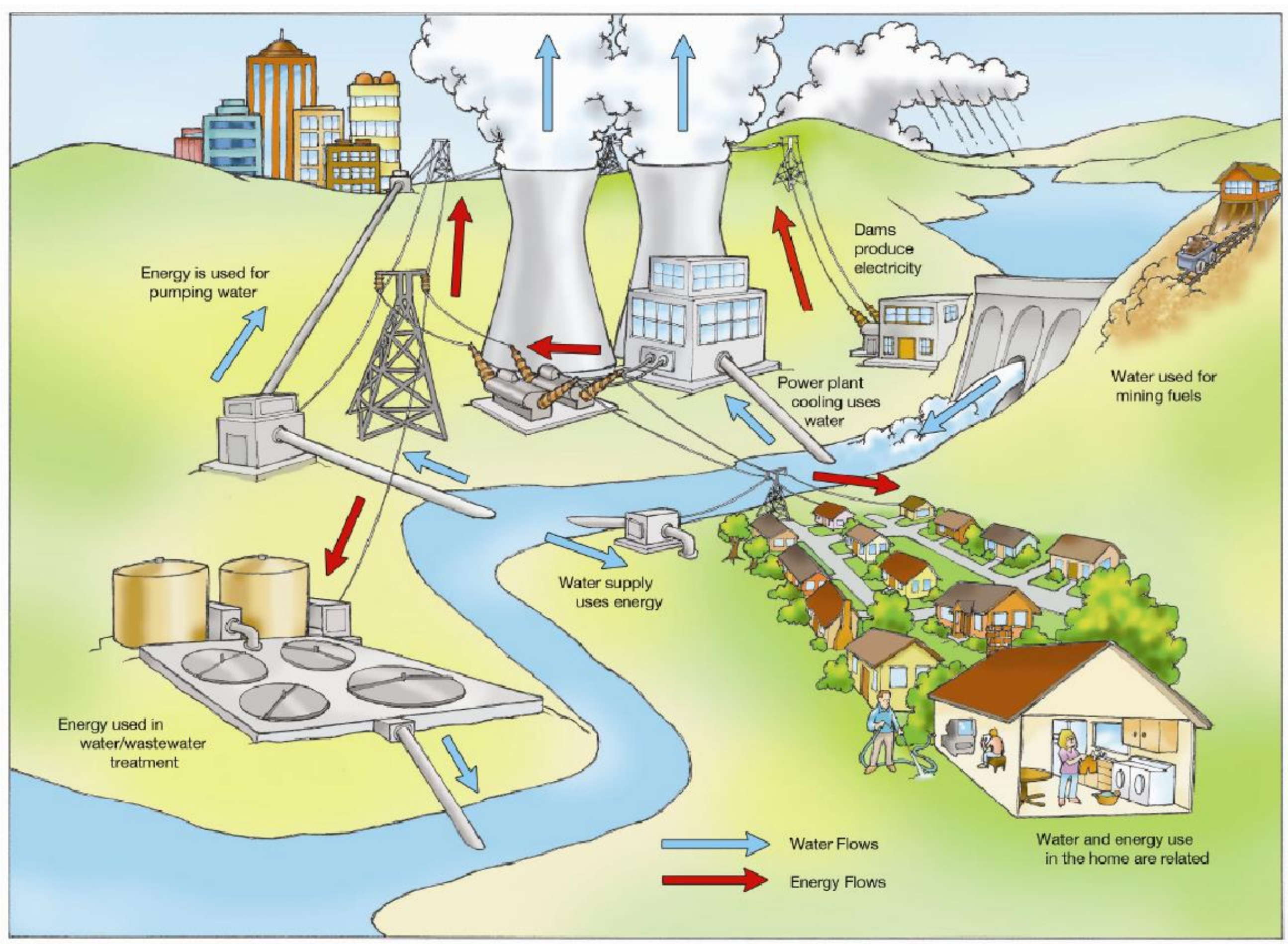
Figure 7.4 Location of Water Cooled and Hydroelectric Power Generating Facilities in 2018



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.

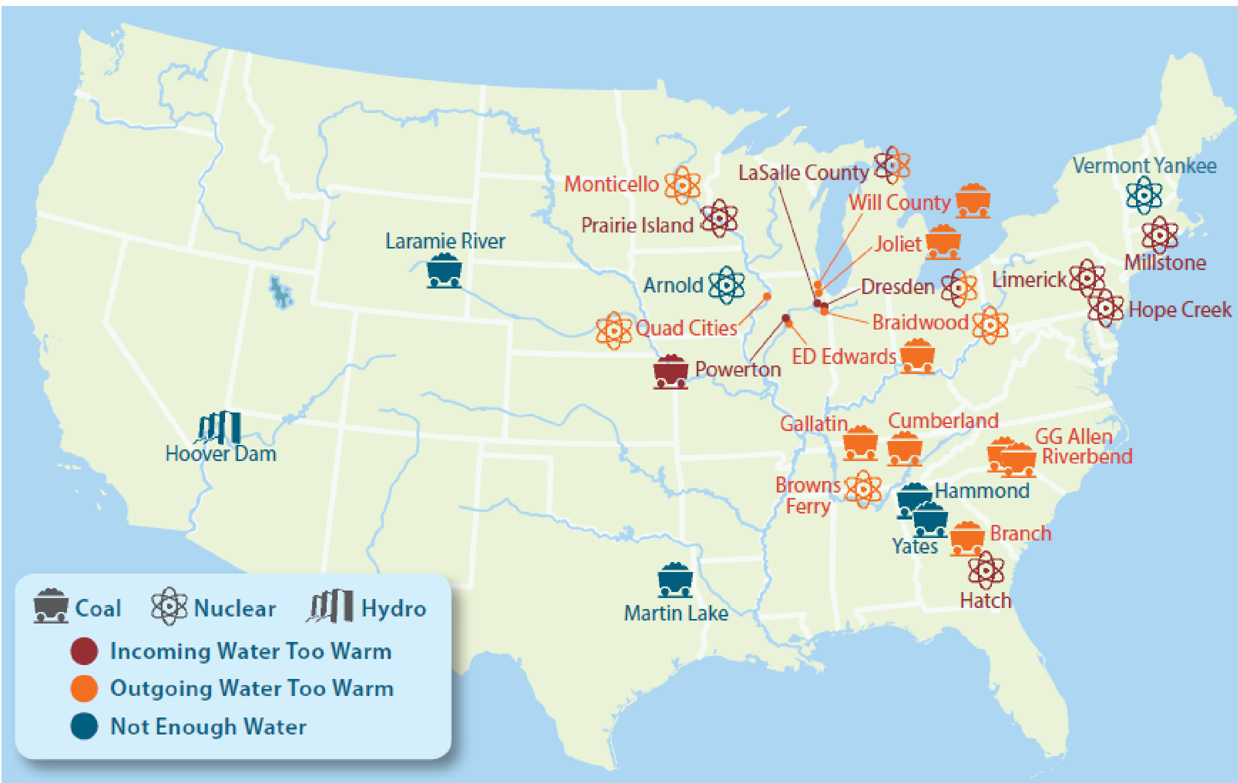
In their analysis, hydropower generation was curtailed based on historical drought operations. Thermal power plants were cut back in areas designated as undergoing a moderate or more severe drought. Based on this analysis, 3,284 MW of power were identified for possible drought curtailment. Under drought 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

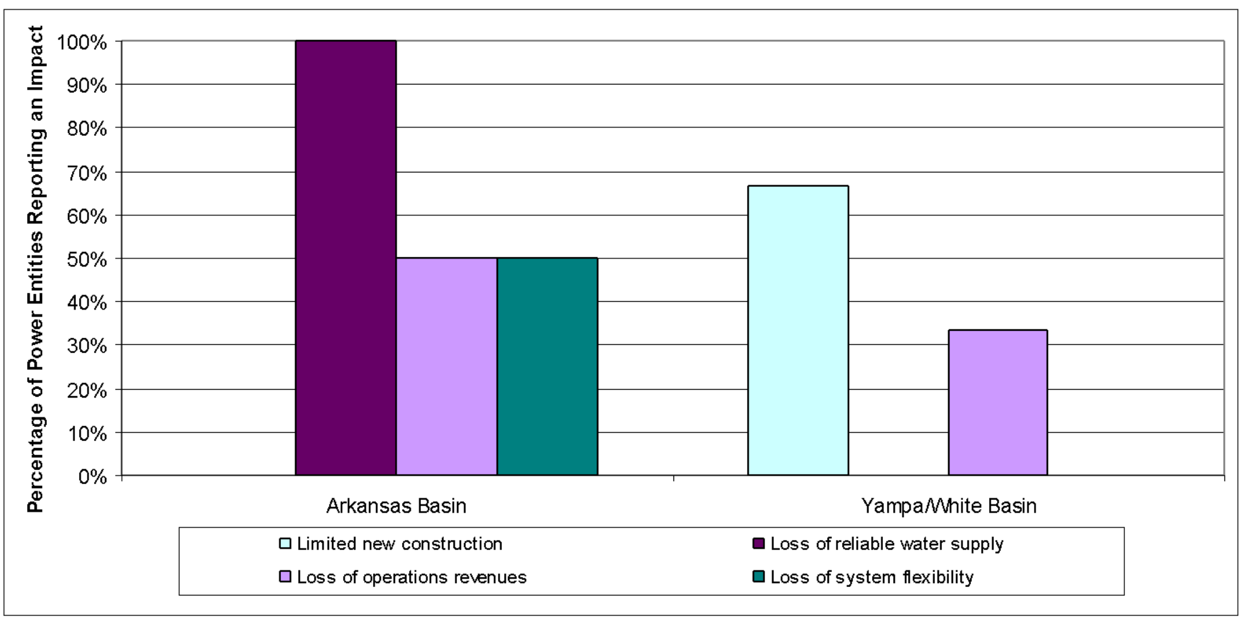
Energy specific drought vulnerability analyses have not been conducted specifically for Colorado. However, there are several studies that address drought and water supply planning in the State that are relevant. The CWCB conducted a Drought and Water Supply Assessment (DWSA) in 2004 to determine the 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

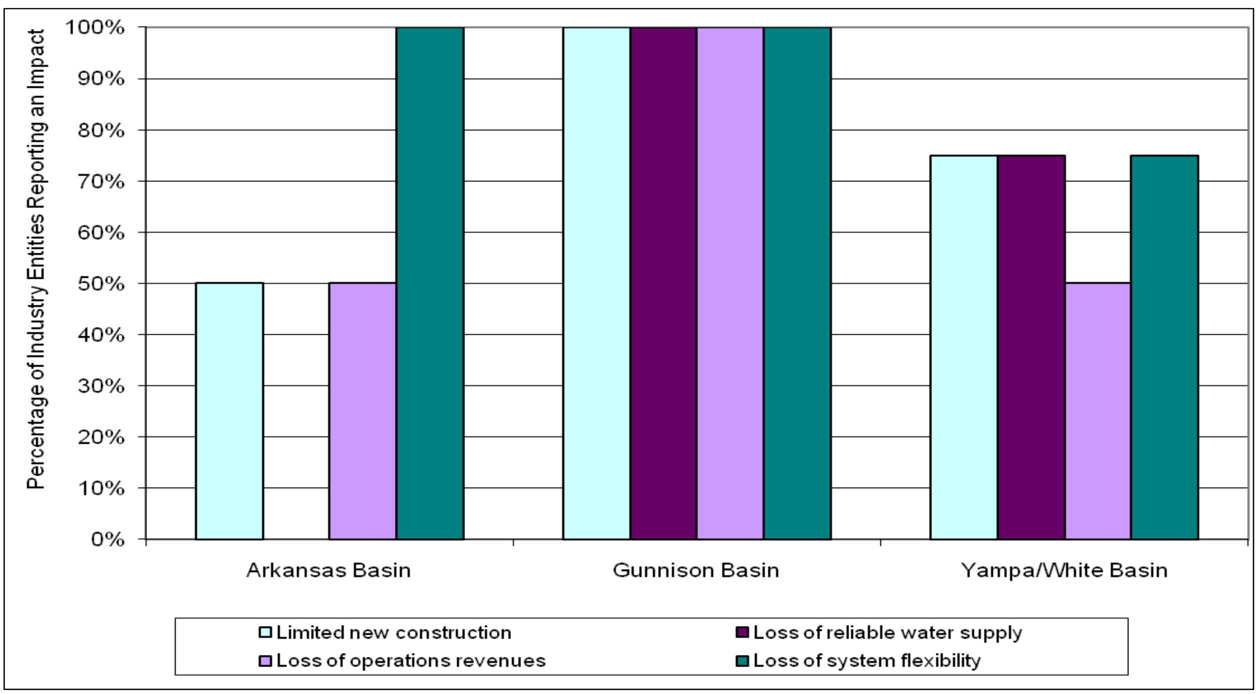


In the Arkansas Basin, both of the power entities surveyed experienced loss of reliable water supply, whereas none of the three entities in the Yampa/White Basin did. Construction was limited in the Yampa/White Basin, and the Arkansas entities felt a loss of system flexibility during this time period. 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 finding 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.

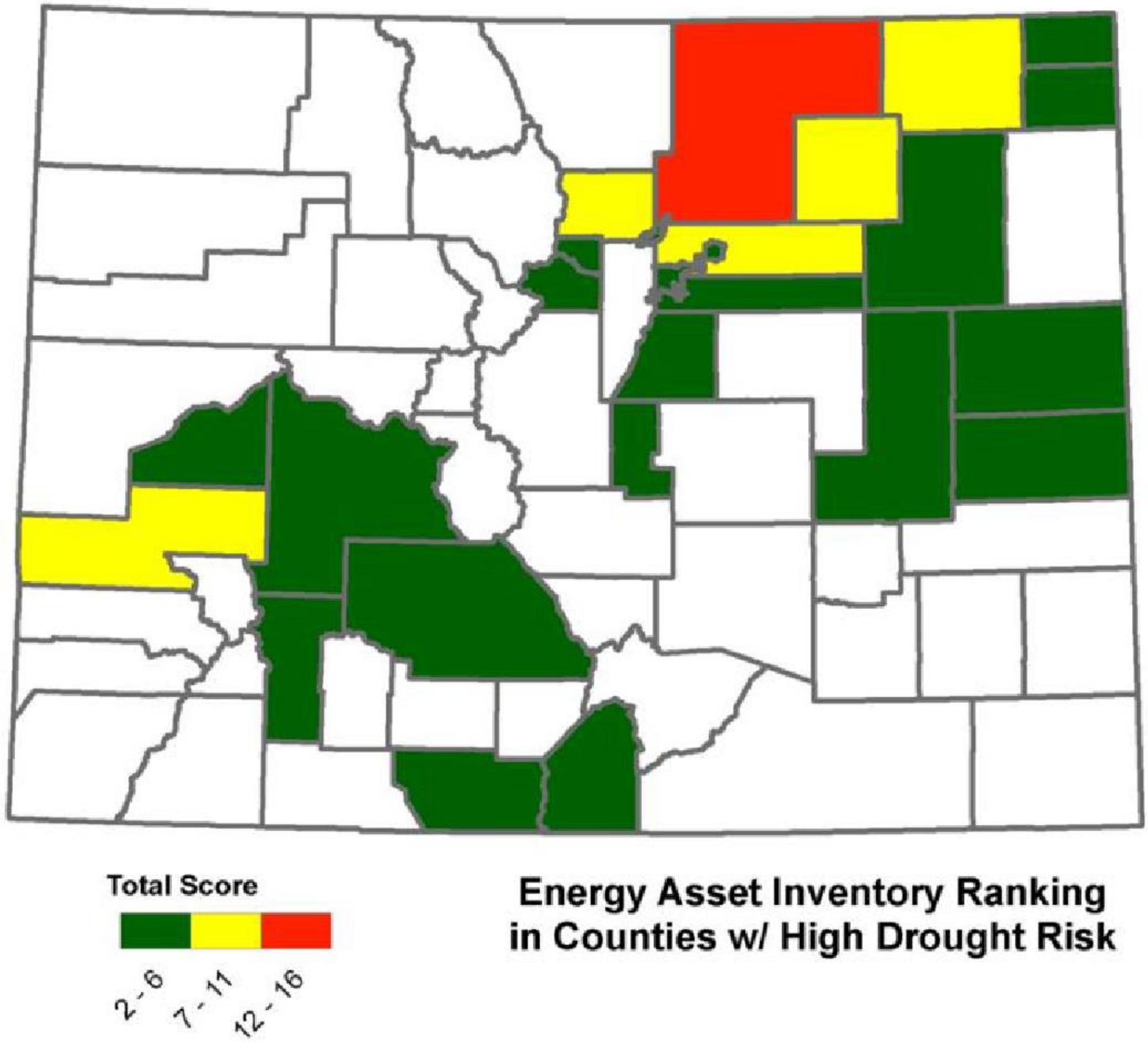
As discussed above, generating capacity can be lost during drought due to decreased water supplies for various processes, namely for thermal power plants and steam turbines. Droughts that occur during the peak summer electrical demand period can produce additional impacts on the energy sector (e.g., 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.

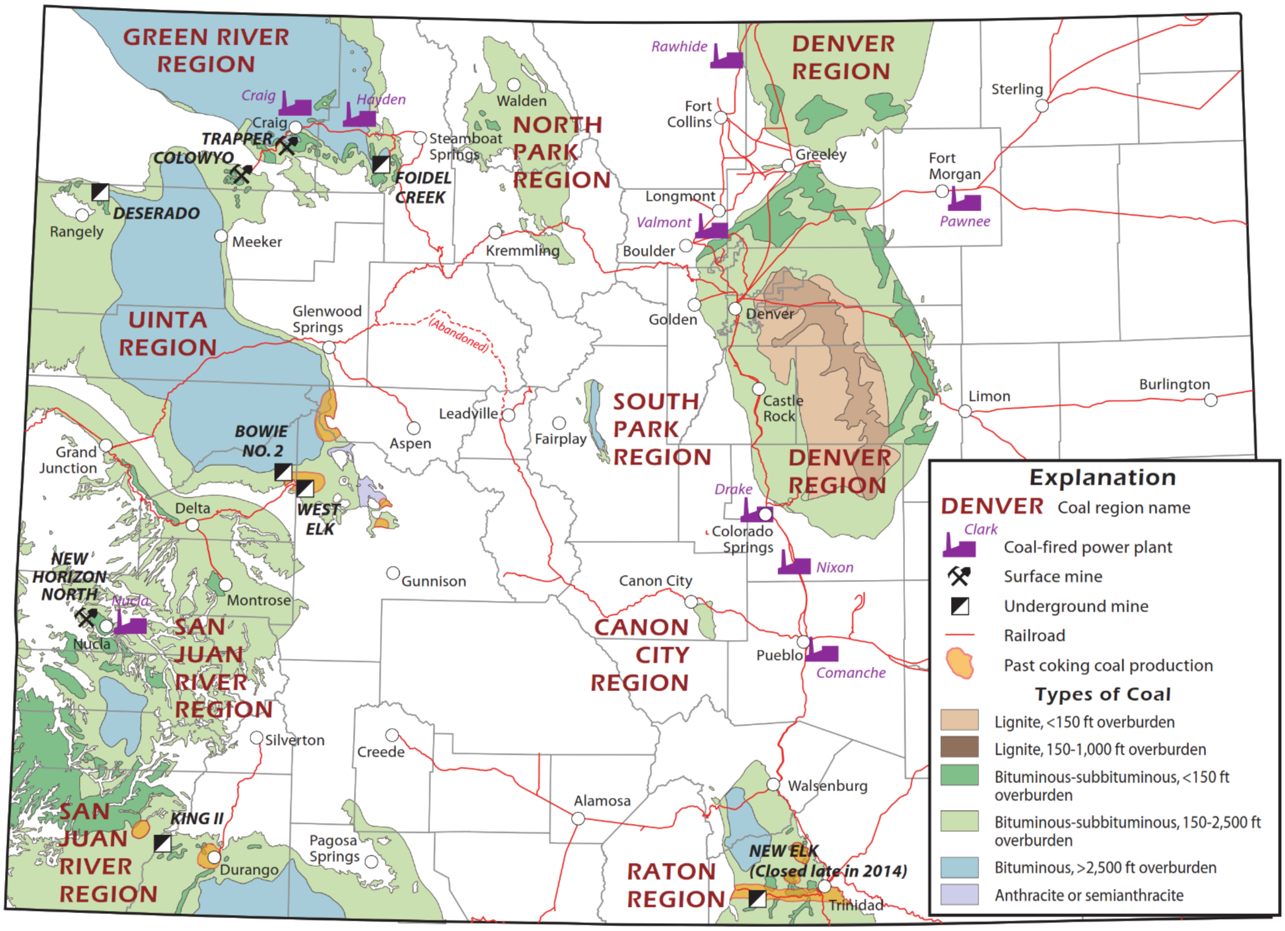
7.3.1 Potential Impacts and Adaptive Capacities of Mining

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

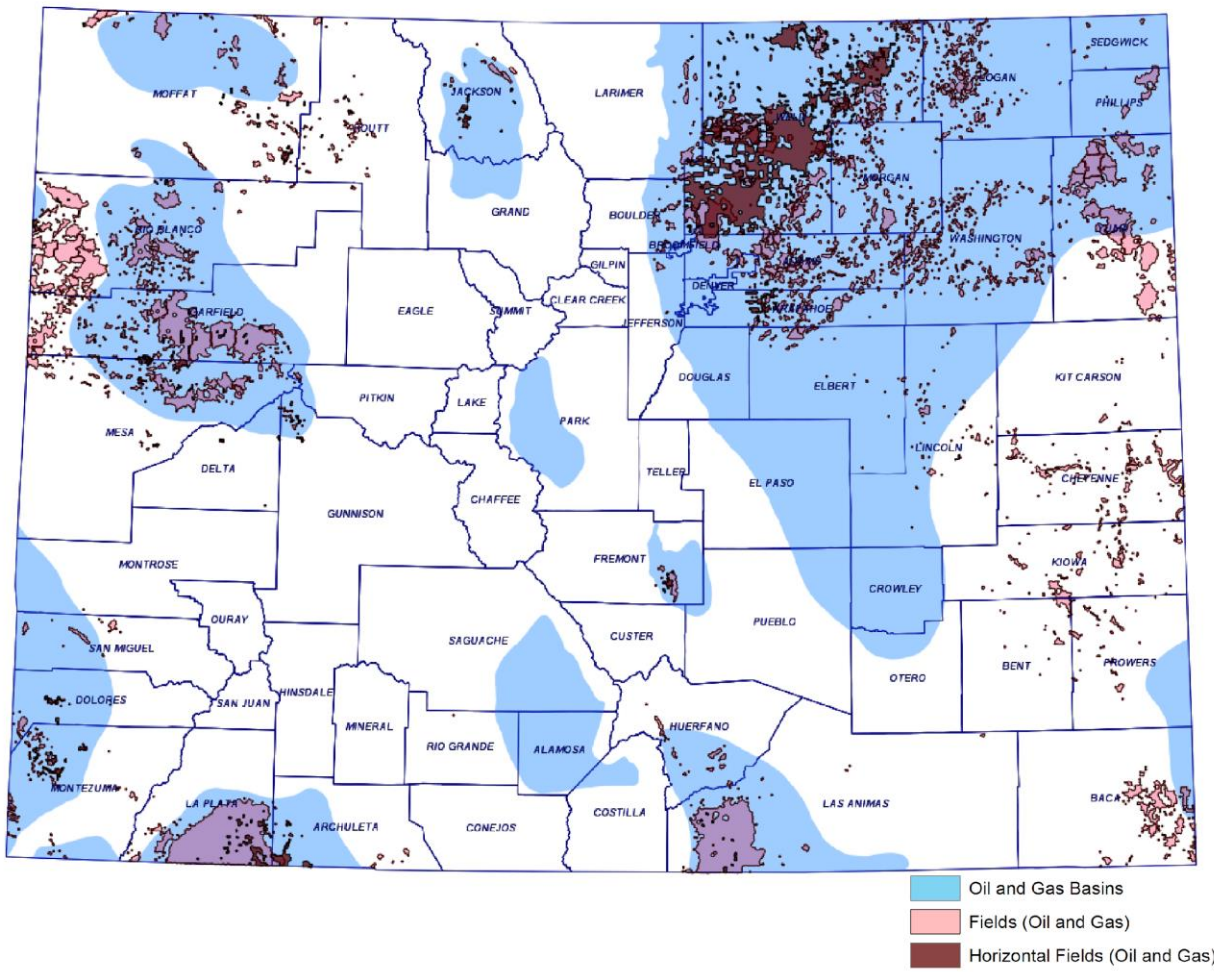


Source: Colorado Geologic Survey, 2015
NOTE: The Valmont power plant in Boulder stopped burning coal in 2017. Other gas-fired generation at the plant continues as of 2018.

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).

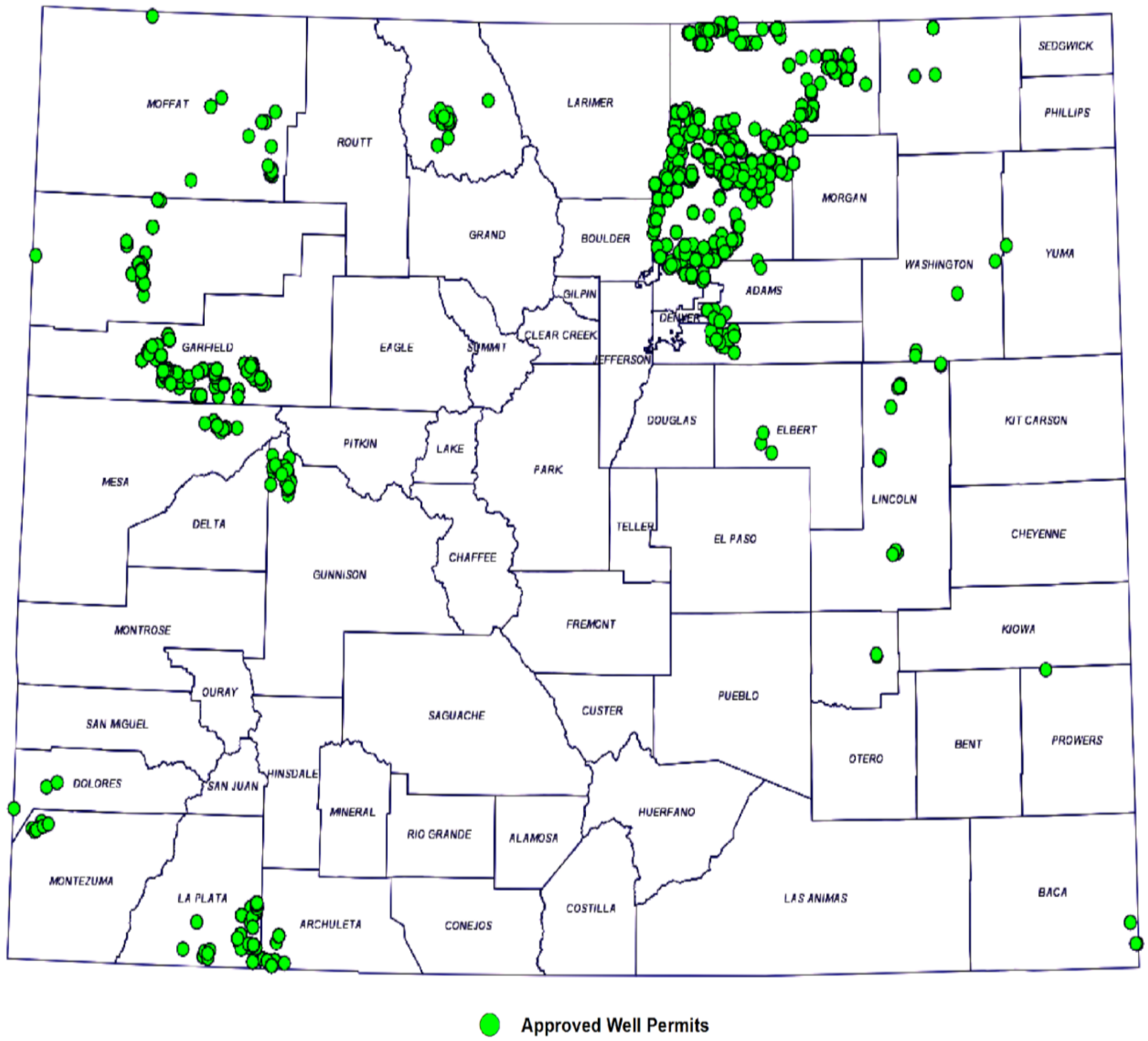
Oil and natural gas production tends to be a net producer of water. Coalbed natural gas production in the San Juan Basin is about 8 gallons of water per barrel of oil equivalent (boe) (Cameron et al., 2006). Water use for natural gas extraction is negligible. Oil extraction requires 5 to 13 gal/boe, 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



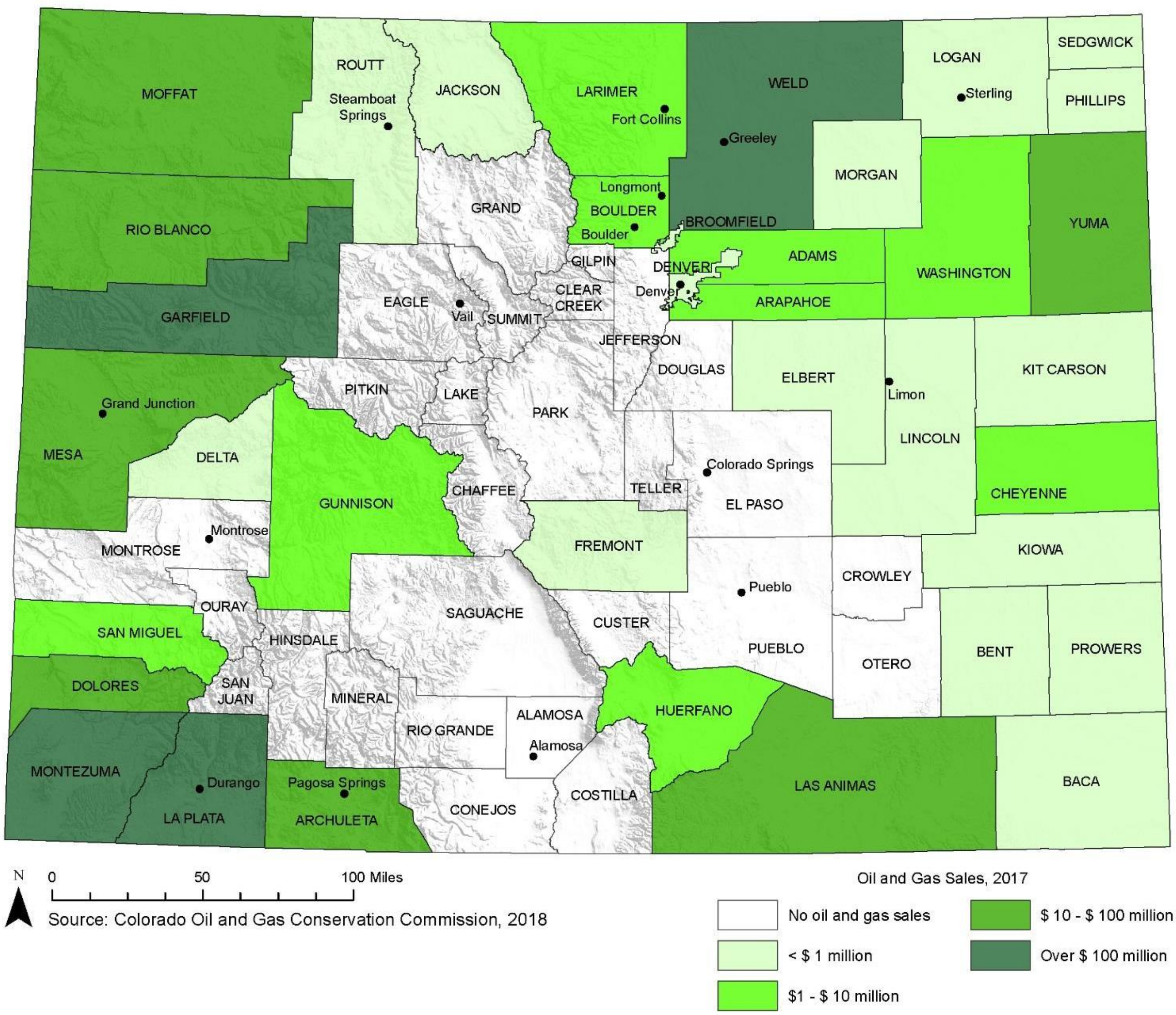
Source: Colorado Oil and Gas Conservation Commission, GIS Online application, 2018

Figure 7.12 Oil and Gas Permit Locations



Source: Colorado Oil and Gas Conservation Commission, GIS Online application, 2018

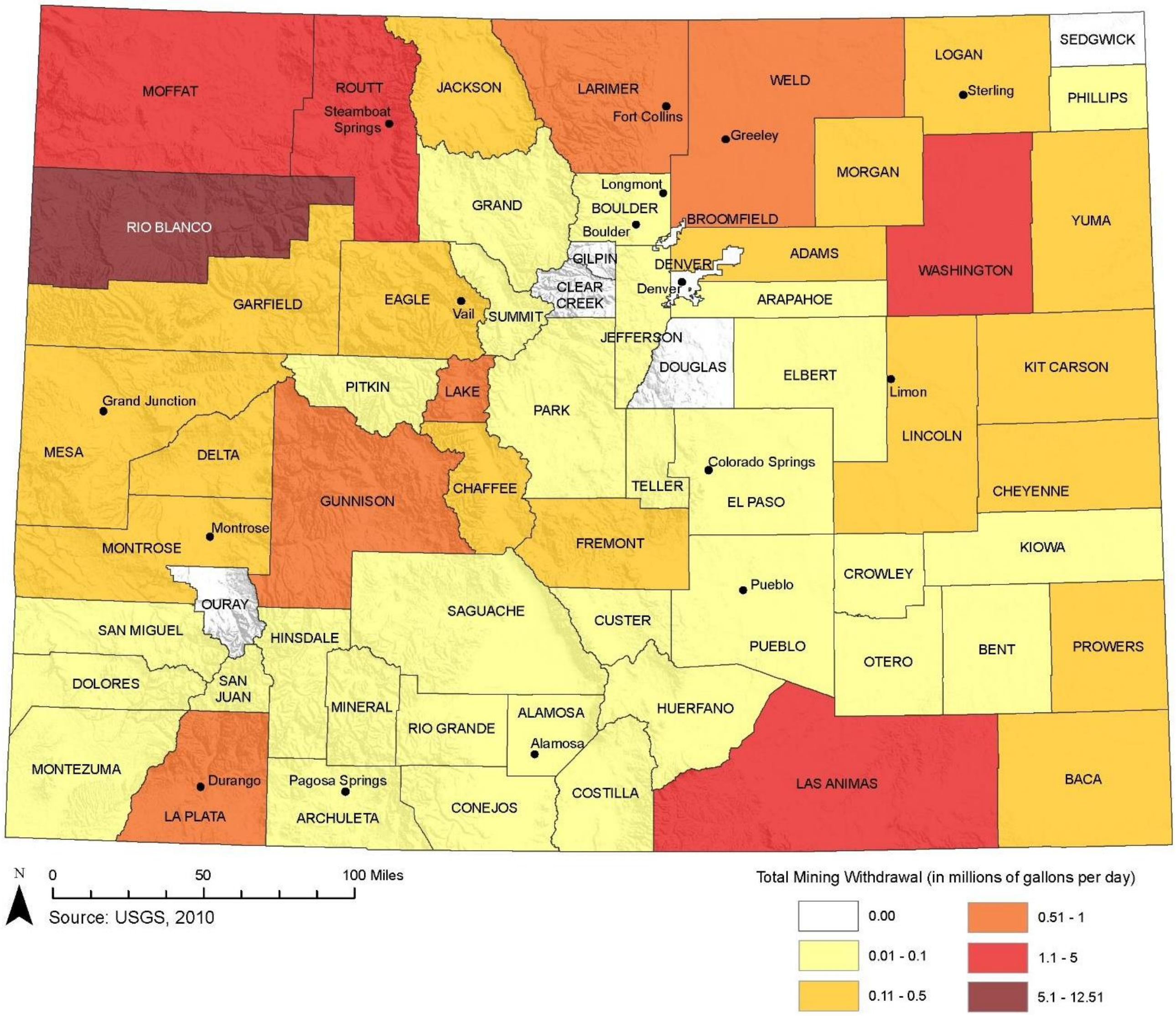
Figure 7.13 Oil and Gas Sales by County



Source: Colorado Oil and Gas Conservation Commission, 2018

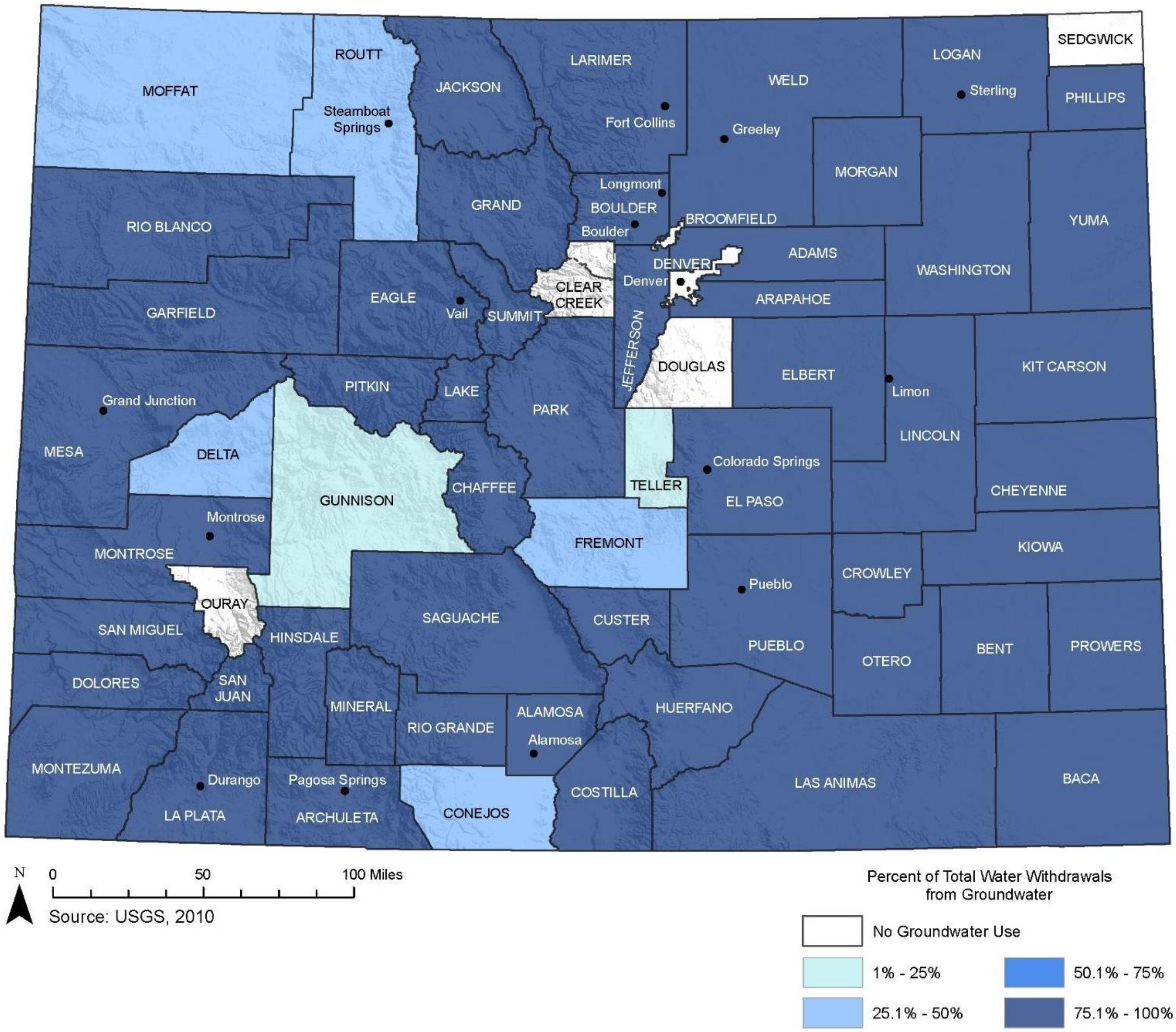
Figure 7.14 shows the total estimated water withdrawals for all mining activity in 2010 (using the most recent data available, from the USGS study published in 2014). Water use for mining activity is distributed across the State but generally higher along the northern edge. Figure 7.15 shows the proportion 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

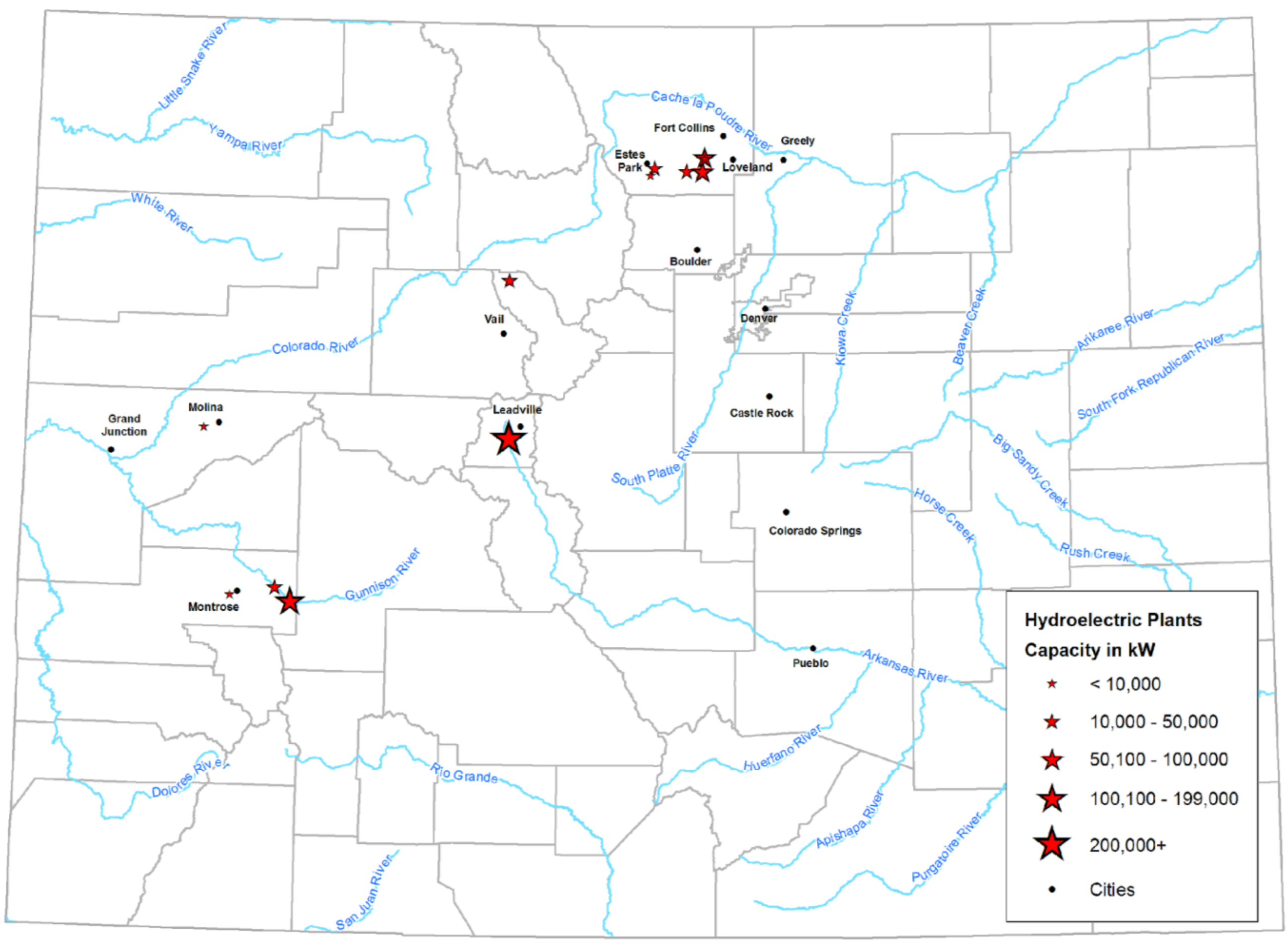
7.3.2 Potential Impacts and Adaptive Capacities of Power Production

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.

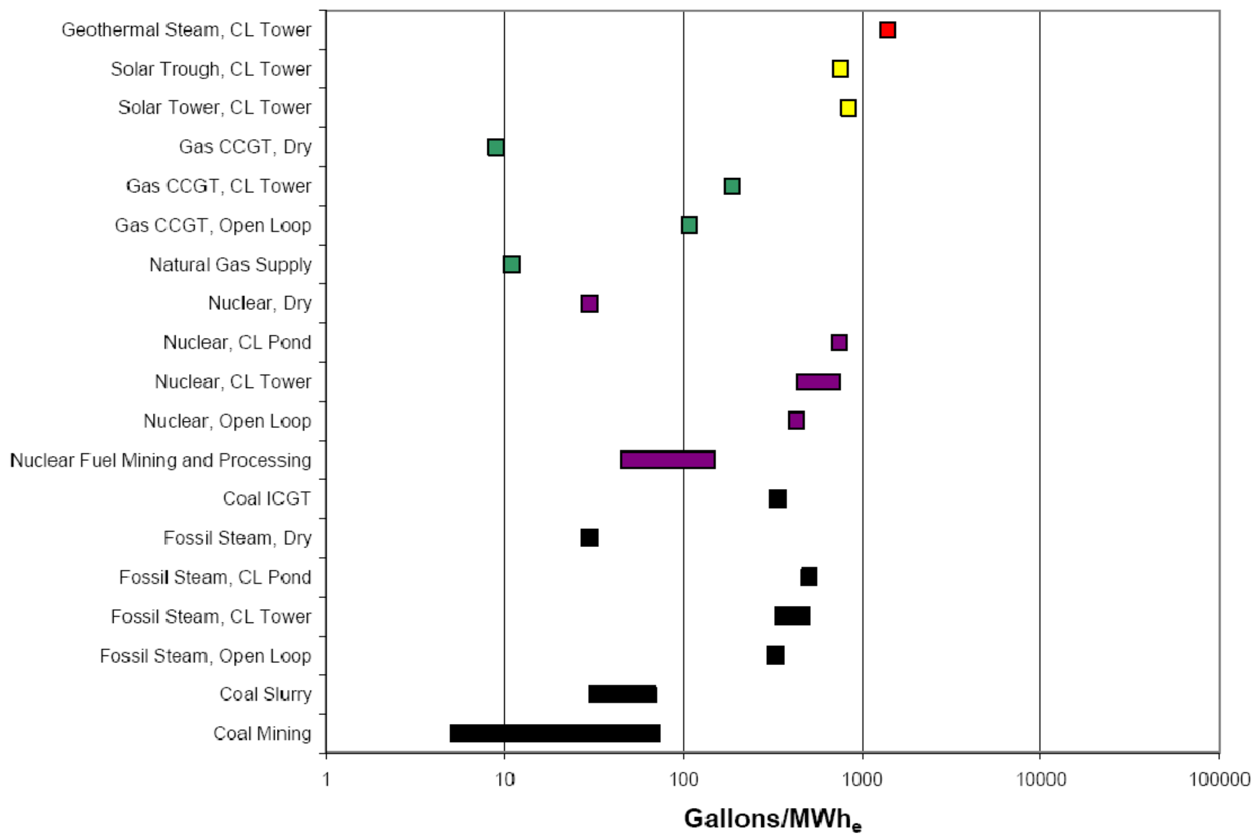
Figure 7.16 Hydroelectric Power Plants 2017



Source: U.S. Bureau of Reclamation, 2017

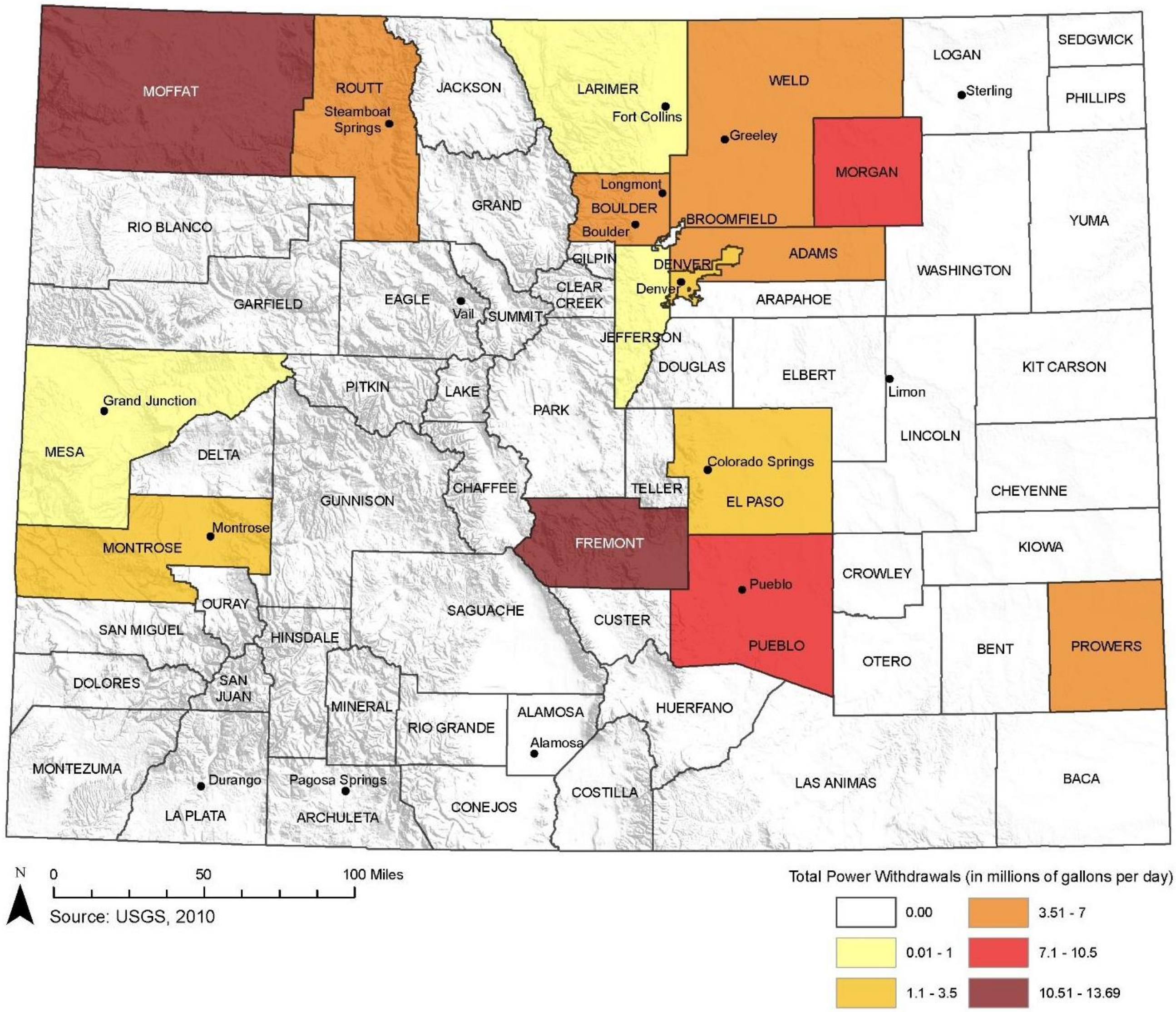
Figure 7.17 shows the water consumption for various power generation methods (where CL stands for 'Closed Loop'). This shows that closed-loop cooling methods generally have the highest consumption rates. Figure 7.18 displays total water withdrawals used for power production by county in. This map shows 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.

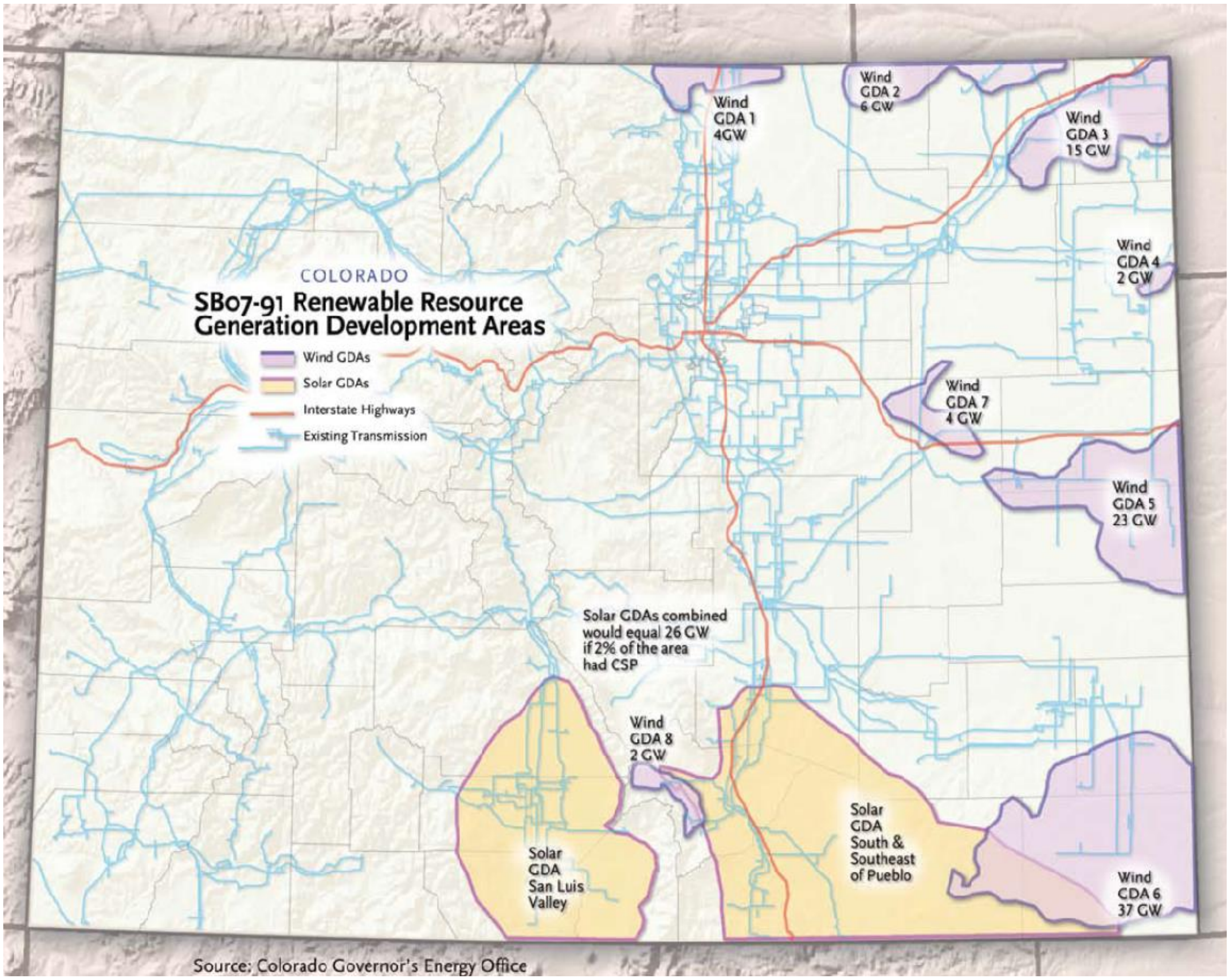
Colorado has experienced steady growth in the renewable energy industry, particularly wind energy, since 2005. Despite the economic hardships in recent years that were coupled with lower electrical demand, new systems have come online, and wind resources (being the largest percent of renewable generation) 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



Source: Colorado Energy Office 2009

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 Office[1] (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

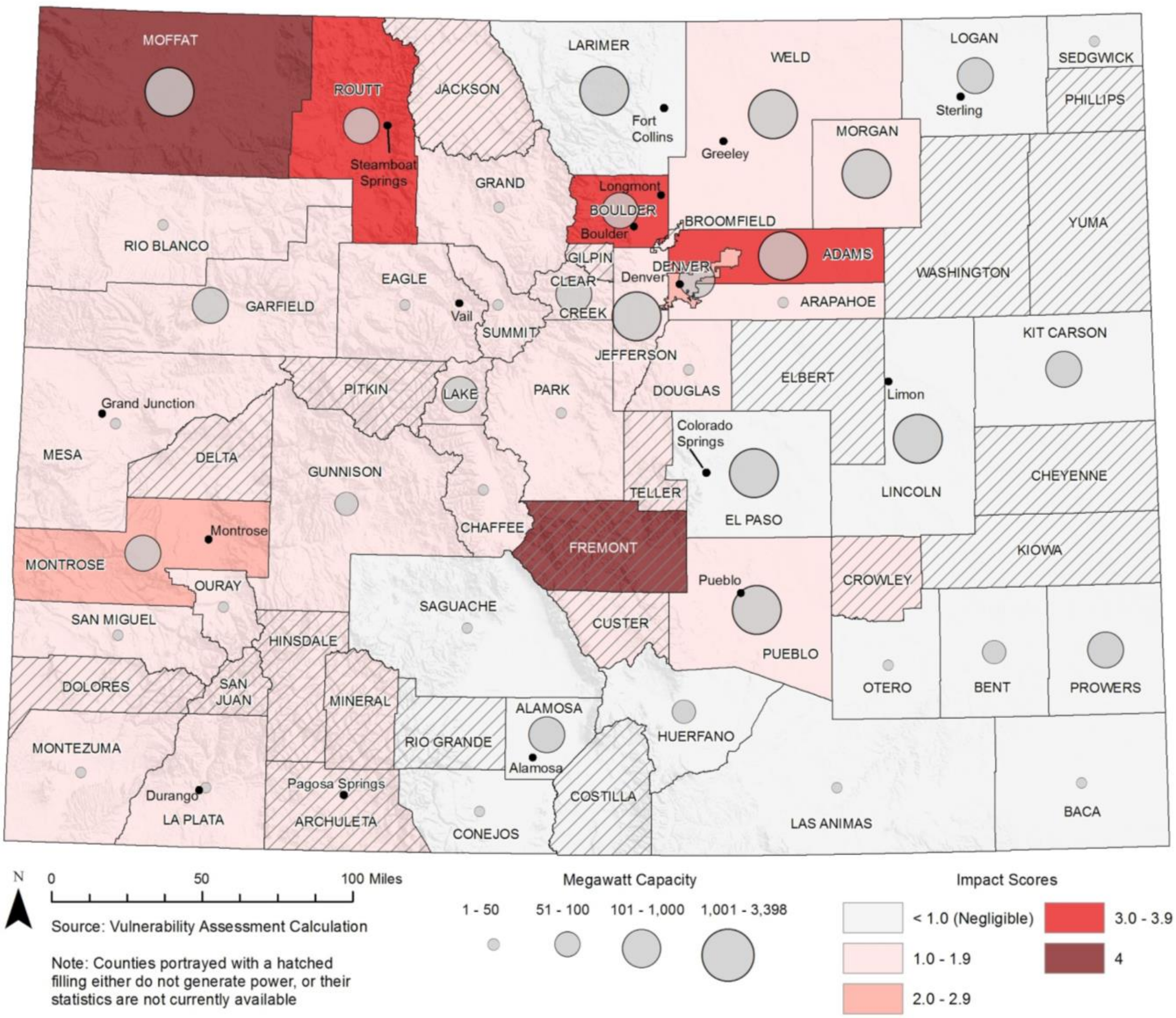


Figure 7.21 Mining Inventory and Impact Scores by County

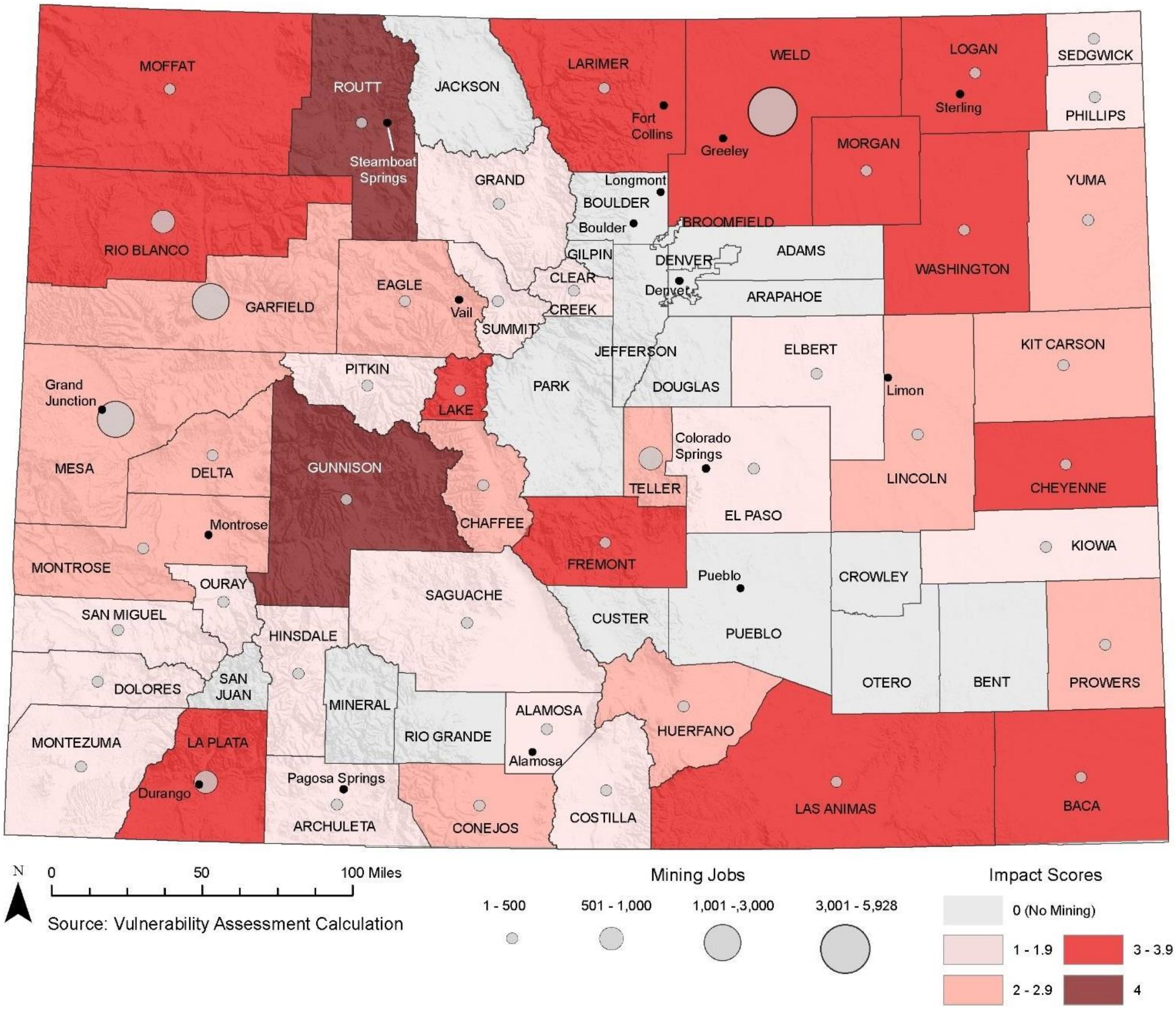
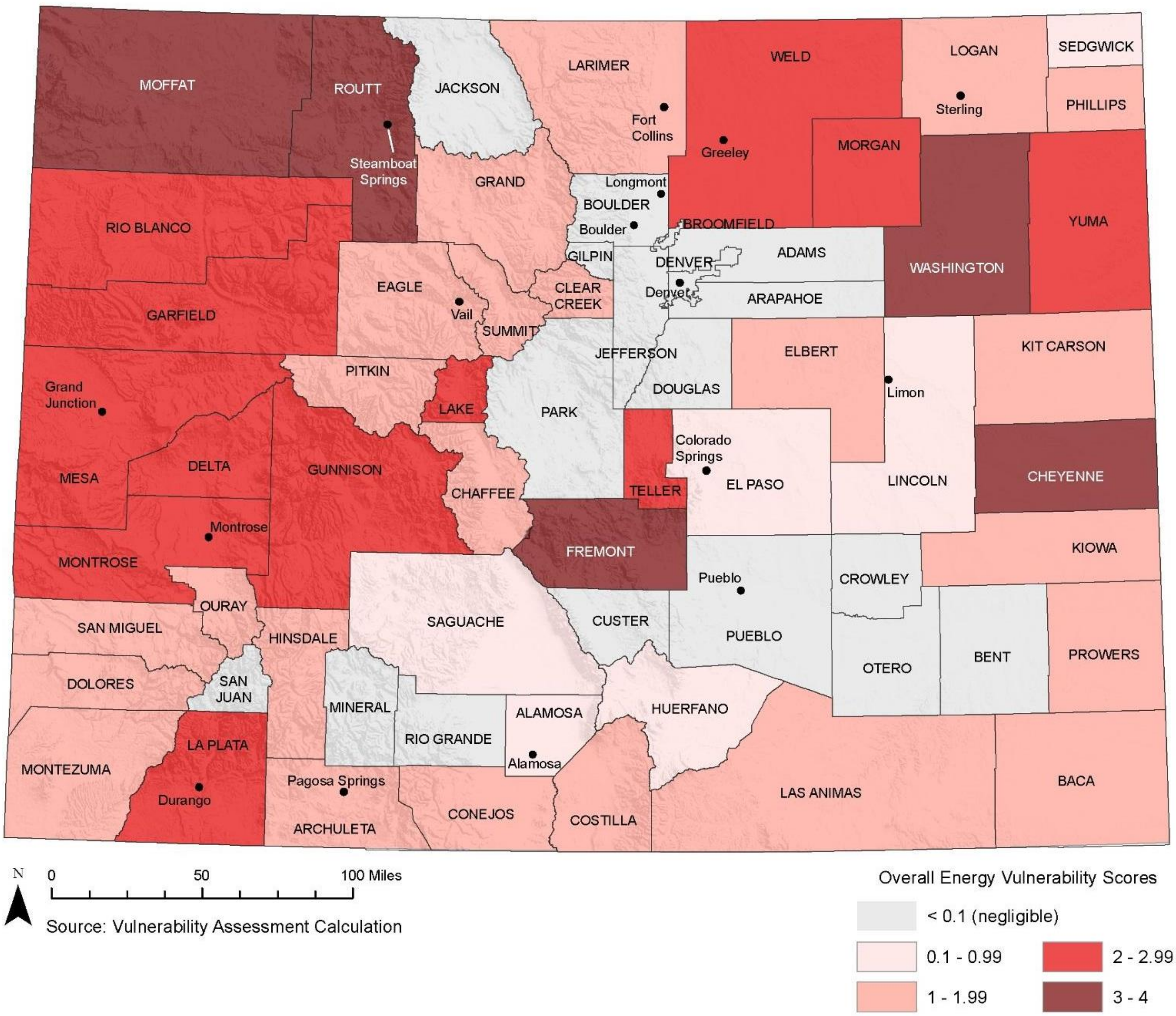


Figure 7.22 Overall Energy Vulnerability by County



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

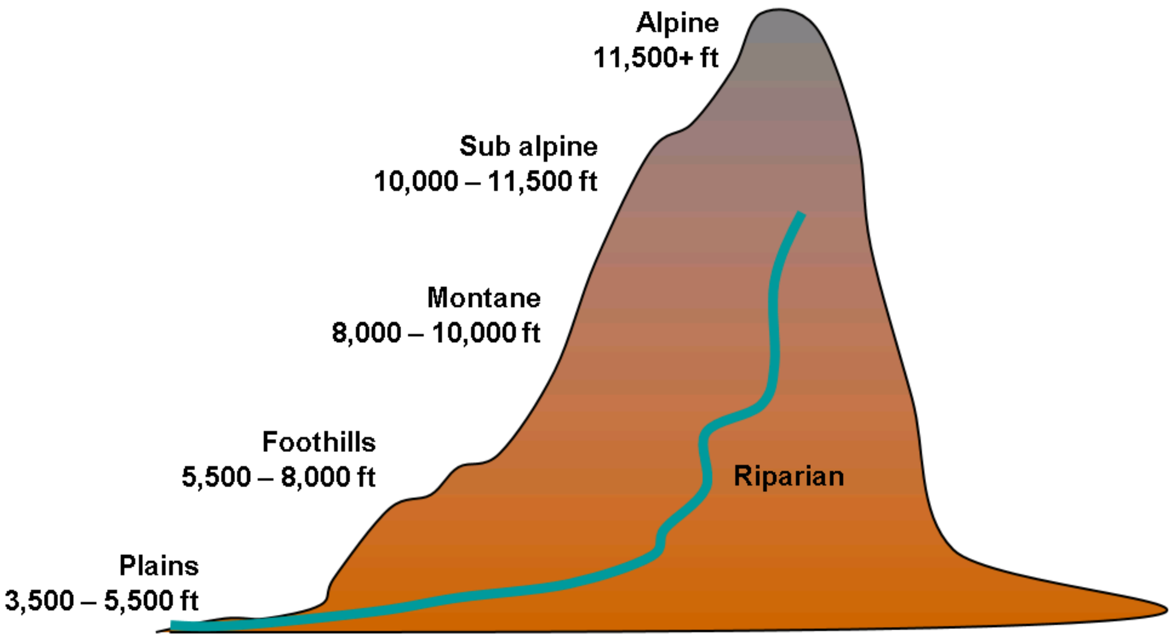
Colorado has an exceedingly diverse environment, with elevations ranging from 3,300 ft. at the Kansas border to over 14,000 ft. in the Rocky Mountains. The State is home to over 960 wildlife species (CPW, 2013) and many more plants, insects, and other organisms.

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.

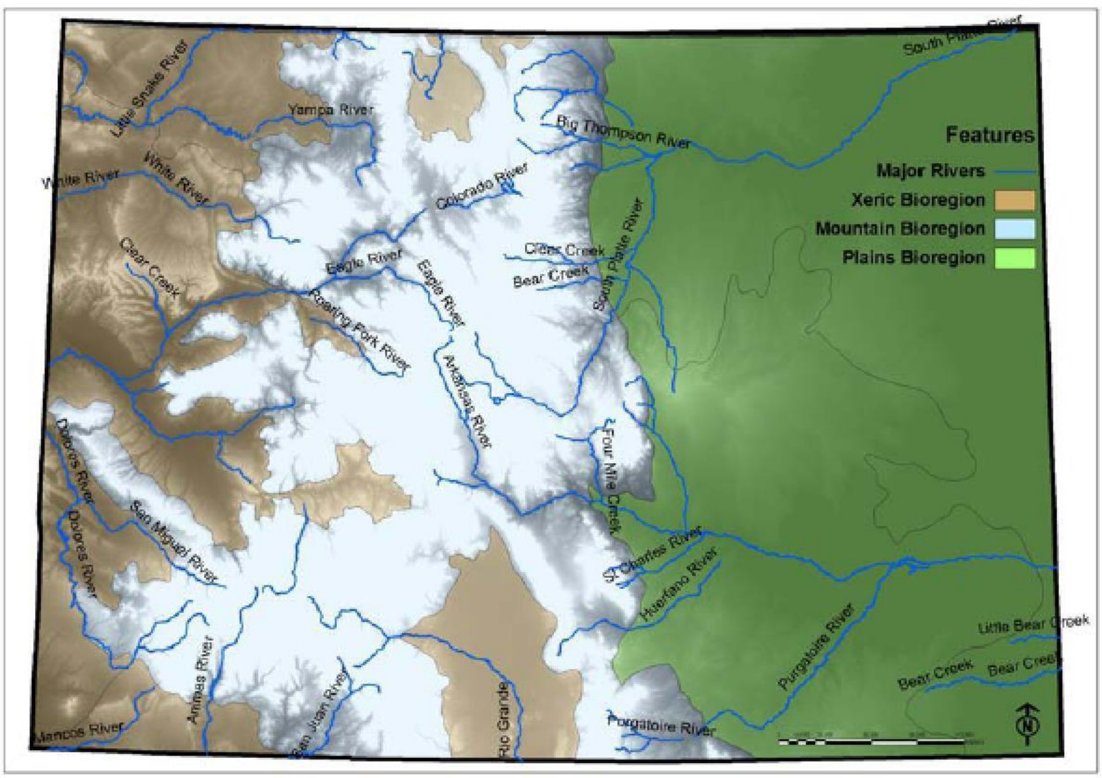
Given the diverse nature of Colorado's environment, accurate analysis is difficult and requires division into assessment categories. Previous work has created ecological groups based on elevation (so-called "life zones"), bioregion, watershed, and forest type, to name a few. Division by major river basins 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



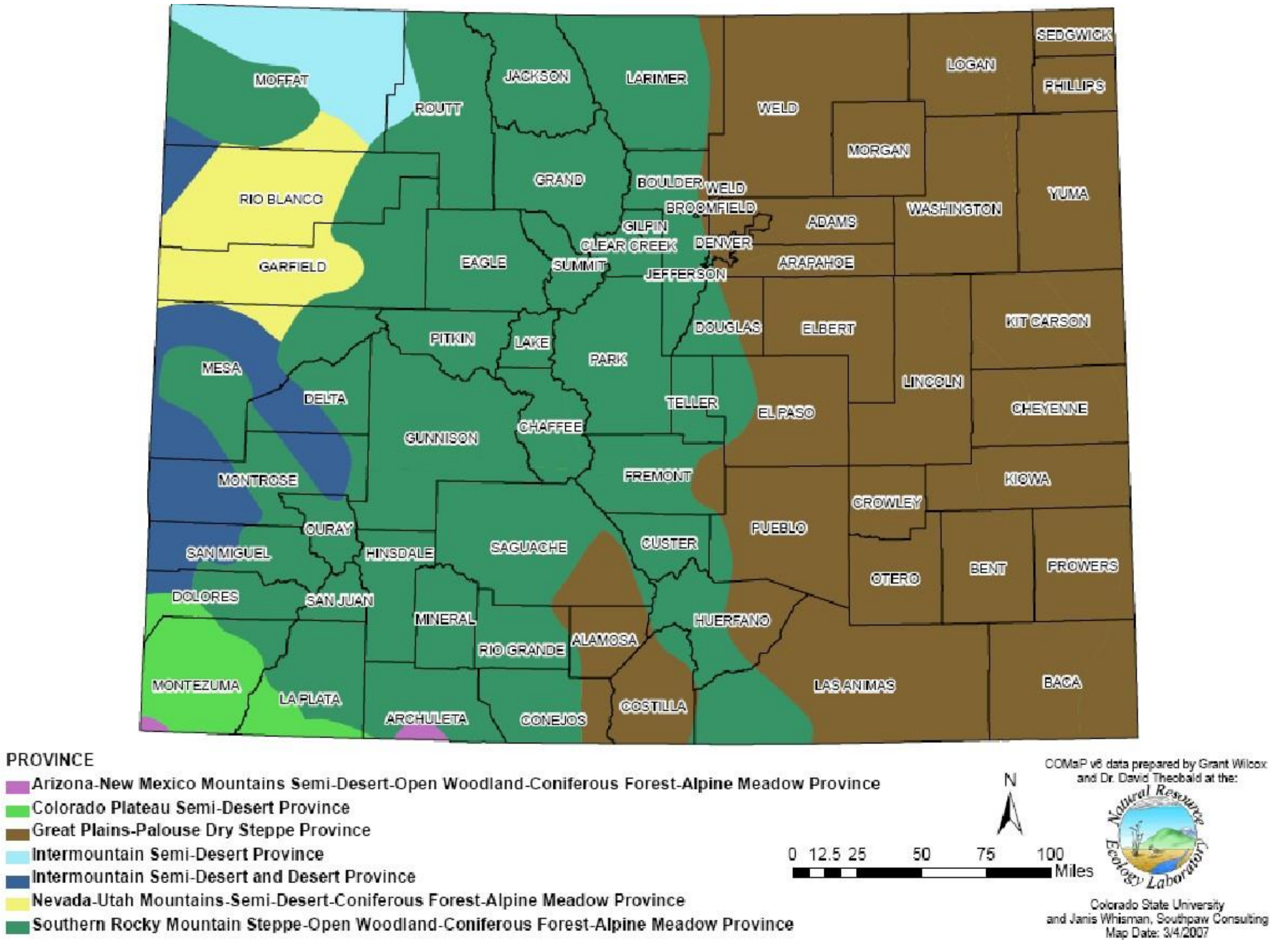
Source: Adapted from NREL 2009

Figure 8.2 Bioregions and Major Rivers



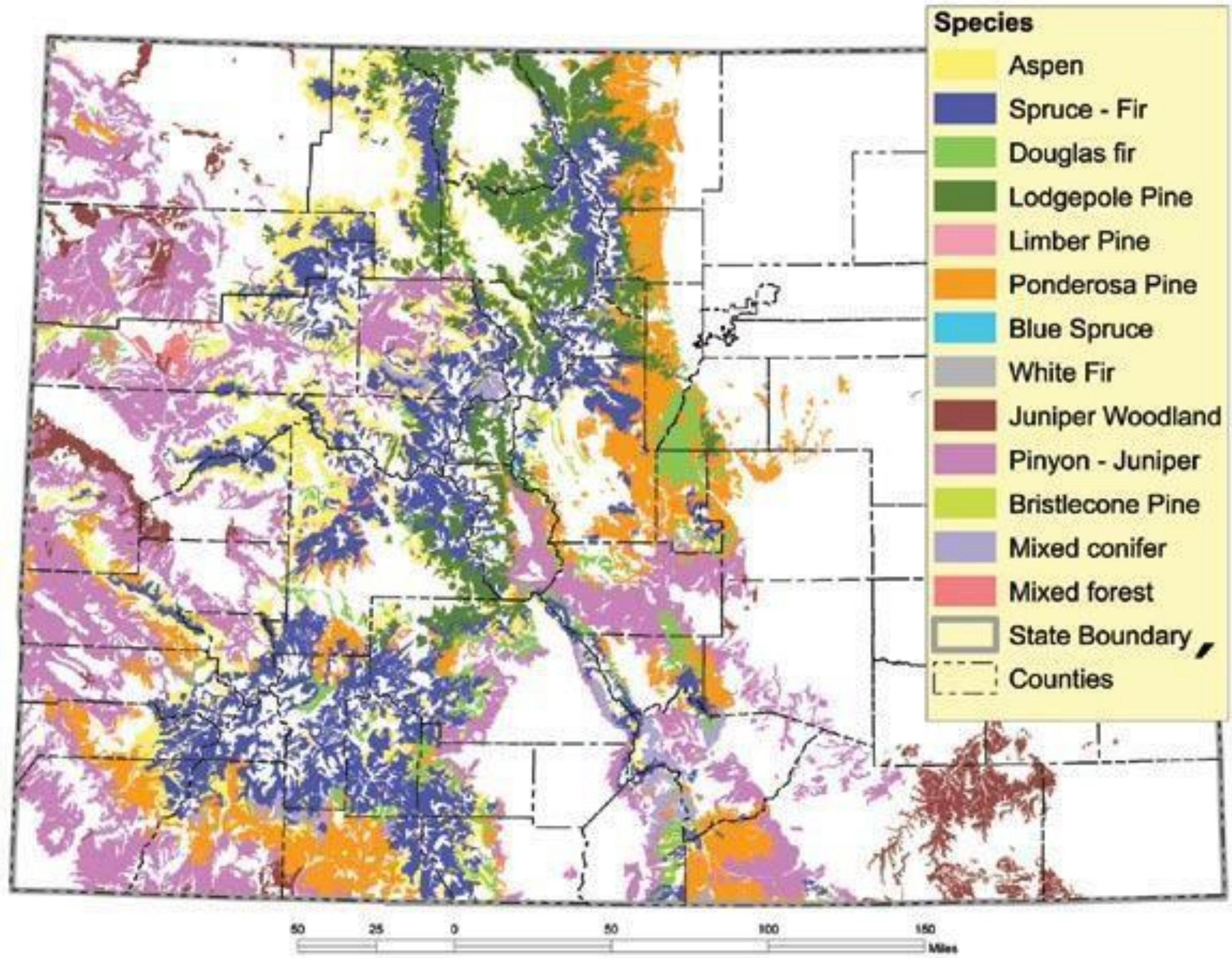
Source: CDPHE 2007

Figure 8.3 Colorado Ecoregions by County



Source: NREL 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. **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. **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.	Holsinger, 2002 DWSA, 2004 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

- 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

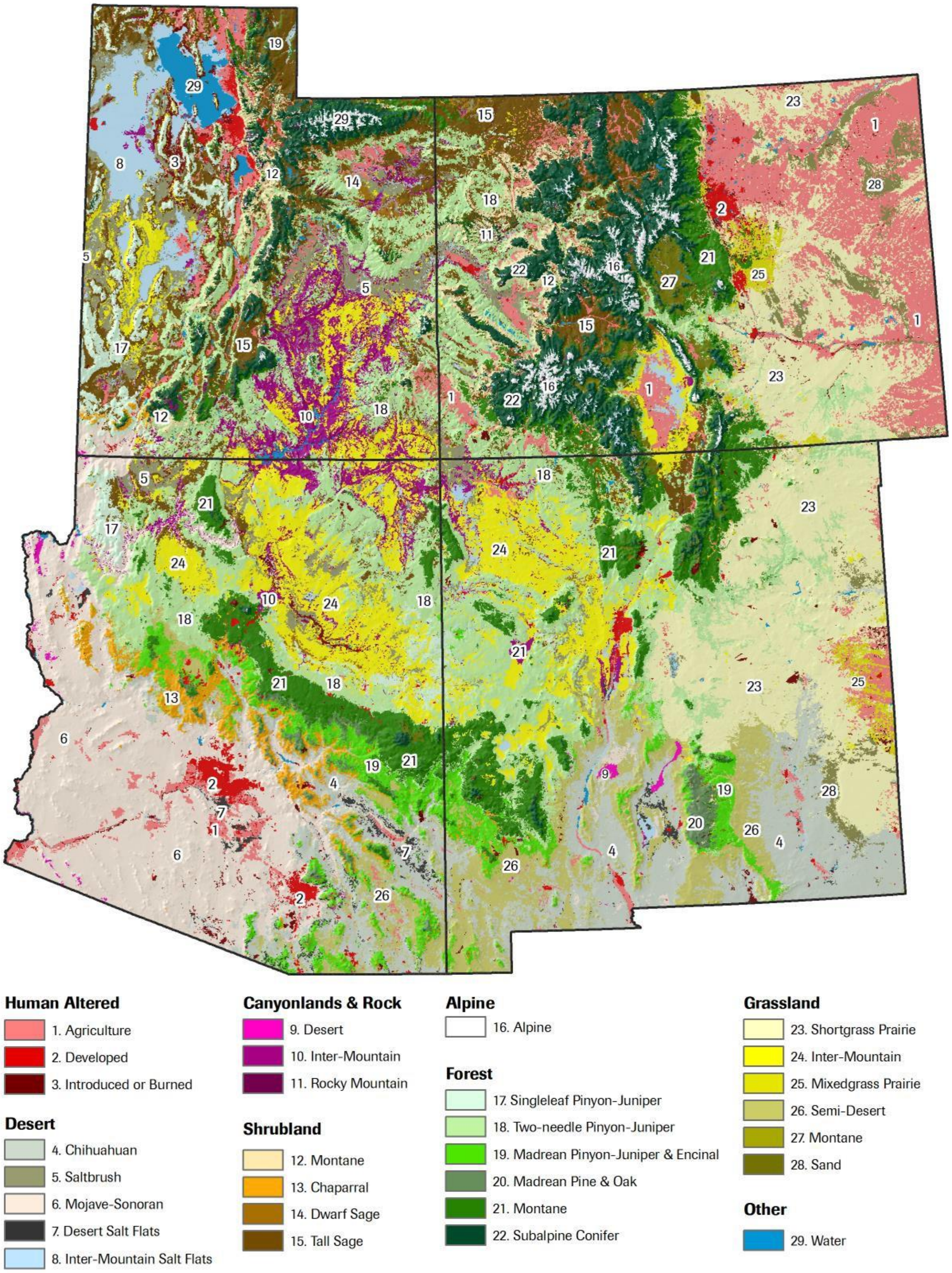
- Wild and Scenic study rivers
- Wildlife viewing
- Yellow mud turtle

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 reginal 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 conflicts[2].

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).

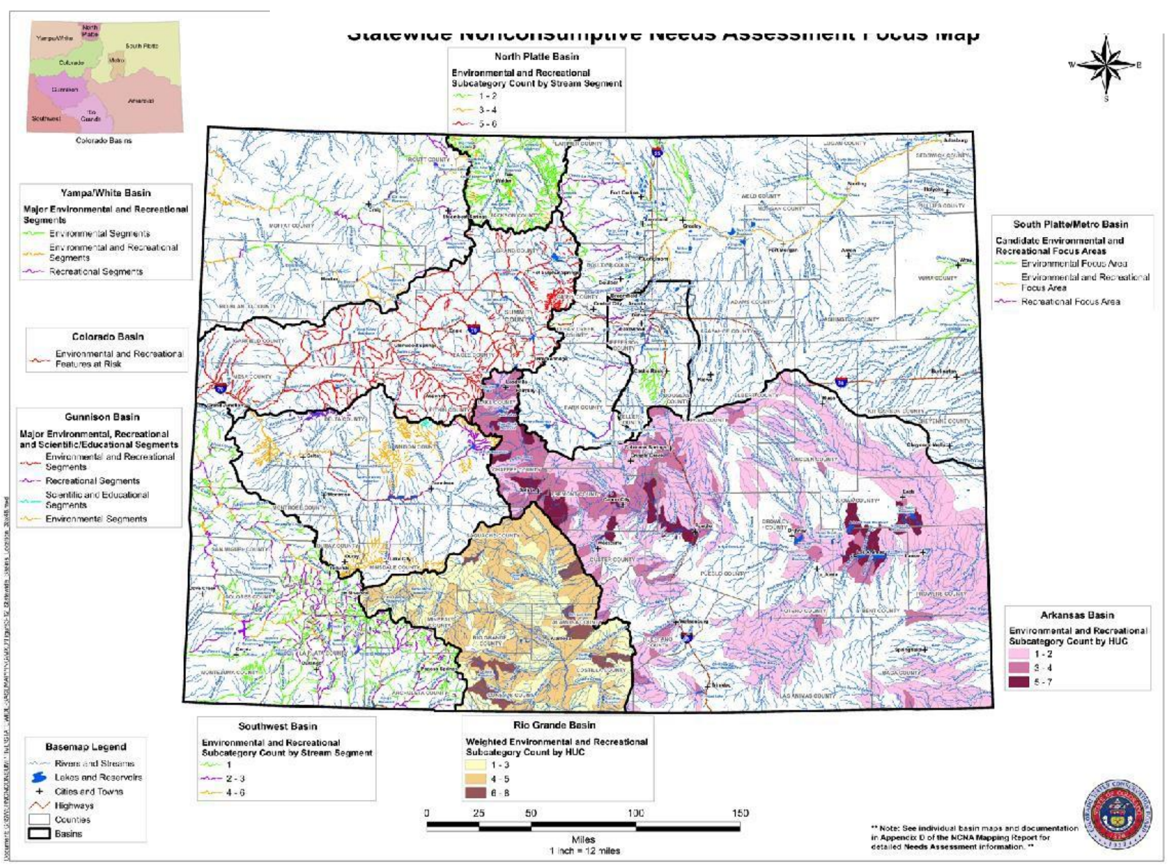
In response to the High Park Fire in 2012, CPW, along with other federal, state and county agencies, participated in the burn area emergency response effort to assess the impacts of the fire on the aquatic habitat and cold-water fisheries of the Poudre River (CPW, 2012).

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 data[4] 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

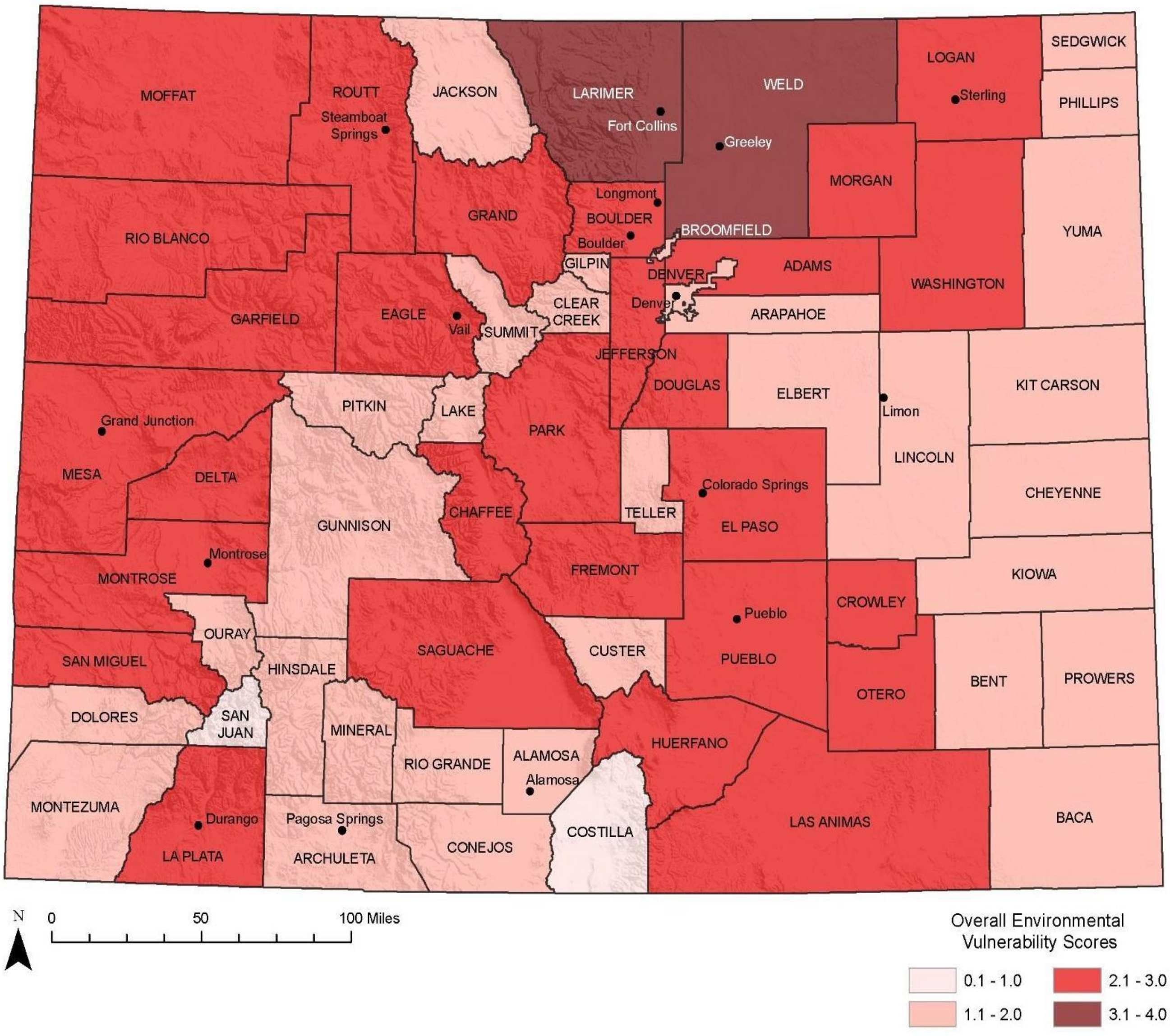
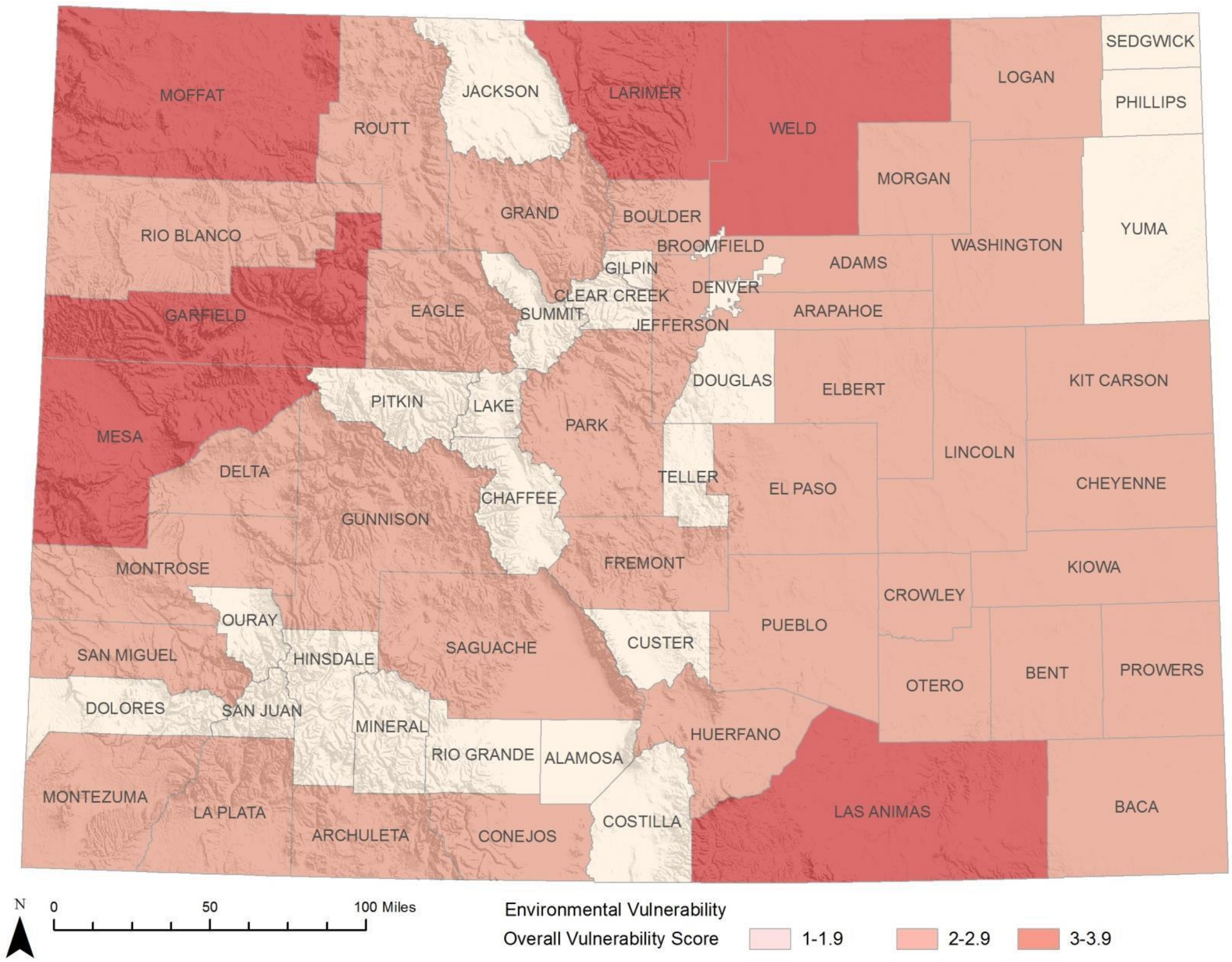


Figure 8.8 Environmental Vulnerability Ranking from 2013 Plan (for comparison)



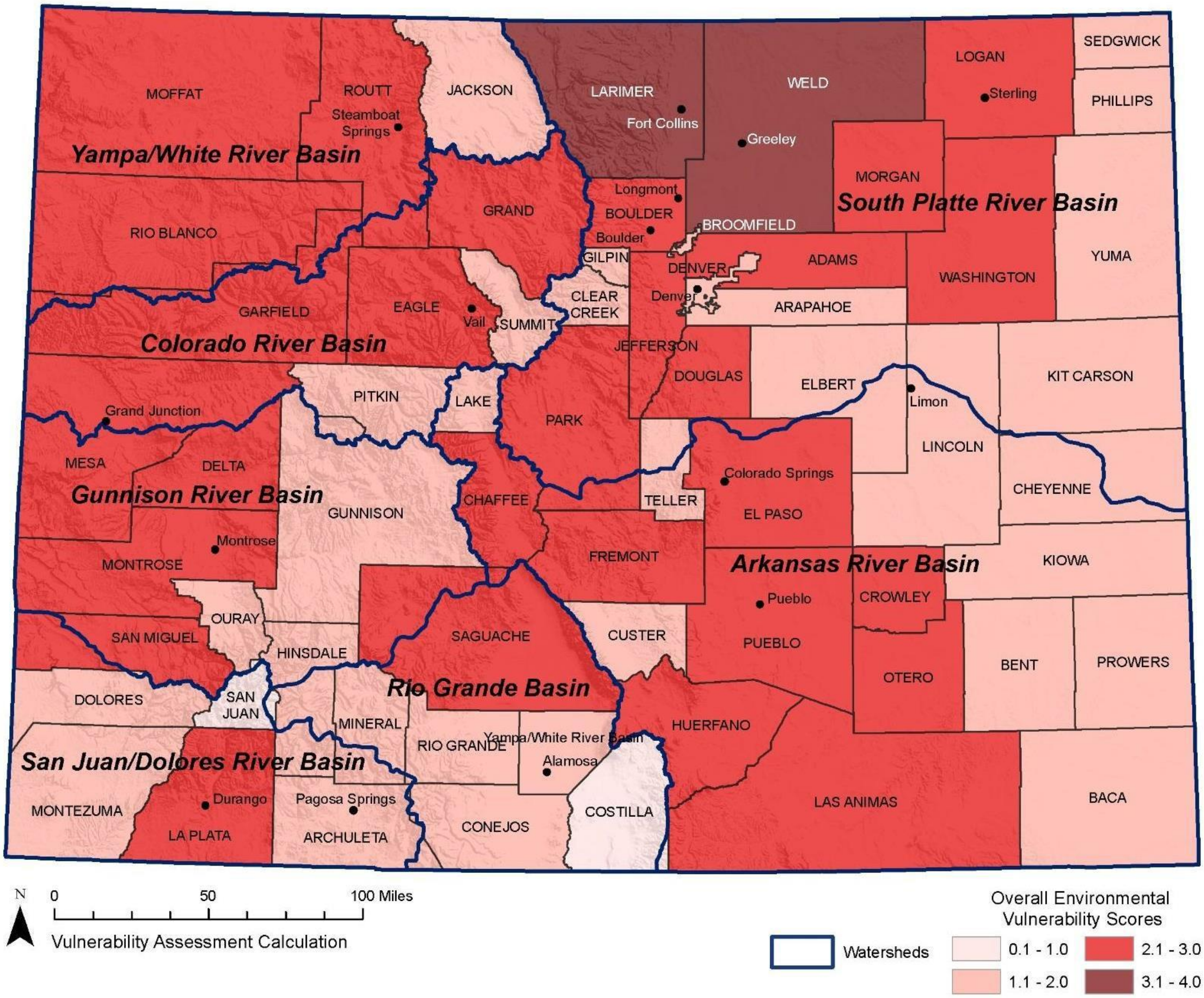
8.5.3 Spatial Analysis

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 NatureServe[5] (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 asses 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 million[2] 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

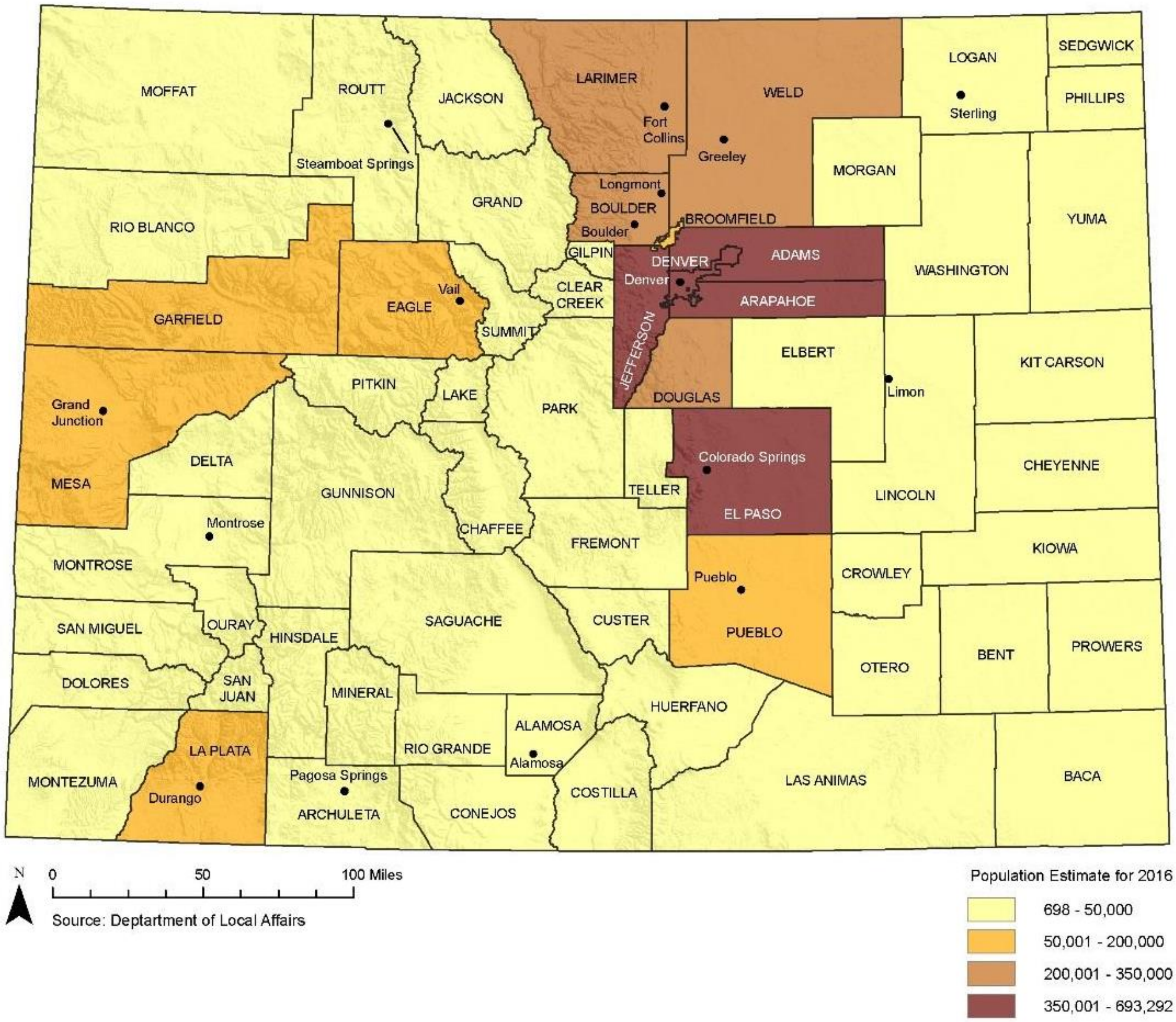
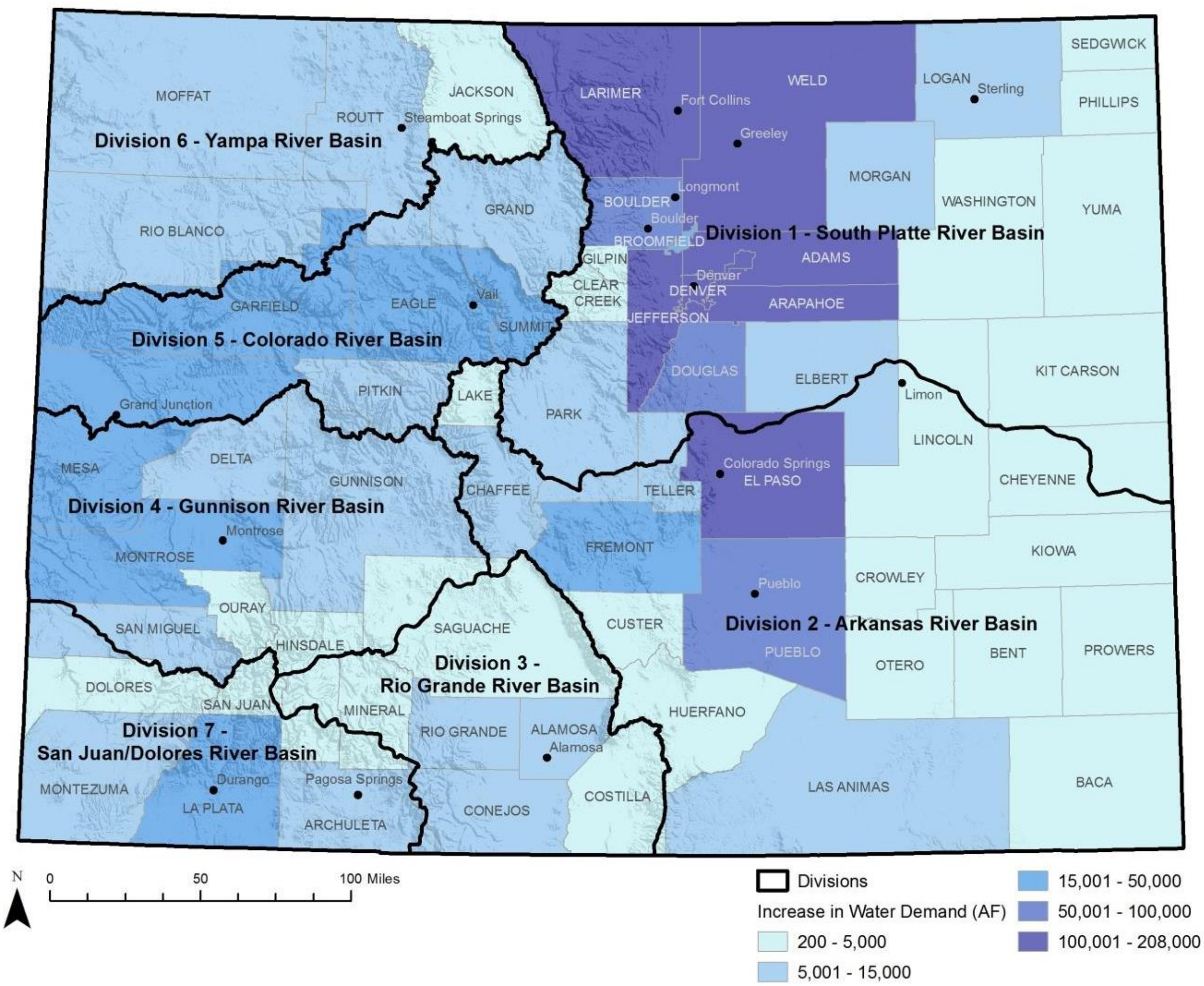


Figure revised for 2018 update.

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 Basins[3]. 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

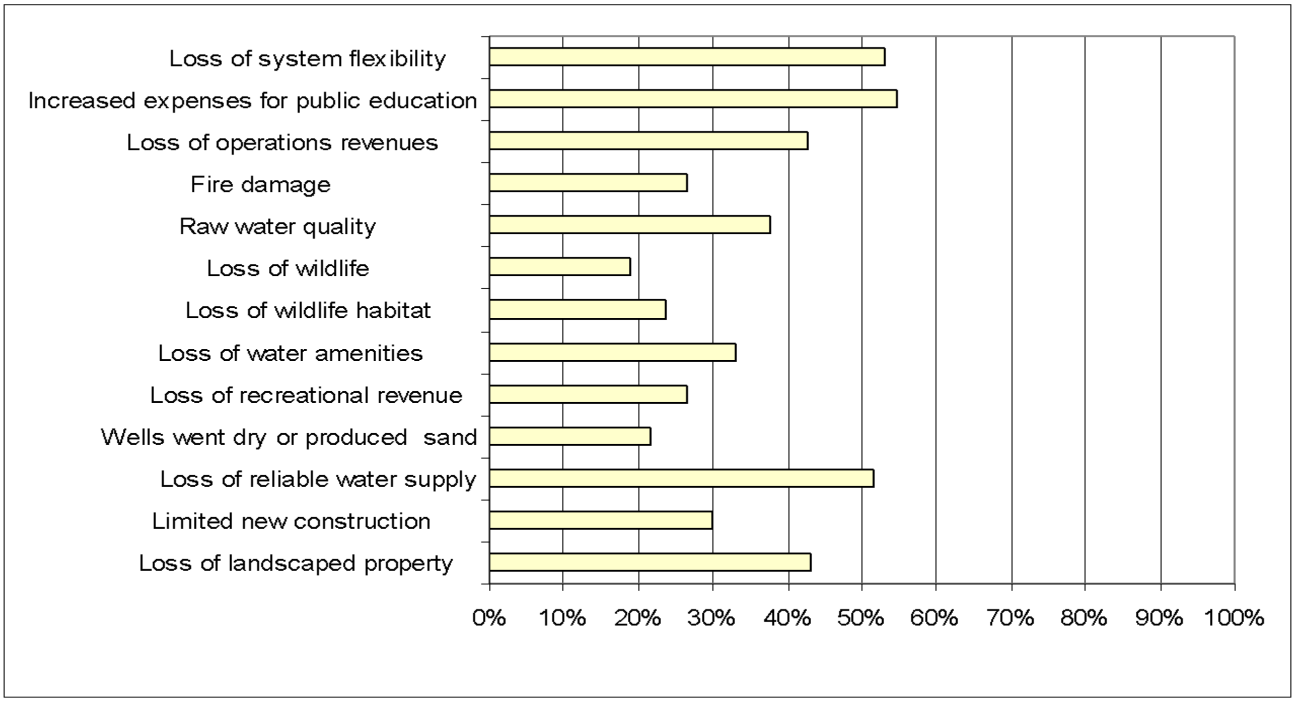
Basin	Response Percent	Response Count
Division 1 - South Platte Basin	48.8%	42
Division 2 - Arkansas River Basin	11.6%	10
Division 3 - Rio Grande River Basin	3.5%	3
Division 4 - Gunnison River Basin	8.1%	7
Division 5 - Colorado River Basin	12.8%	11
Division 6 - Yampa River Basin	5.8%	5
Division 7 - San 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 Impacts[7]



Source: DWSA 2004 survey data.

Additional impacts commonly experienced by M&I providers that were not included in the DWSA survey are:

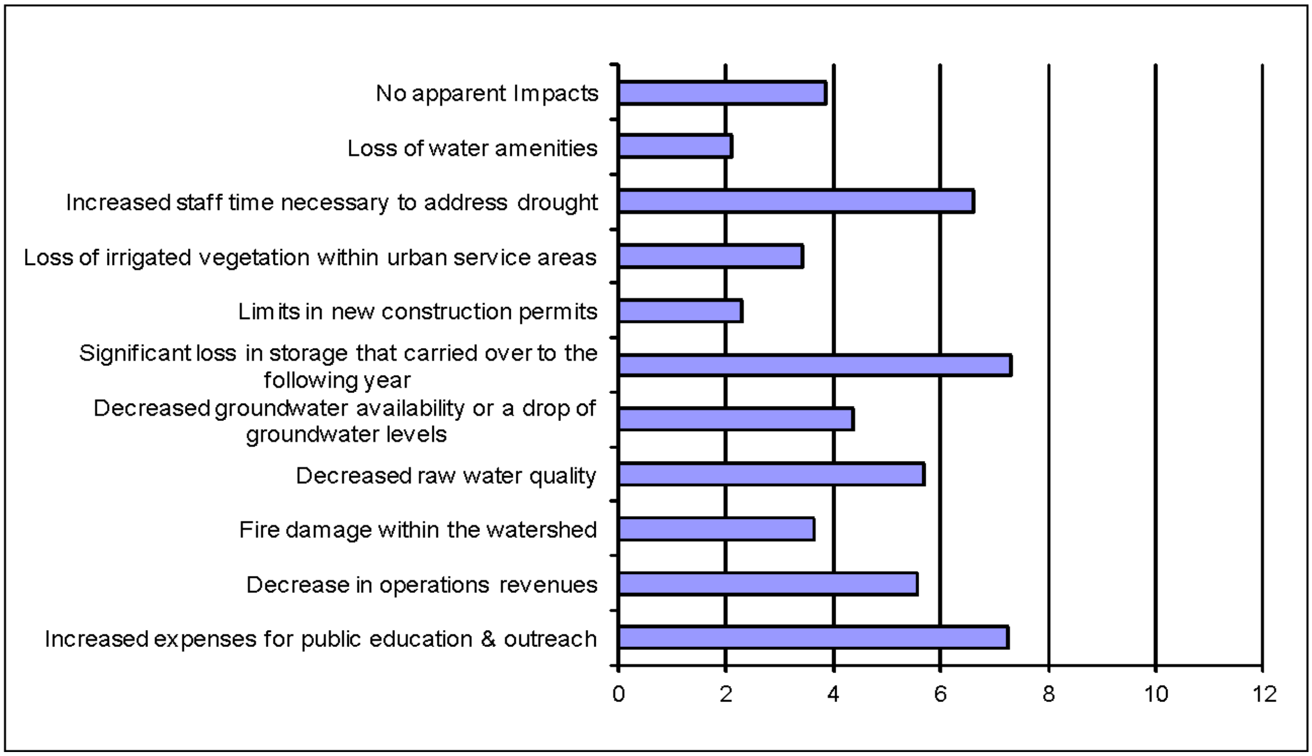
- Reduction in M&I well production and/or reduction in storage reserves
- Increased costs and staff time to implement drought plan and manage public perception of response to drought
- Disruption of water supplies
- Degraded source water quality and higher water treatment costs
- Sediment and fire debris 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.

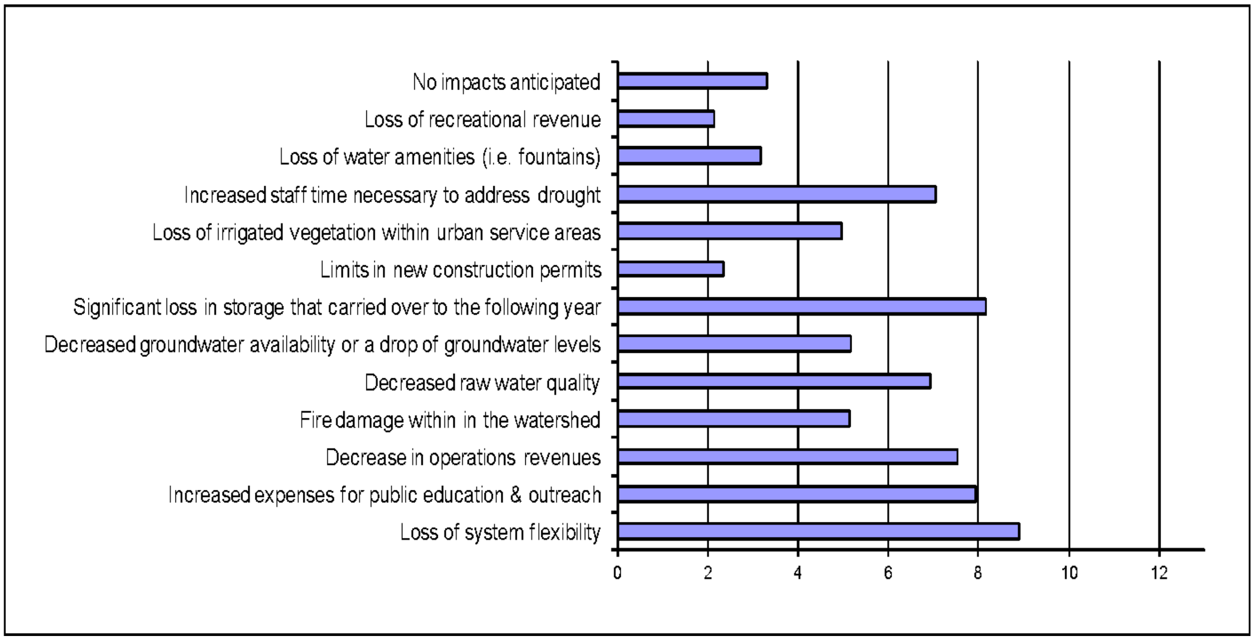
Figure 9.4 Frequency and Relative Level of Impacts During the 2012 Drought



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.

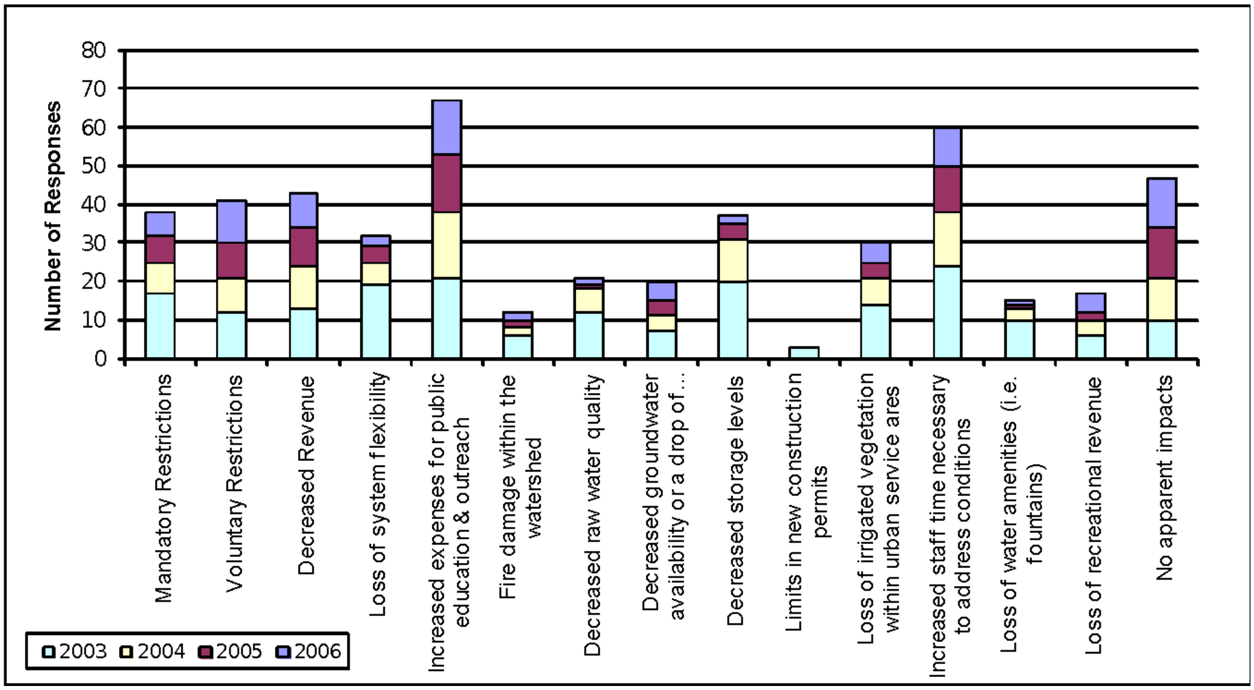
Figure 9.5 Statewide Anticipated Impacts For 2013, per 2013 Survey



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 *respondents*	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 *respondents*	1) Increased expenses for public education & outreach 2) Increased staff time necessary to address conditions 3) Voluntary restrictions 23 *respondents*
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 *respondents*	1) Loss of system flexibility 2) Significant loss in storage that carried over to the following year 3) Loss of recreational revenue 7 *respondents*	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 *respondents*
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 *respondent*	1) Loss of system flexibility 2) Significant loss in storage that carried over to the following year 3) Decrease in operations revenue 1 *respondent*	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 *respondent*
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 *respondents*	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 *respondents*	1) Loss of system flexibility 2) Decreased raw water quality 3) Increased staff time necessary to address drought 3 *respondents*
Colorado Basin	1) Decreased raw water quality 2) Loss of system flexibility 3) Increased expenses for public education & outreach 7 *respondents*	1) Increased expenses for public education & outreach 2) Loss of system flexibility 3) Decreased raw water quality 7 *respondents*	1) Voluntary restrictions 2) Mandatory restrictions 3) Increased expenses for public education & outreach 4) Decreased storage levels 7 *respondents*

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 2 *respondents*	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 2 *respondents*	No apparent impacts 2 *respondents*
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 3 *respondents*	1) Limits in construction permits 2) Loss of irrigated vegetation with urban service areas 3) Loss of recreational revenue 4) Increased staff time necessary to address conditions 3 *respondents*	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 3 *respondents*

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 Agreements[8]		
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.

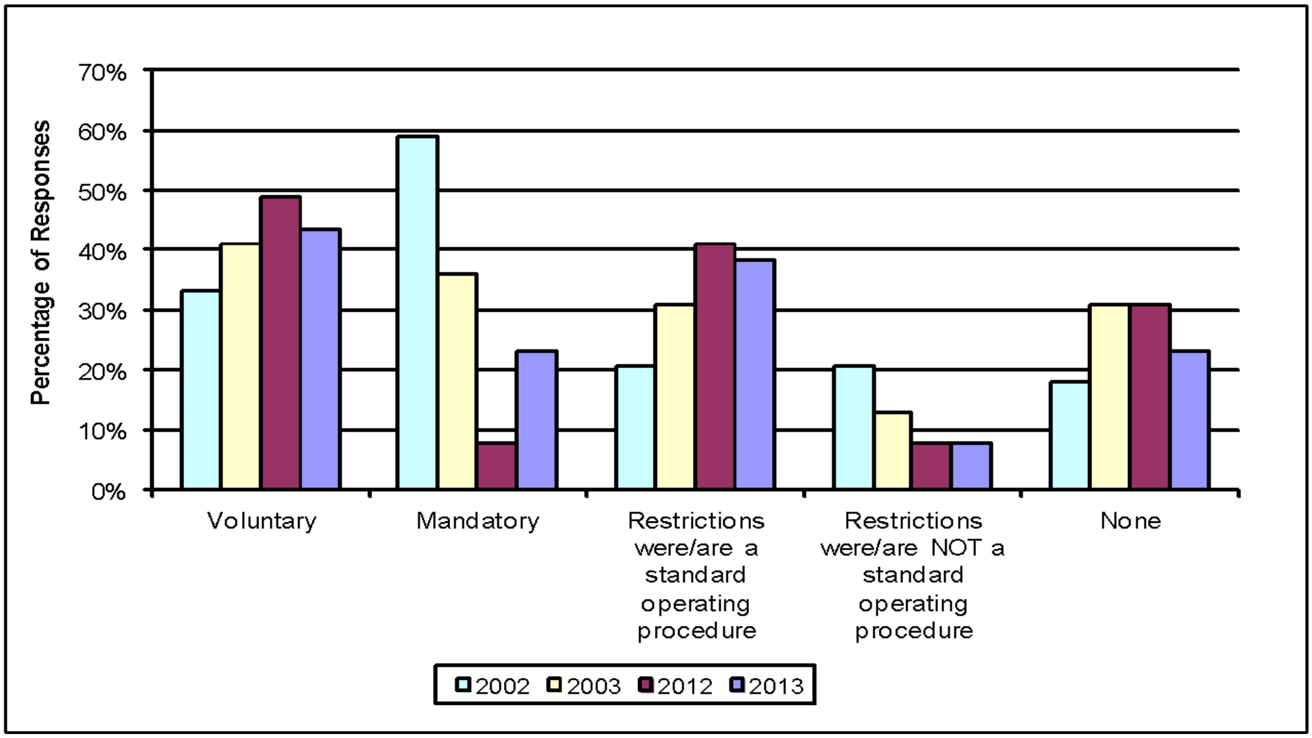
Adaptive Capacity - Mitigation and Response Actions	Long-term Mitigation	Short-term Response Actions
Demand Management		
Establish and enforce percent water use reduction goals	X	X
Identify high water use customers and develop water saving targets	X	X
Implement conservation measures that also provide 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.

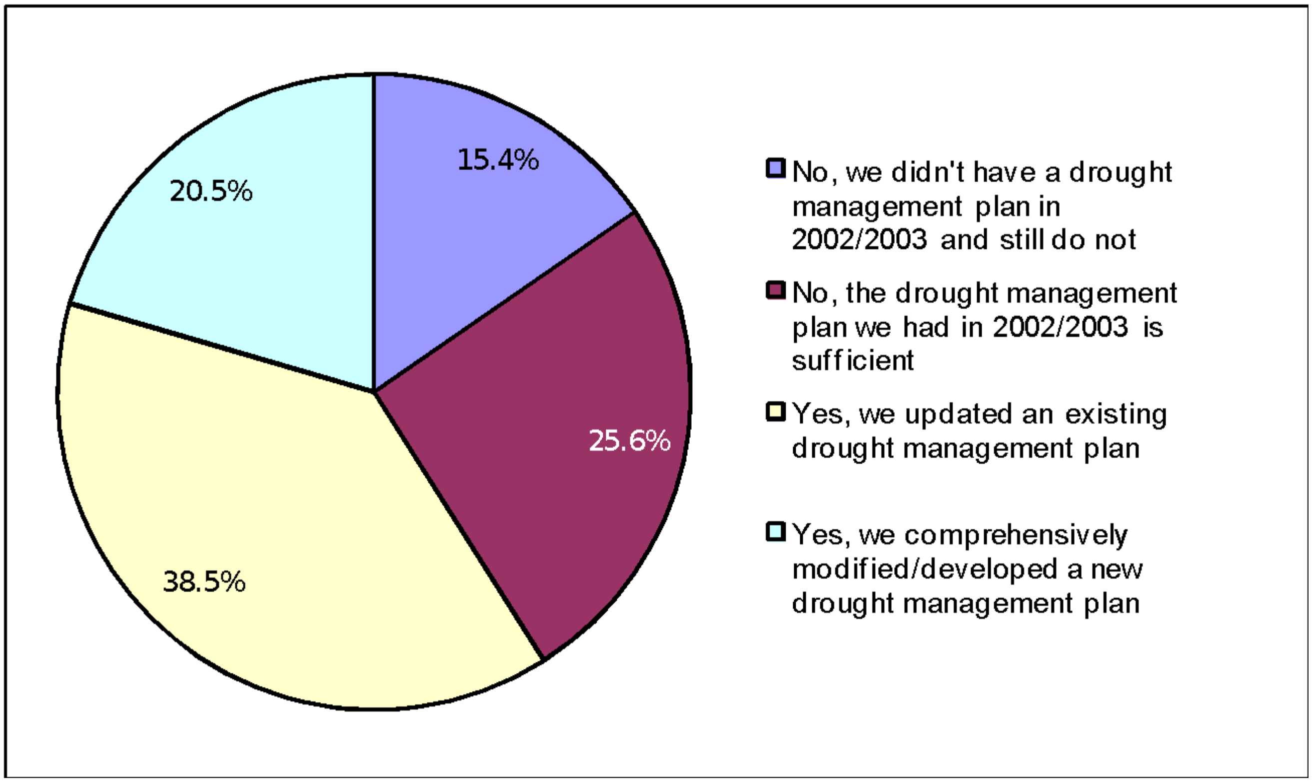
Figure 9.7 Water Restrictions



Source: CWCB 2013 drought survey data
Note: These results are based on 39 survey responses

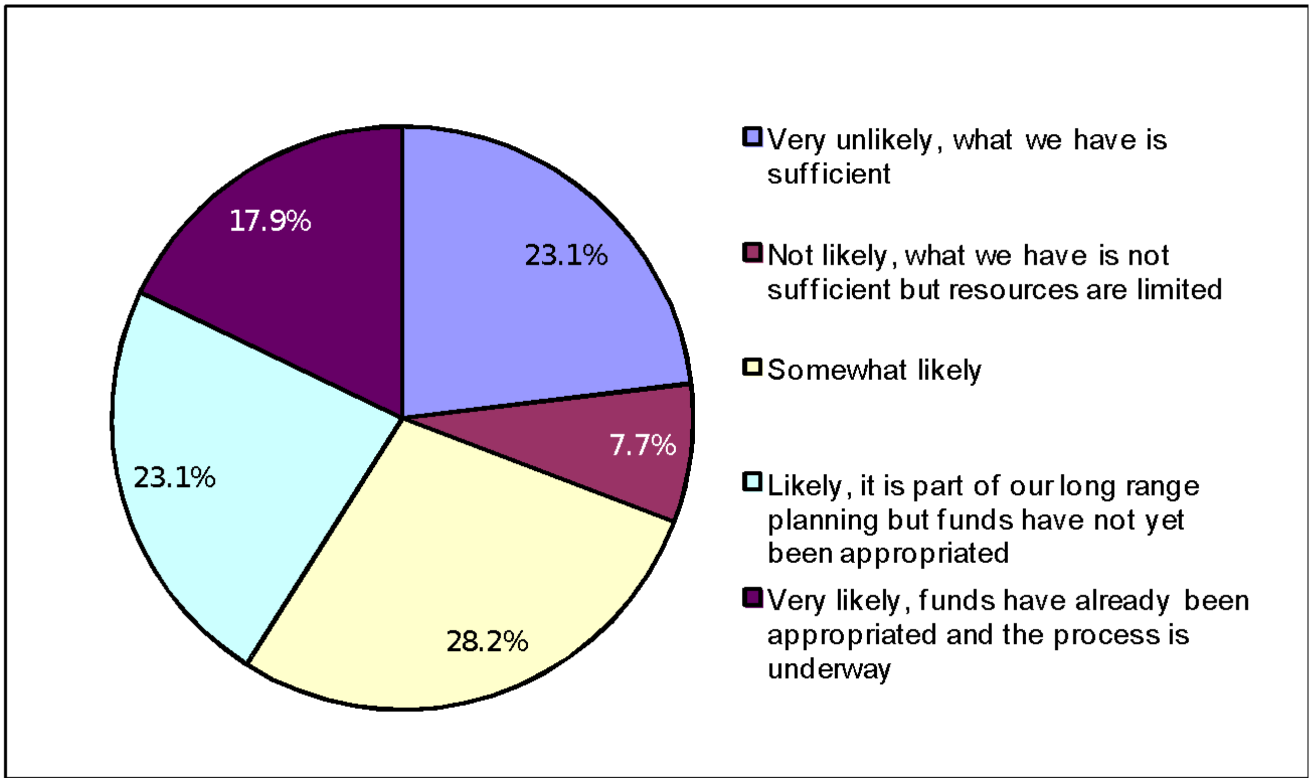
Drought management plans are an adaptive capacity mitigation strategy. In 2013, 15% of survey respondents did not have a drought management plan, while 59% of survey respondents both had a drought management plan and had updated it in the years since 2002 (Figure 9.8). When asked if they would work to 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



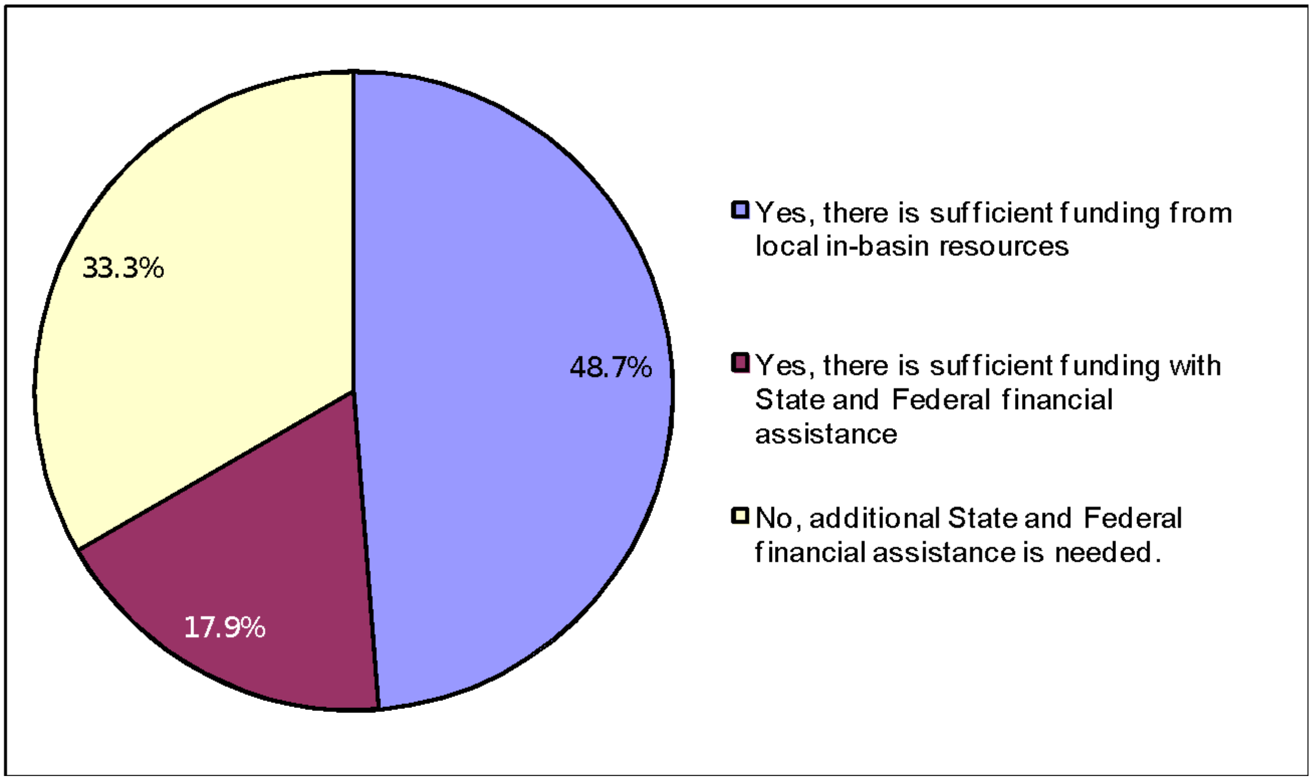
Source: CWCB 2013 drought survey data
Note: These results are based on 39 survey responses

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).

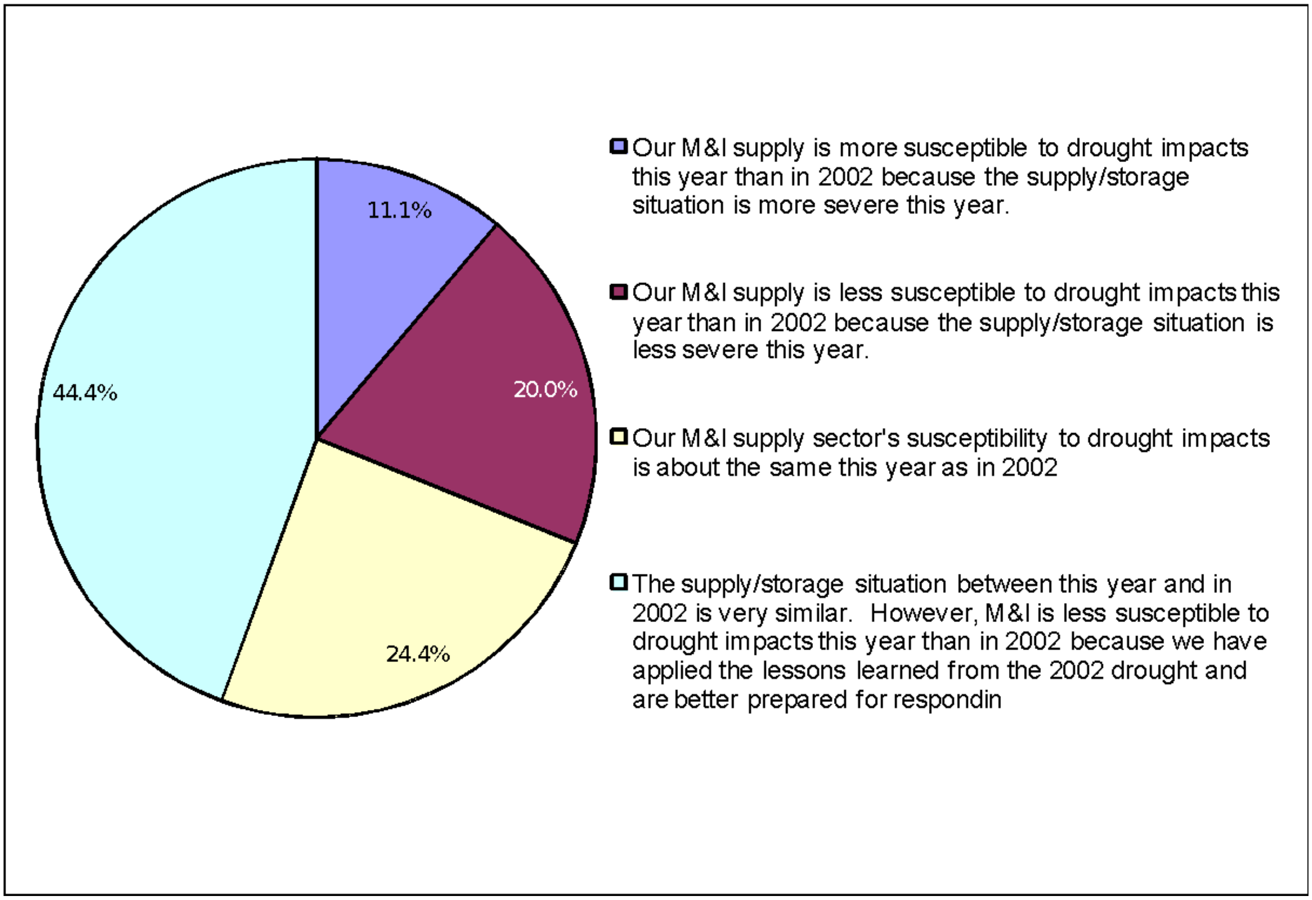
9.4 Measurement of Vulnerability

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).

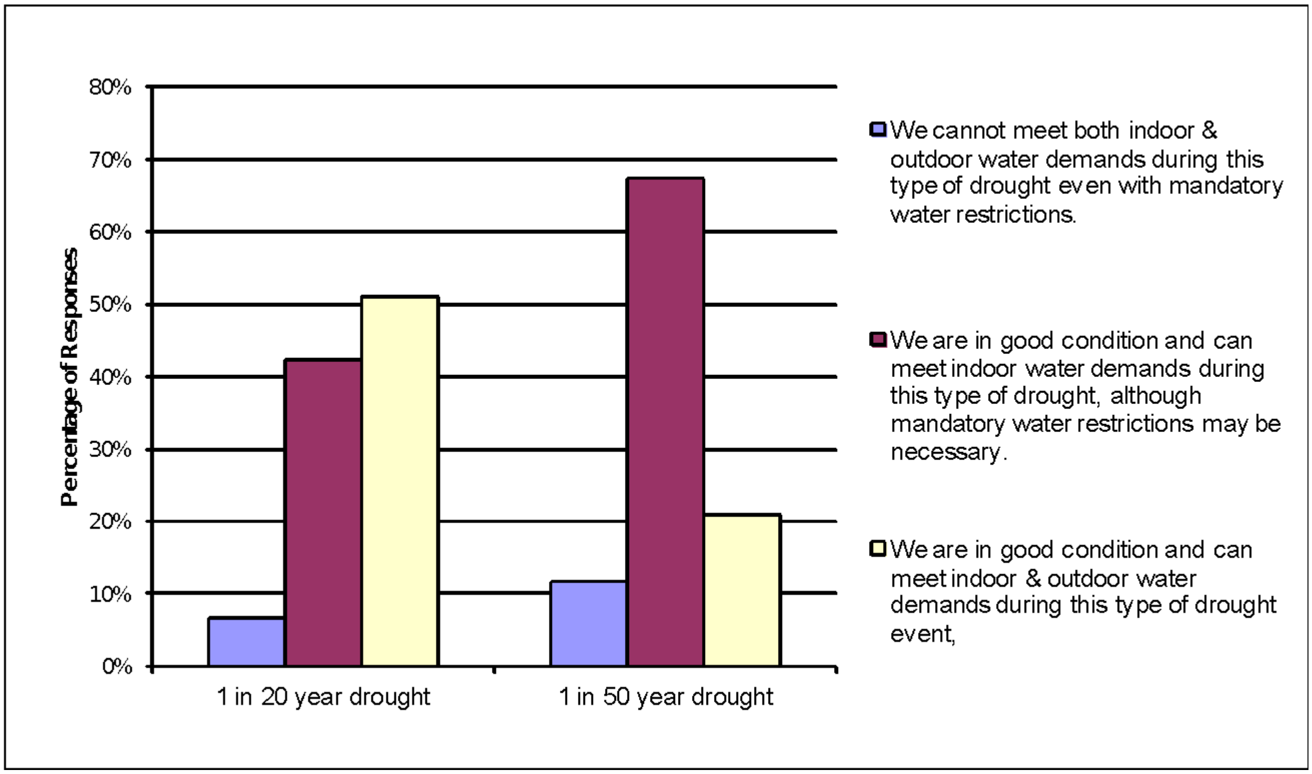
Table 9.8 shows the basin results. Although the sample size is small, the responses indicate the following important points:

- 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

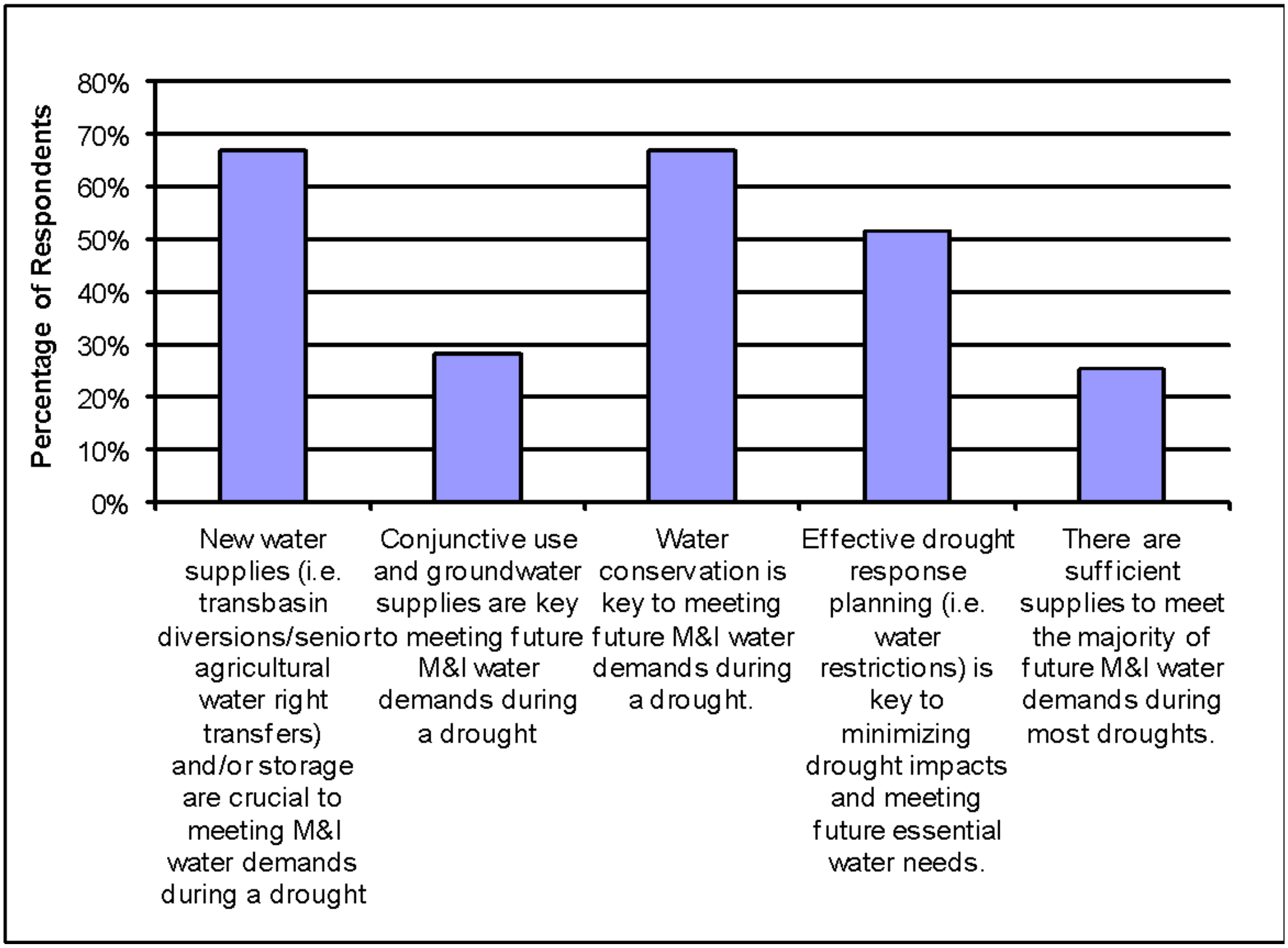
Basin	1-in-20 year drought			1-in-50 year drought			Number of Respondents
	Can meet indoor & outdoor water demands	Can meet indoor water demands, although mandatory water restrictions may be necessary	Cannot meet indoor & outdoor water demands even with mandatory water restrictions	Can meet indoor & 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%

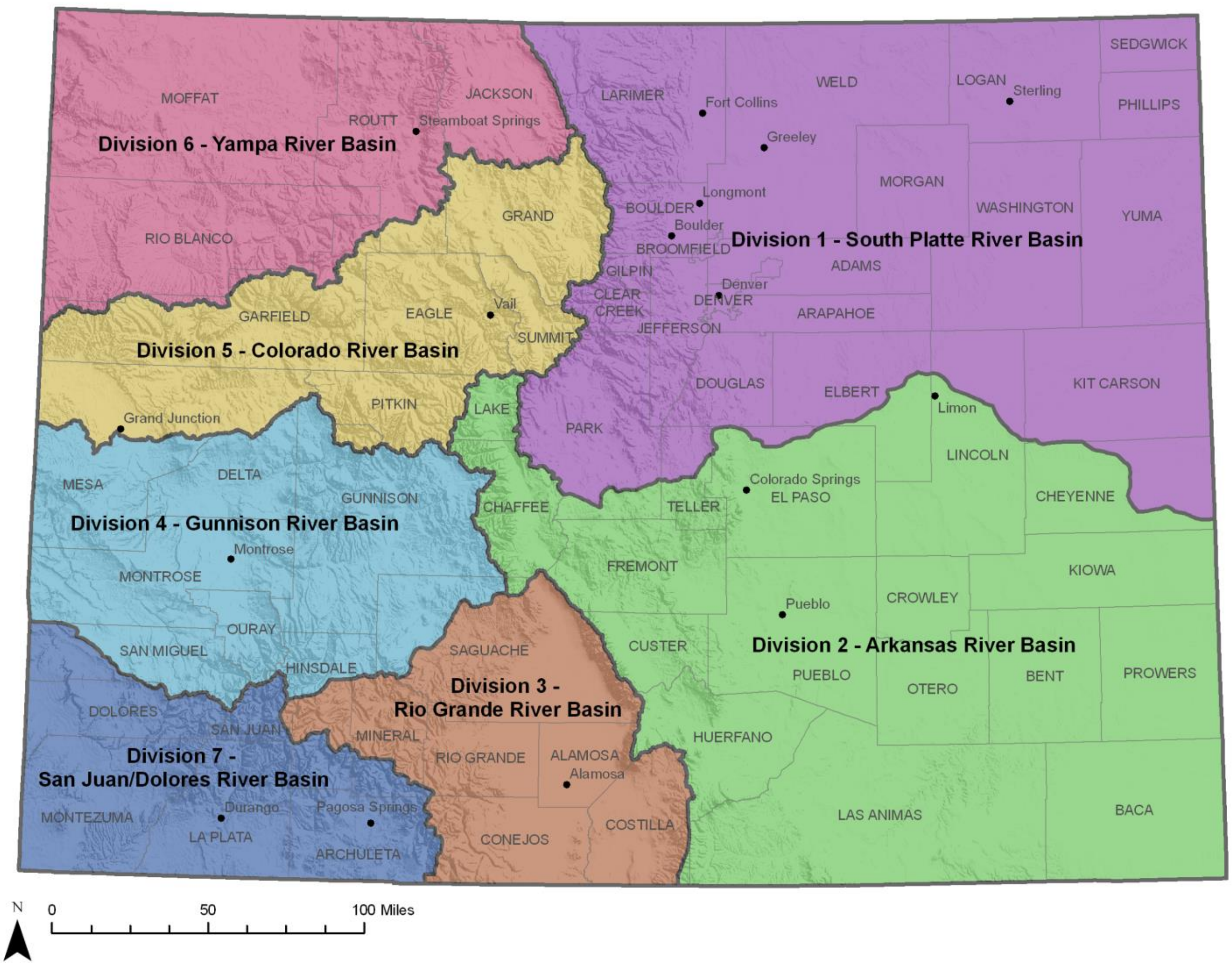
Source: CWCB 2013 drought survey data

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

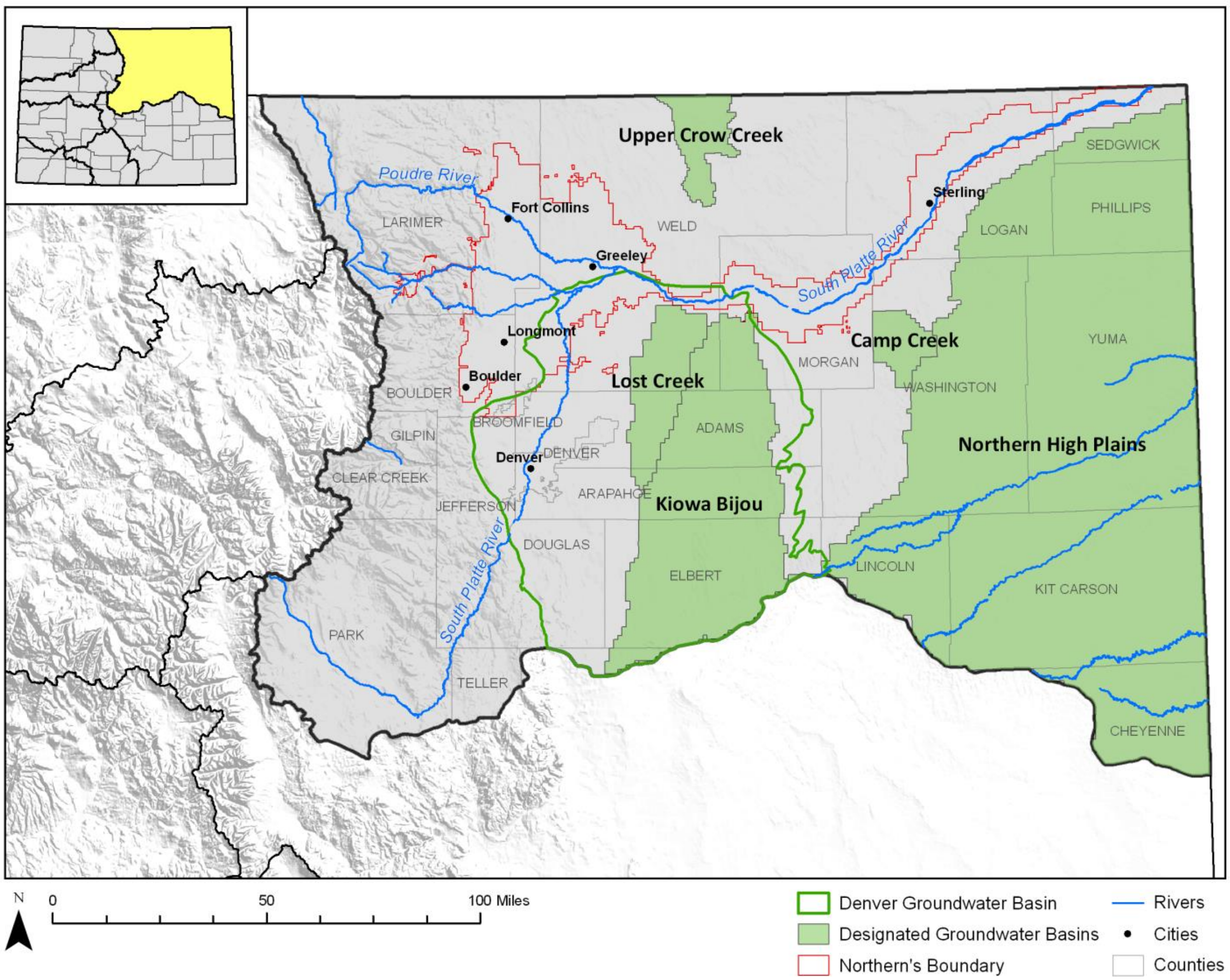


While historical drought information is not a direct reflection of future drought vulnerability, historical 2002 and 2012 drought impact data do provide a relatively recent snapshot of M&I drought vulnerability in a specific drought situation. The majority of historical drought-related impact information 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 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

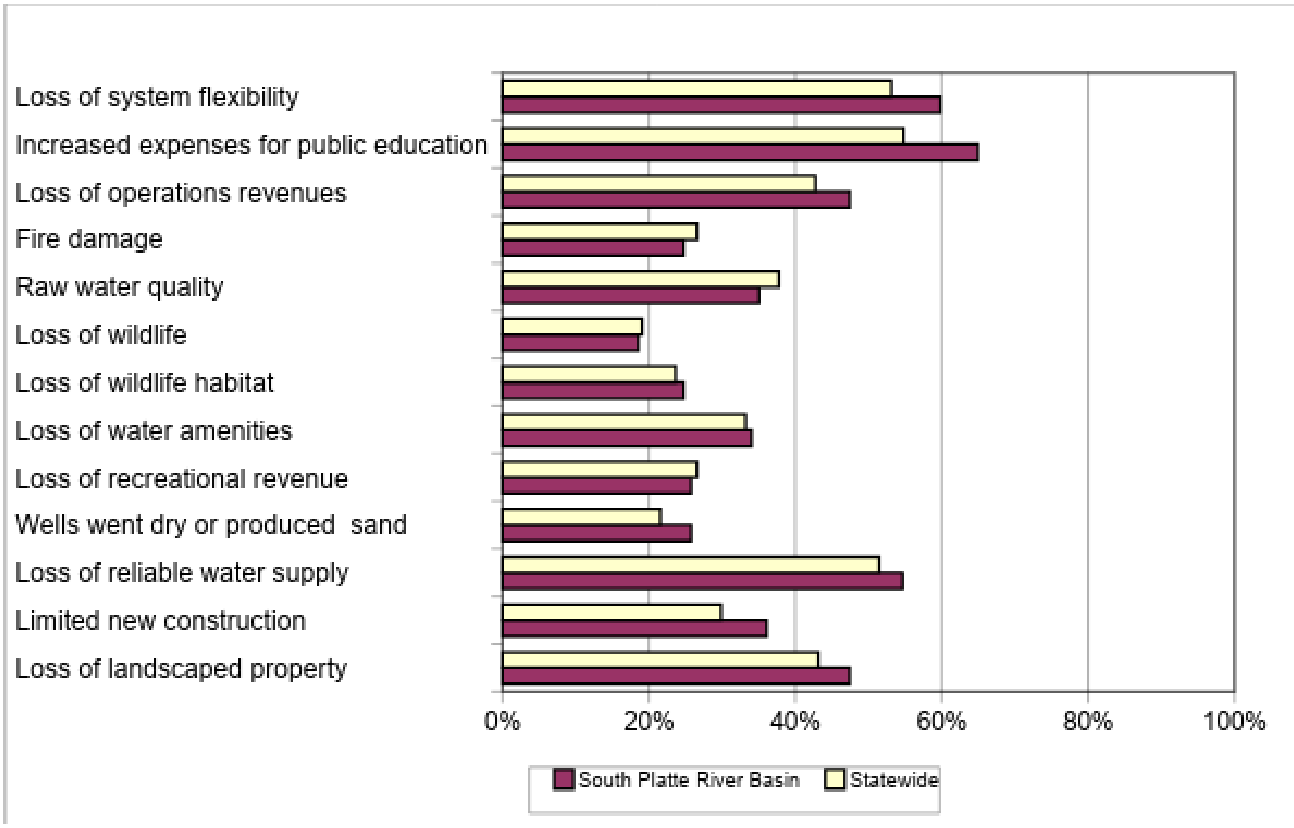
The increased expense for public education was the most frequently experienced impact, exceeding the statewide level percentage and suggesting that South Platte Basin M&I providers on average placed more financial investment into responding to the drought through public education than other basins in 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 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
- 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 Impacts[10]



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 Results[11]

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 Basin[12]

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 2050[15] (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).

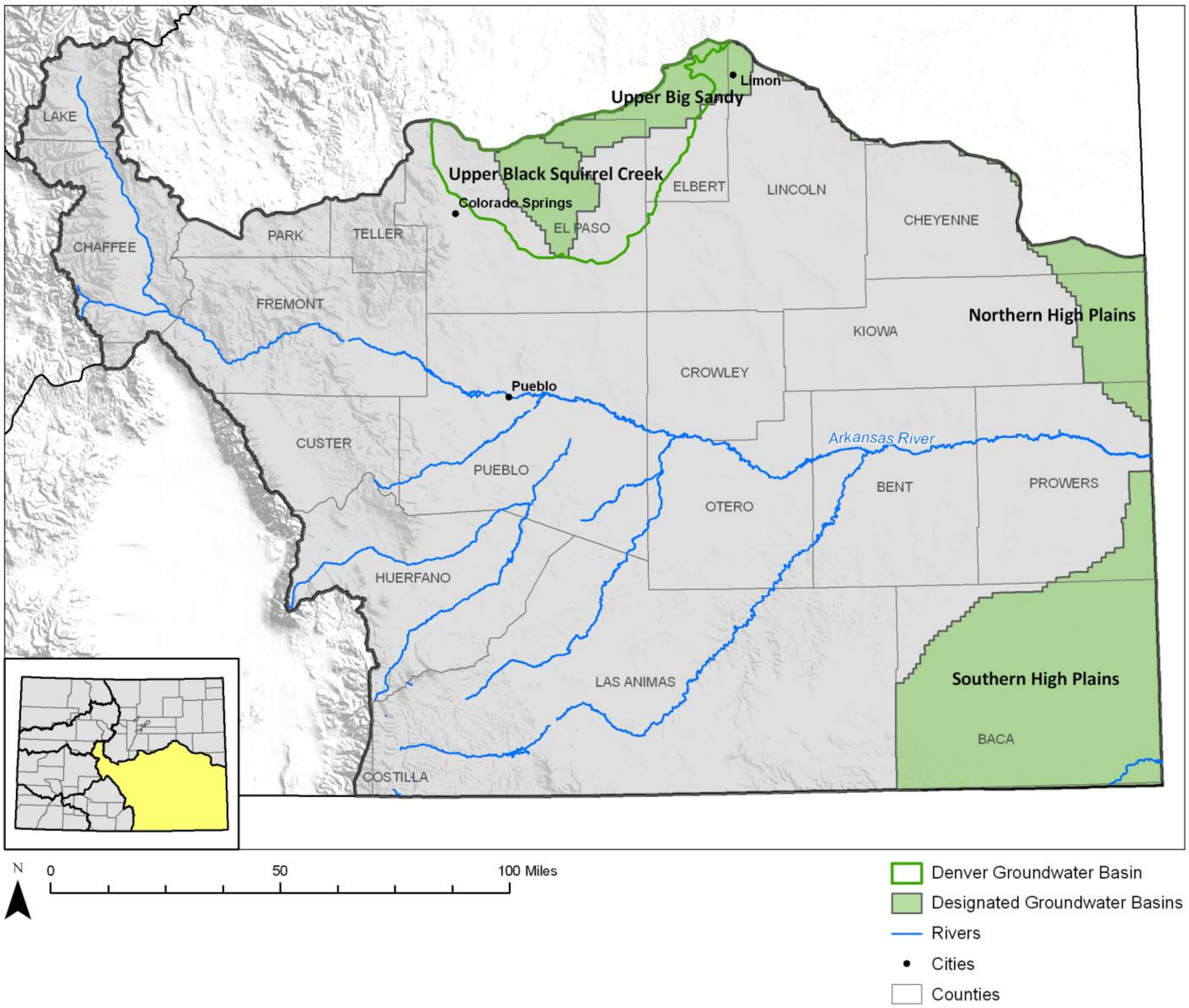
Despite long-term water supply concerns, the South Metro Area was not severely affected by the 2002 drought. Relatively few water providers enforced mandatory watering restrictions. Loss of well production was observed in some areas as a result of increased demands. However, despite these well production 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

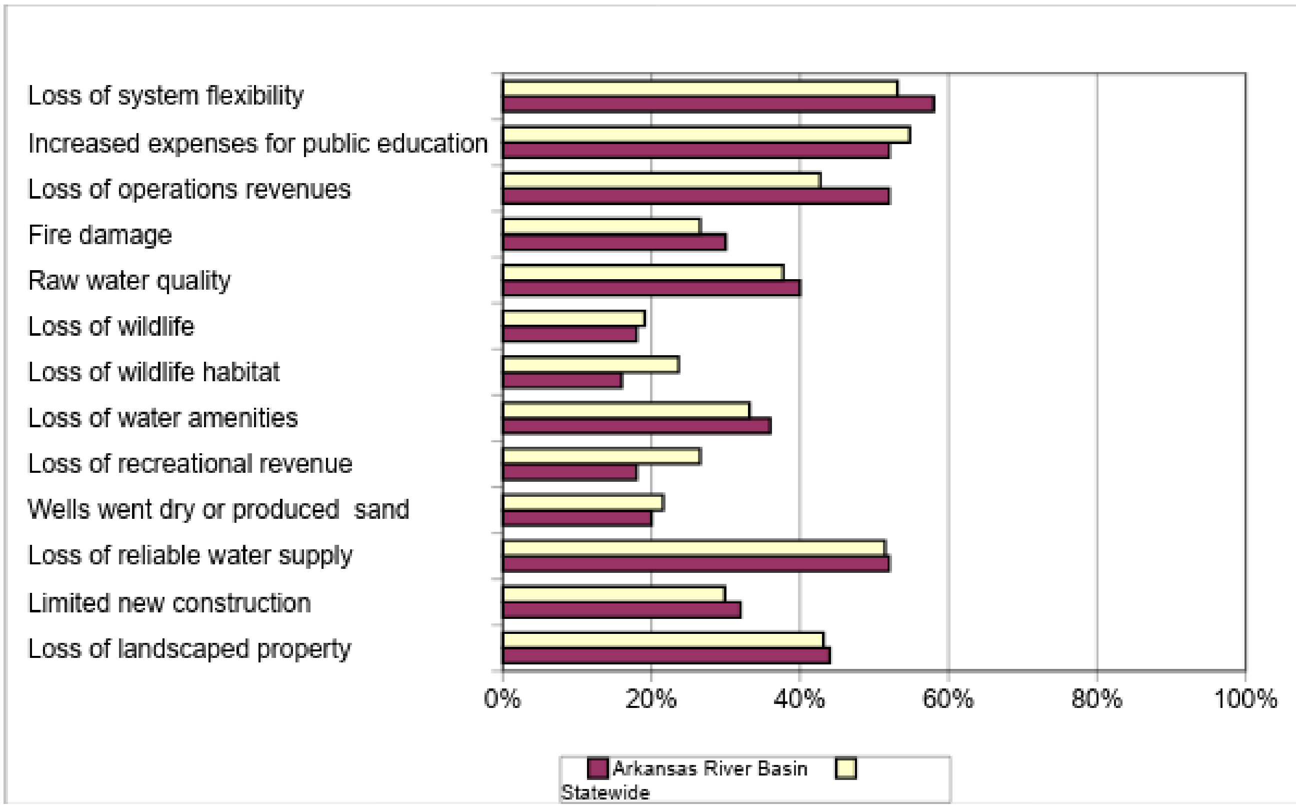
The 2004 DWSA survey results shown in Figure 9.18 indicates that over 40% of the 50 surveyed M&I providers in the Arkansas River Basin experienced the following impacts during the 1999-2003 drought period:

- 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 Impacts[16]



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

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[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 Results[17]

	Arkansas River Basin		Statewide Average	
Drought-Related Planning Efforts	**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 Basin[18]

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.

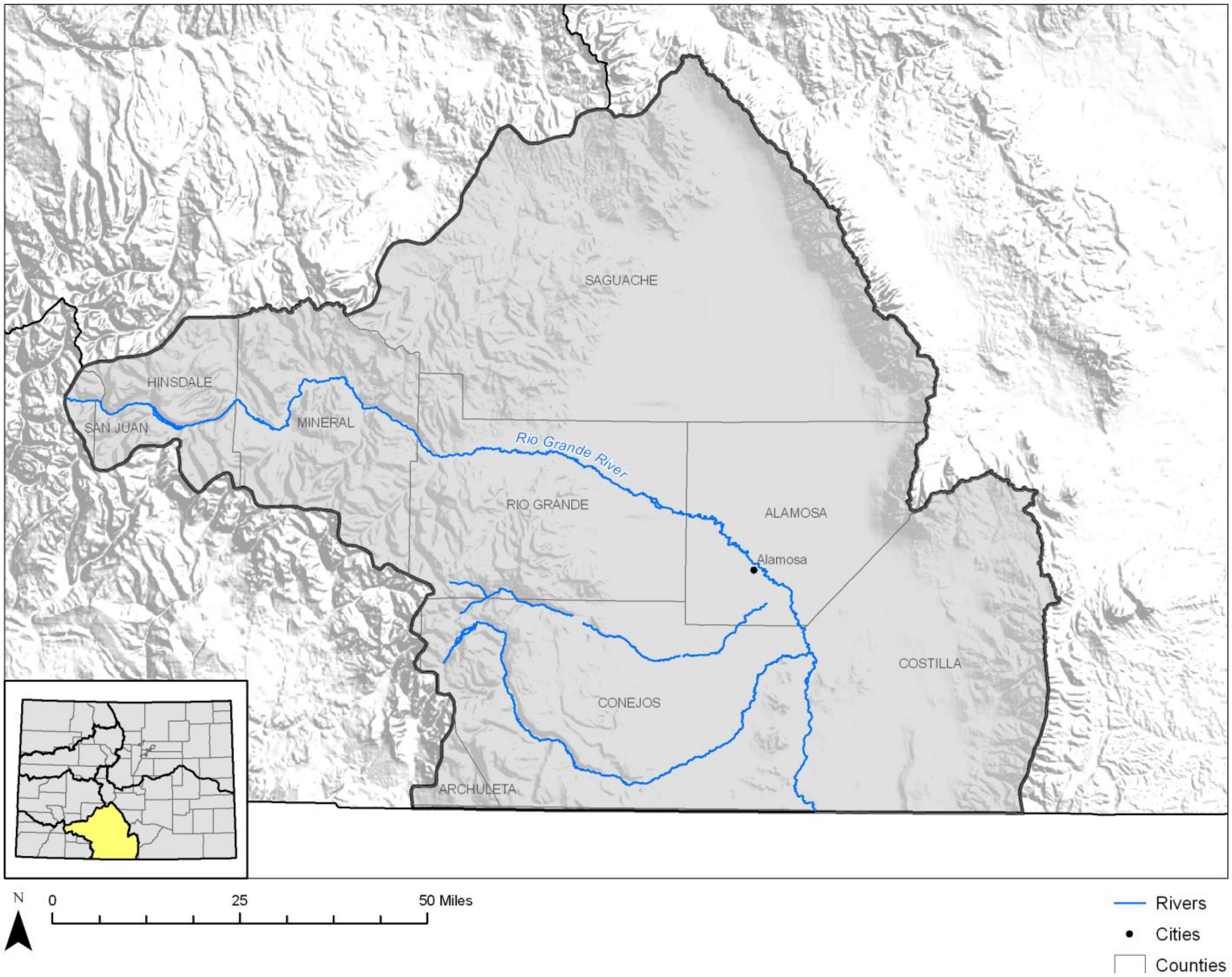
There is interest and economic incentive to sell agricultural rights to municipalities outside of the Basin (Arkansas Valley Irrigator Incorporated, 2013). The Super Ditch Company was developed with the Lower Arkansas Valley Water Conservancy District to preserve irrigated agriculture in the Lower Arkansas 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

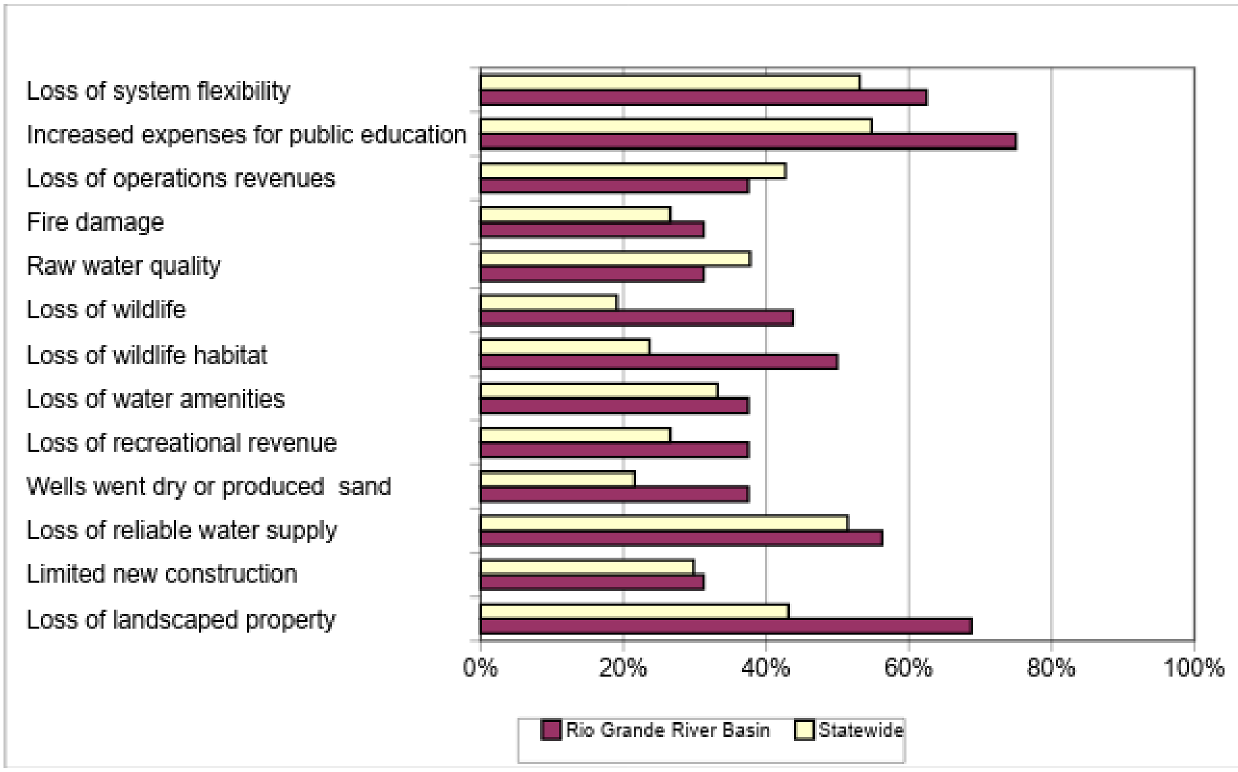


Historical Drought Impacts

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 Impacts[19]



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 Results[20]

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:

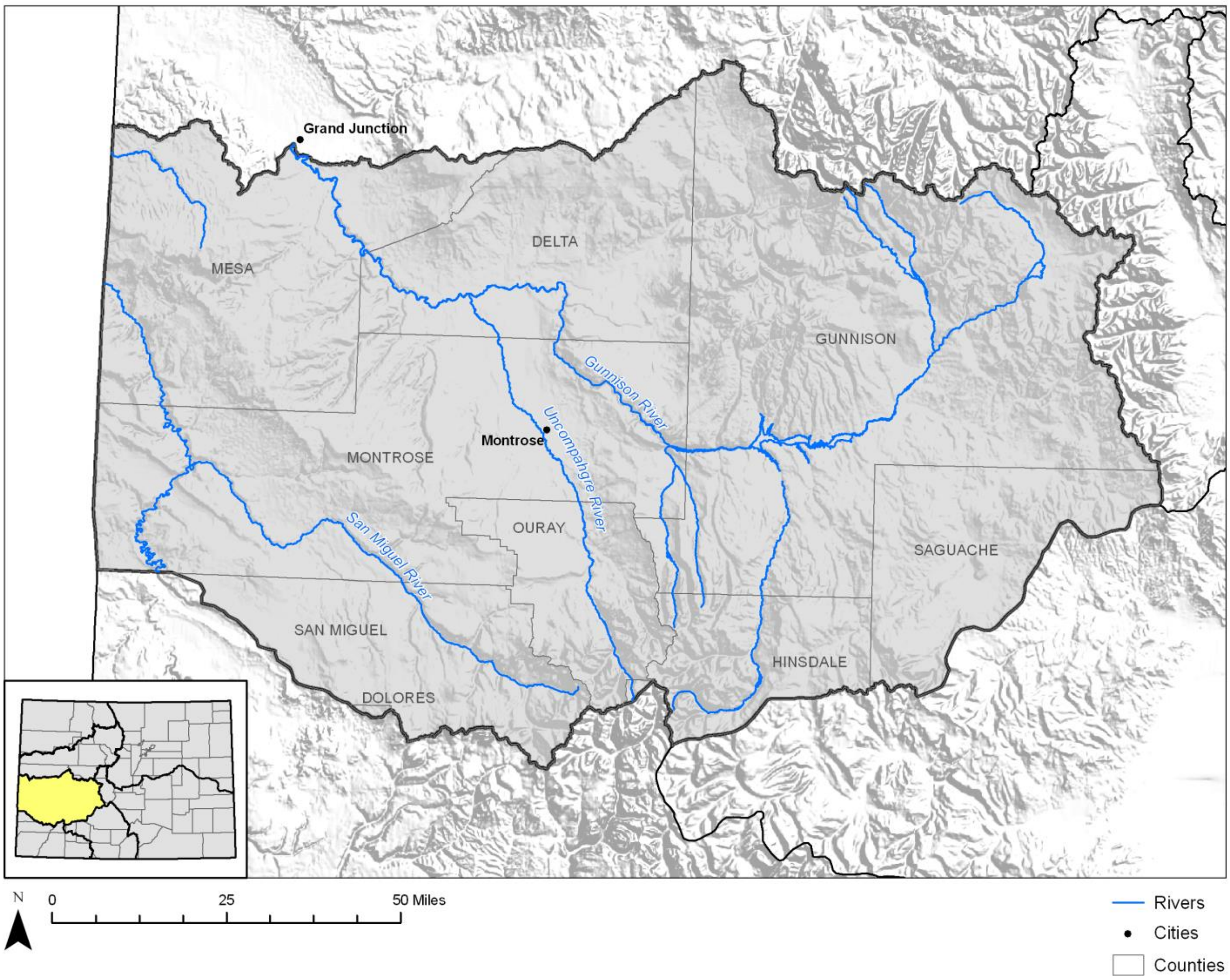
- Doppler Radar Weather Forecasting Project
- Groundwater Management Subdistricts
- Rio Grande Basin Hydrology Study (Long-Term)
- Rio Grande Cooperative Project
- Rio Grande Headwaters Restoration Project
- Rio Grande Initiative Conservation Easements
- Rio Grande National Forest Plan Revision
- Rio 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



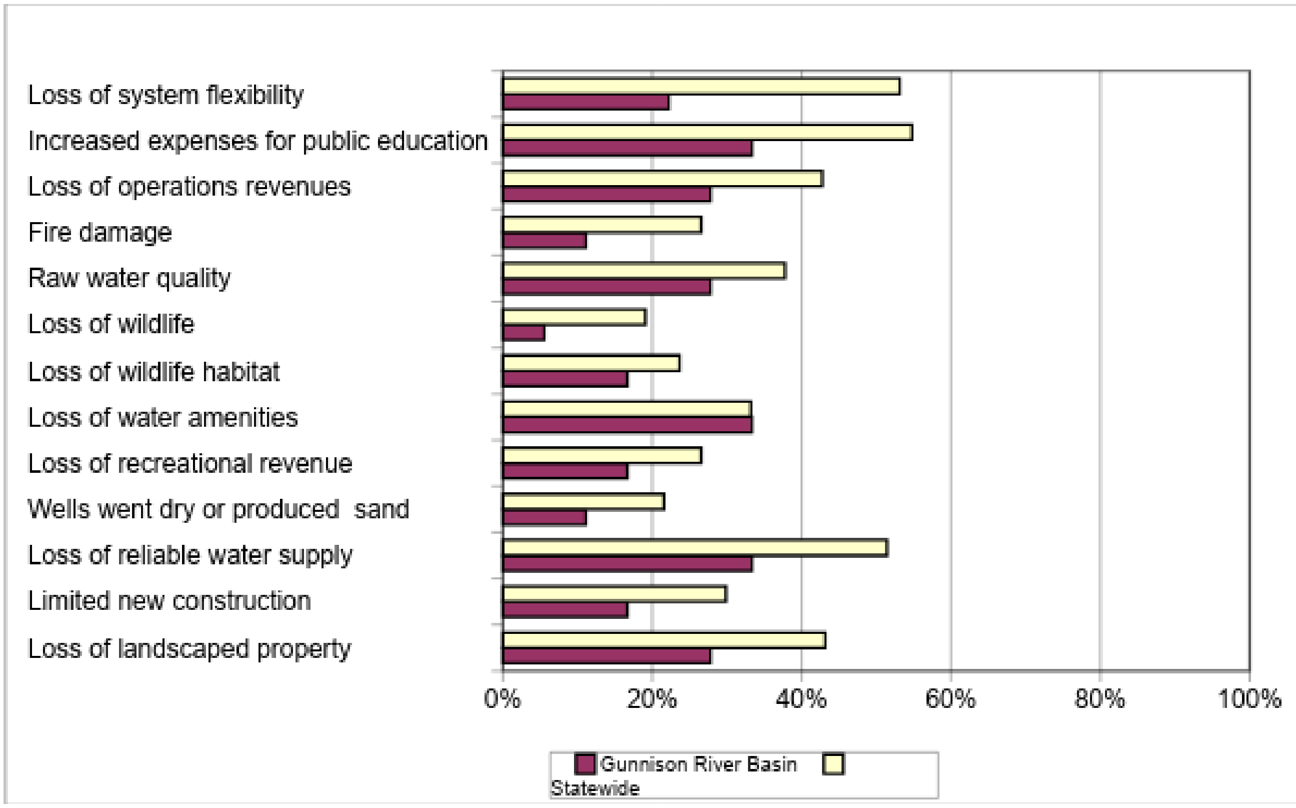
Historical Drought Impacts

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 Impacts[23]



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 Basin[25]

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

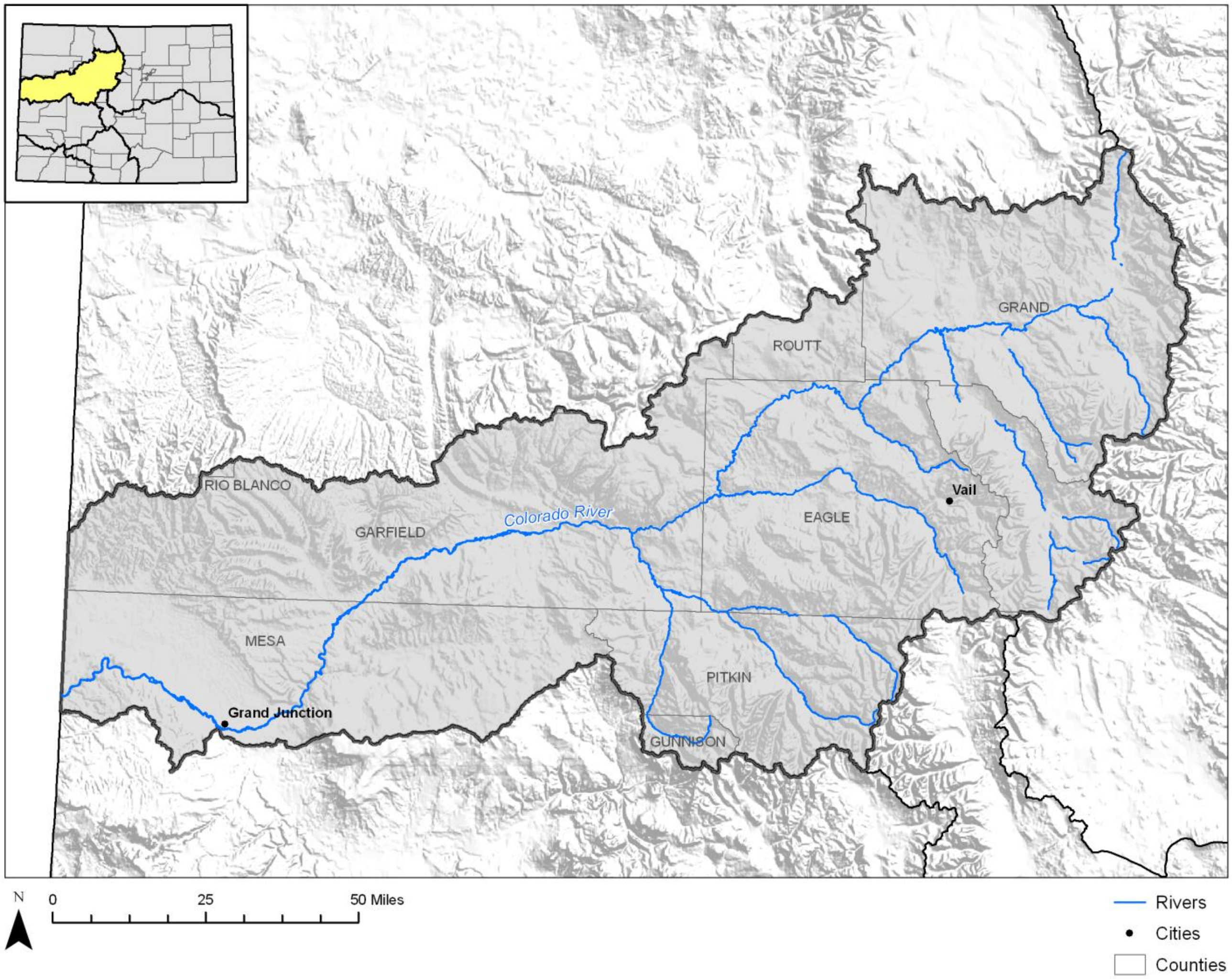
Well augmentation water is necessary to meet many of the M&I demands in the upper Gunnison and Uncompahgre sub-basins; the Upper Gunnison River Water Conservancy District provides augmentation for wells in a portion of the upper basin. The drought impacts recorded in Figure 9.23 are generally well below 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



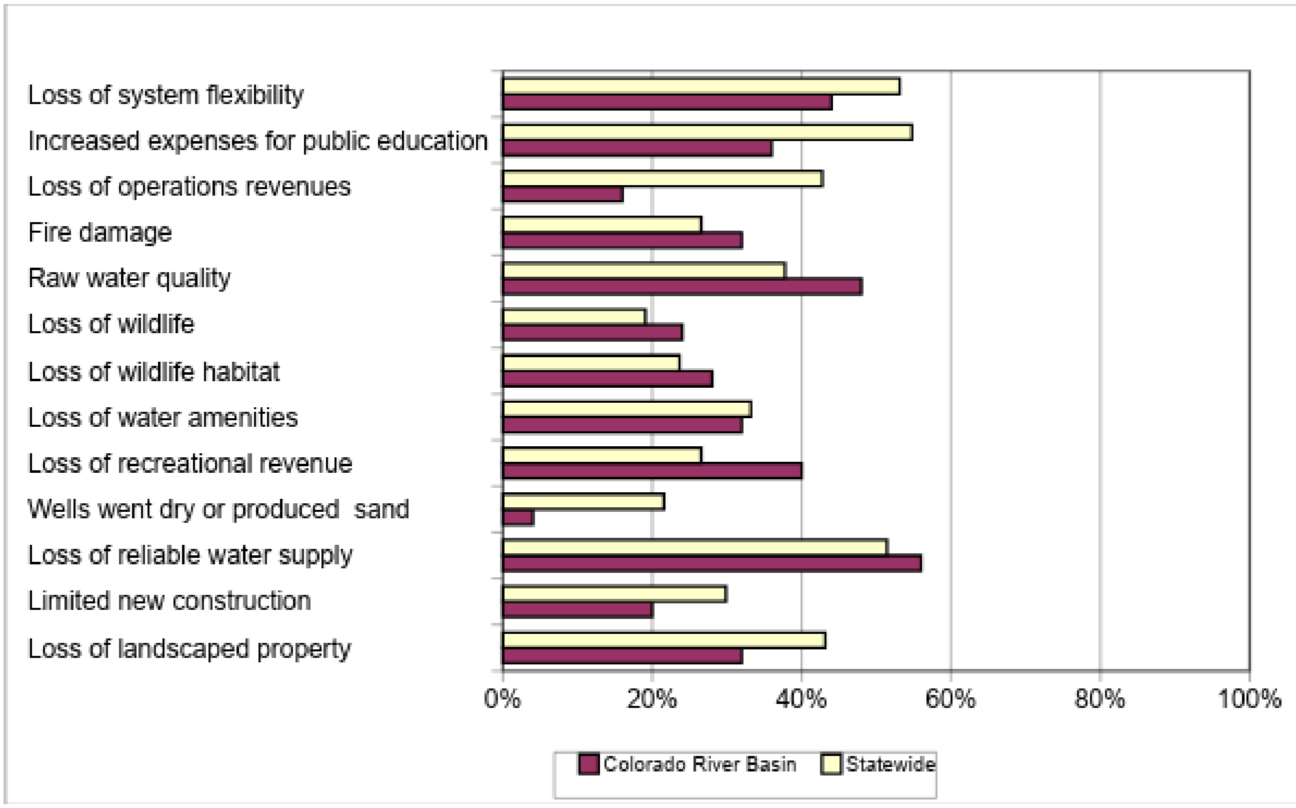
Historical Drought Impacts

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 Impacts[26]



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 Results[27]

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

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

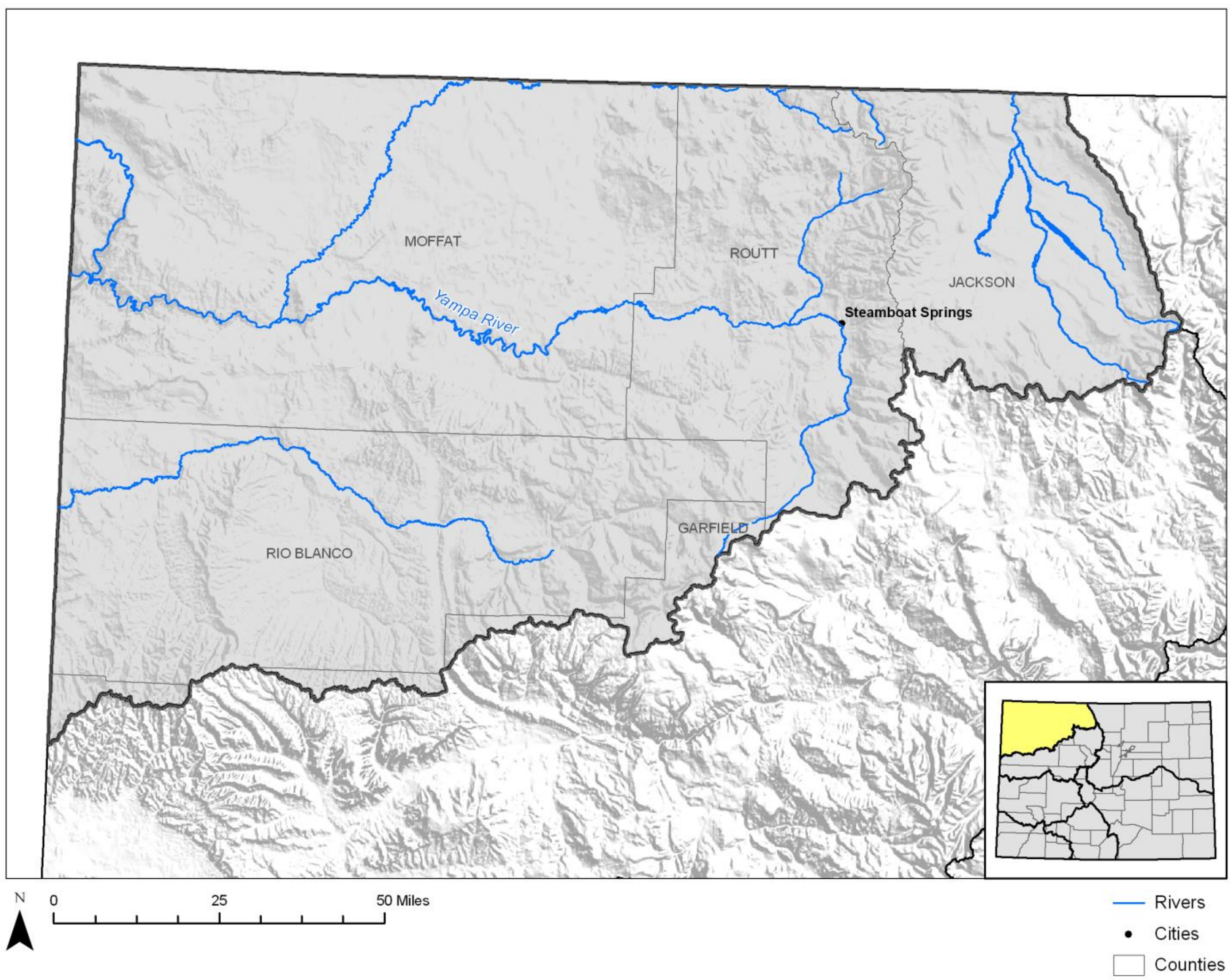
[28] The data presented in the table is based on the Baseline M&I forecast for the medium 2050 growth scenario presented in *Final State of Colorado 2050 Municipal and Industrial Water Use Projections*

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.

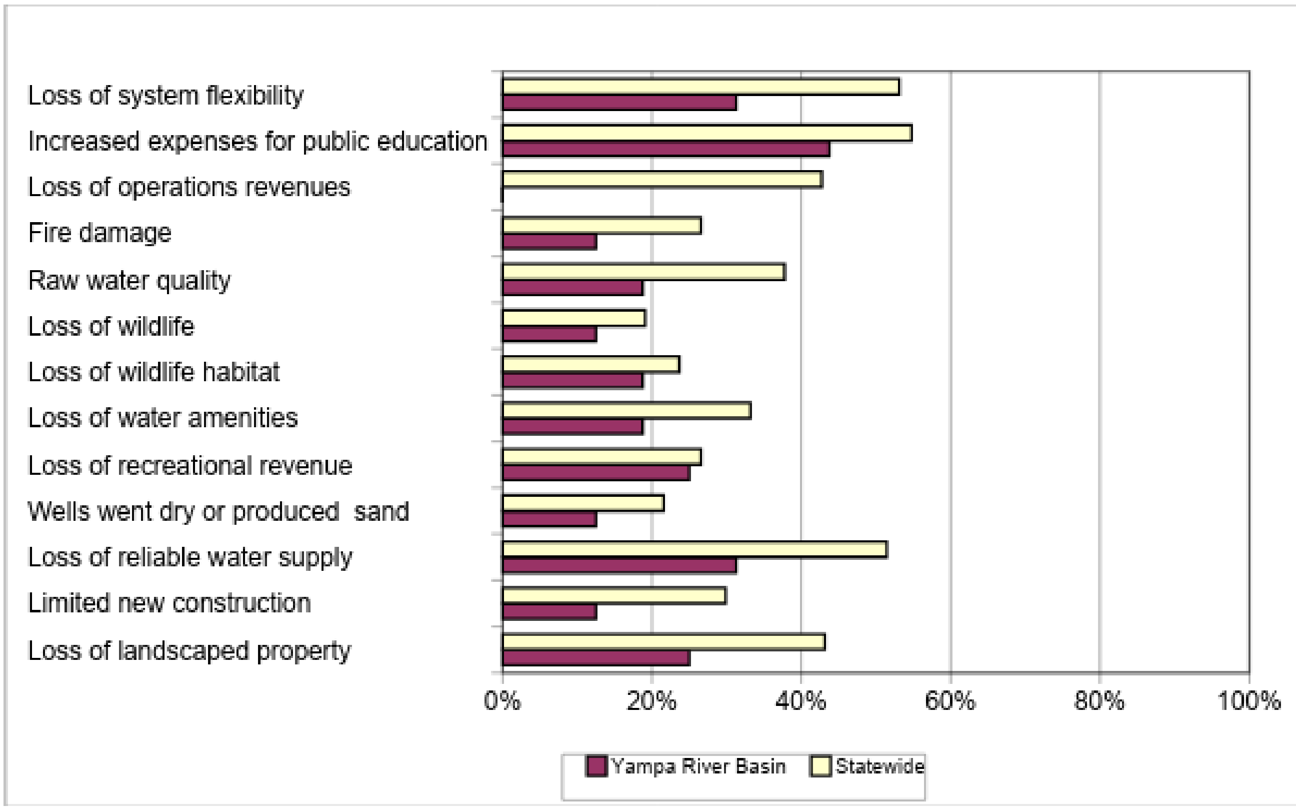
Figure 9.25 Yampa River Basin



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 Impacts[29]



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 Results[30]

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

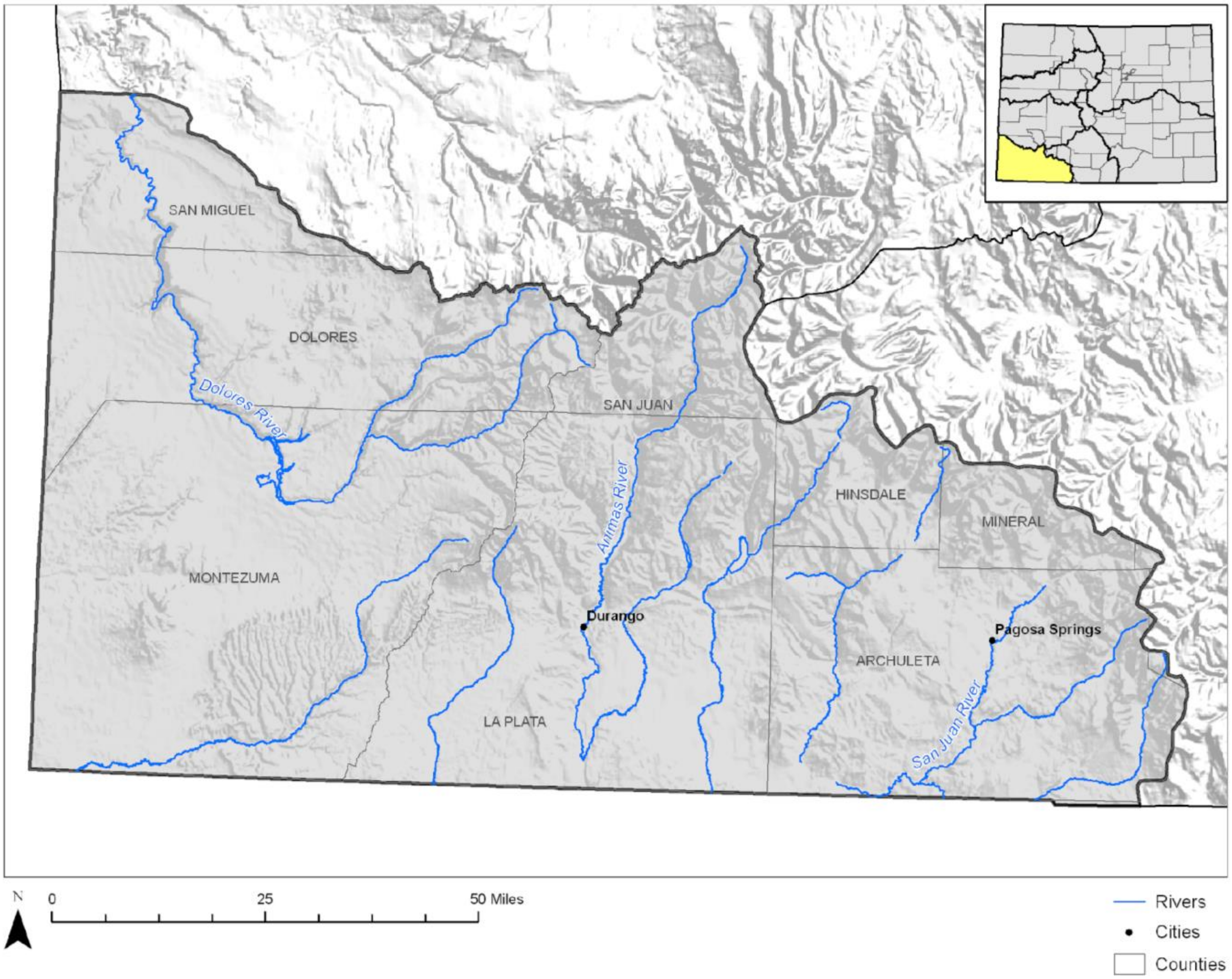
Project	Project Location	Primary Purpose of Project
Lake Avery Enlargement	Expansion to Big Beaver Reservoir (Avery Lake)	The only operation for the Lake Avery Enlargement is making direct releases to meet oil shale demands.
Little Bear 1 Reservoir	Fortification Creek Basin	Agricultural needs
Milk Creek 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



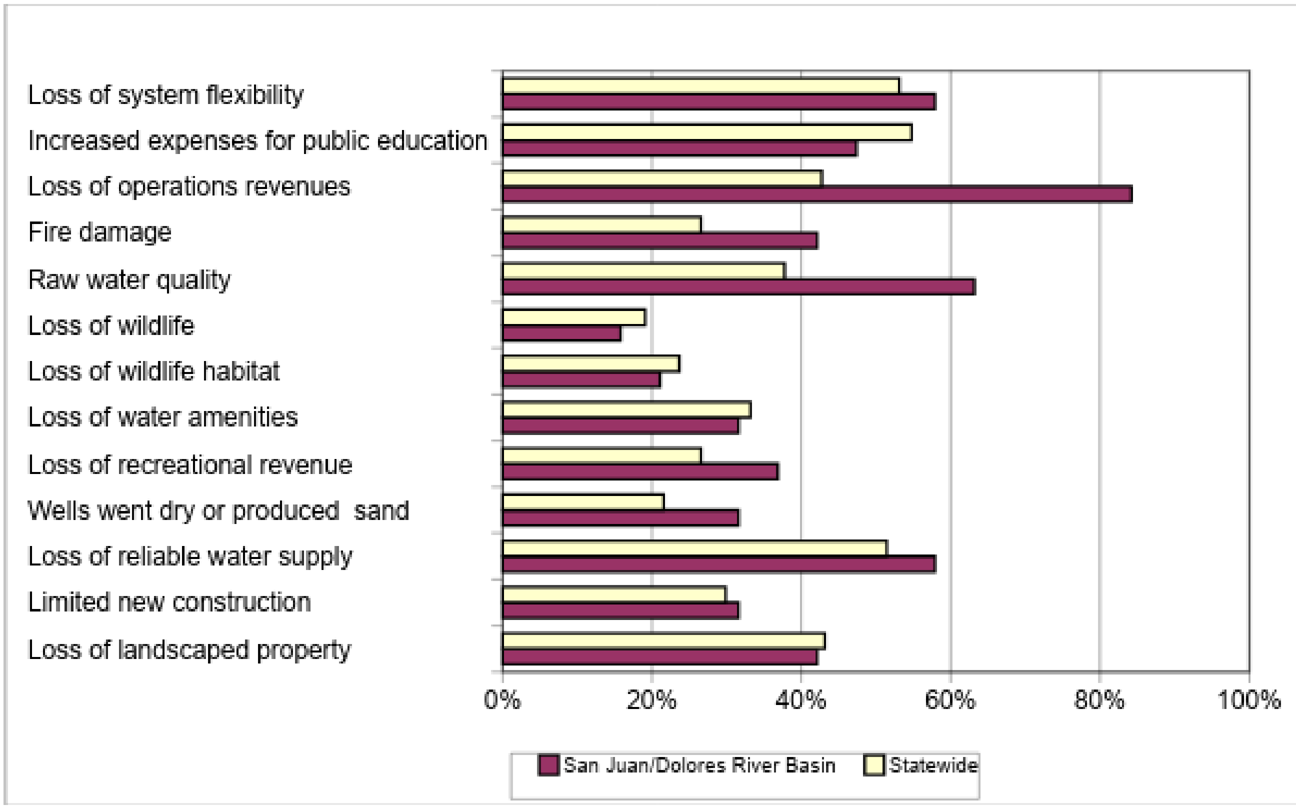
Historical Drought Impacts

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 Impacts[31]



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 Results[32]

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 Basin[33]

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 potential[34] 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 if difficult to come by. Therefore, specifics 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

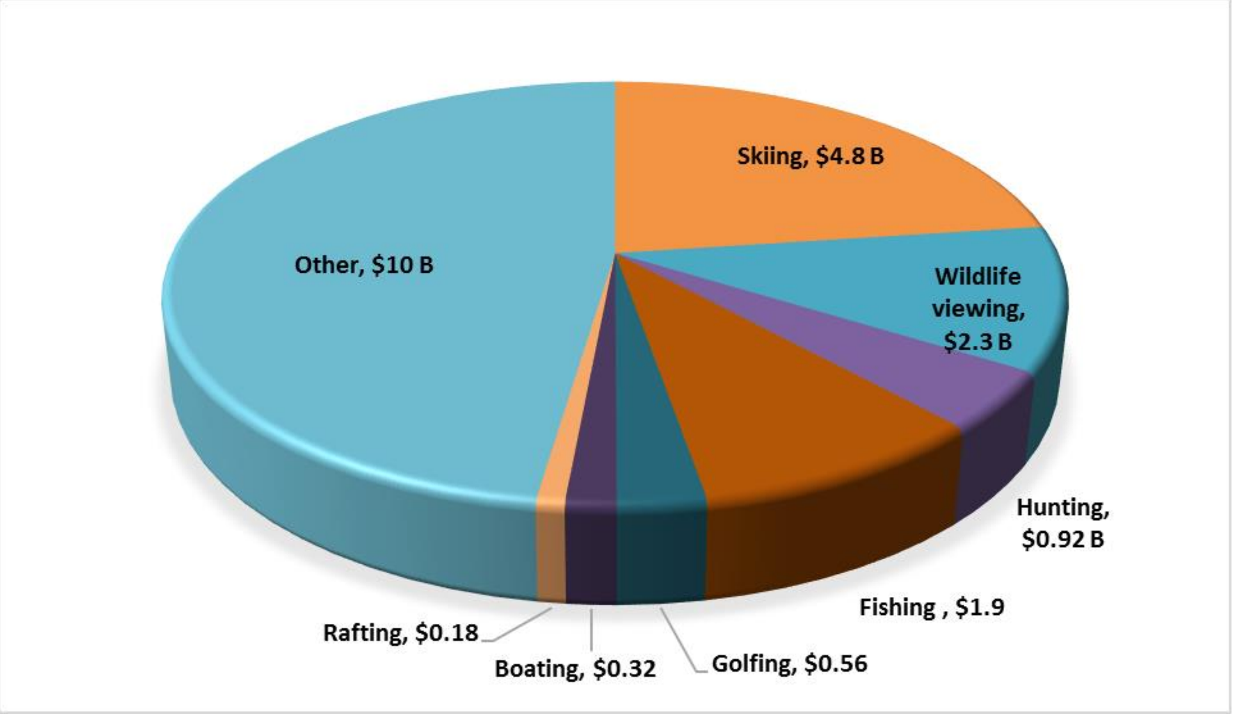
linkages between drought and recreation/tourism, and identify successes from which best practices can be identified.

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 Billions[1]



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 sources[3] confirm that number as of 2018. The USGS report discussed below and Ivanhenko, 2009 are

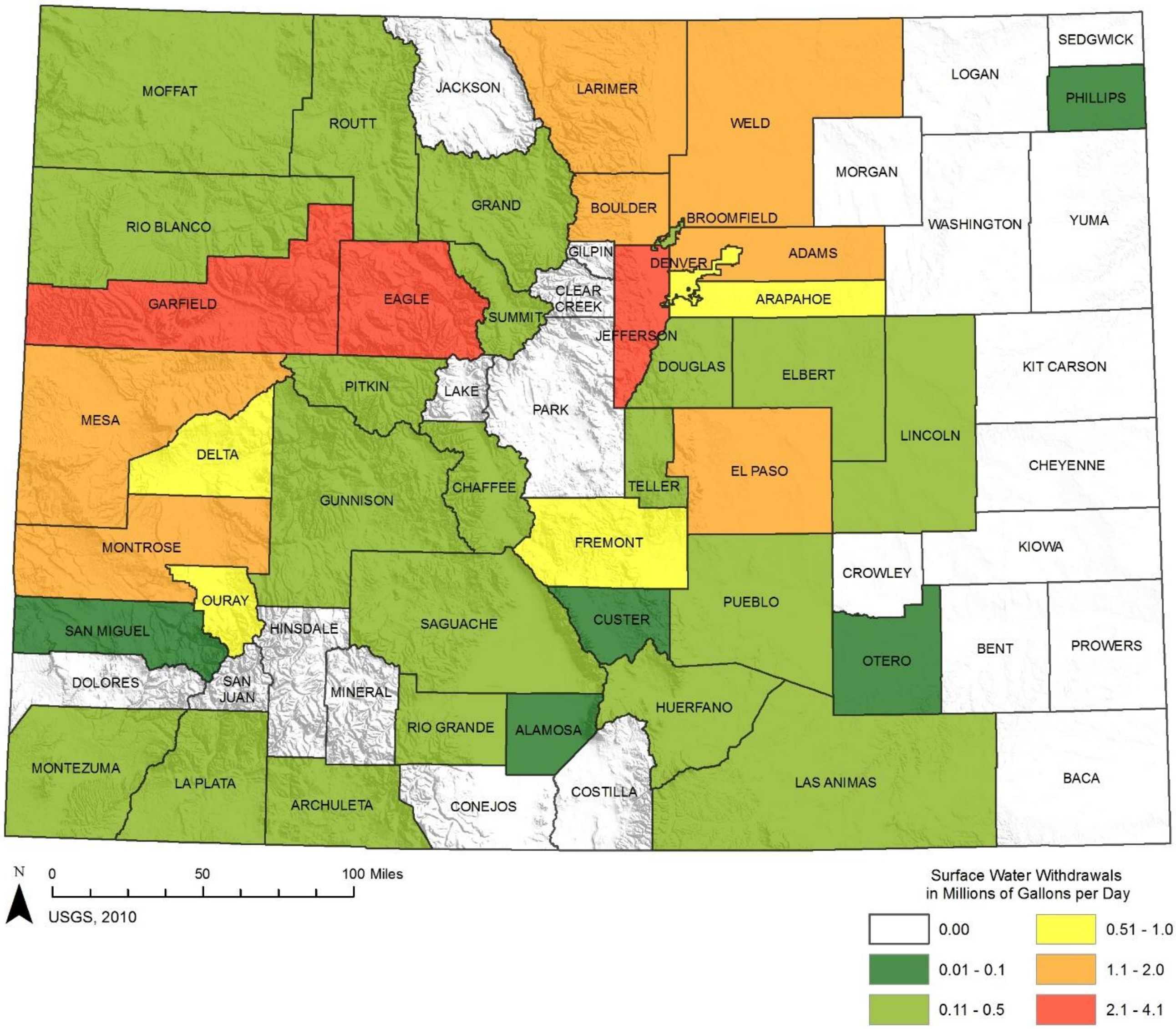
[2] All figures referenced in this section are located at the end of Section 10.1, before the start of the Vulnerability discussion.
[3] https://www.coloradoavidgolfer.com/courses/

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).

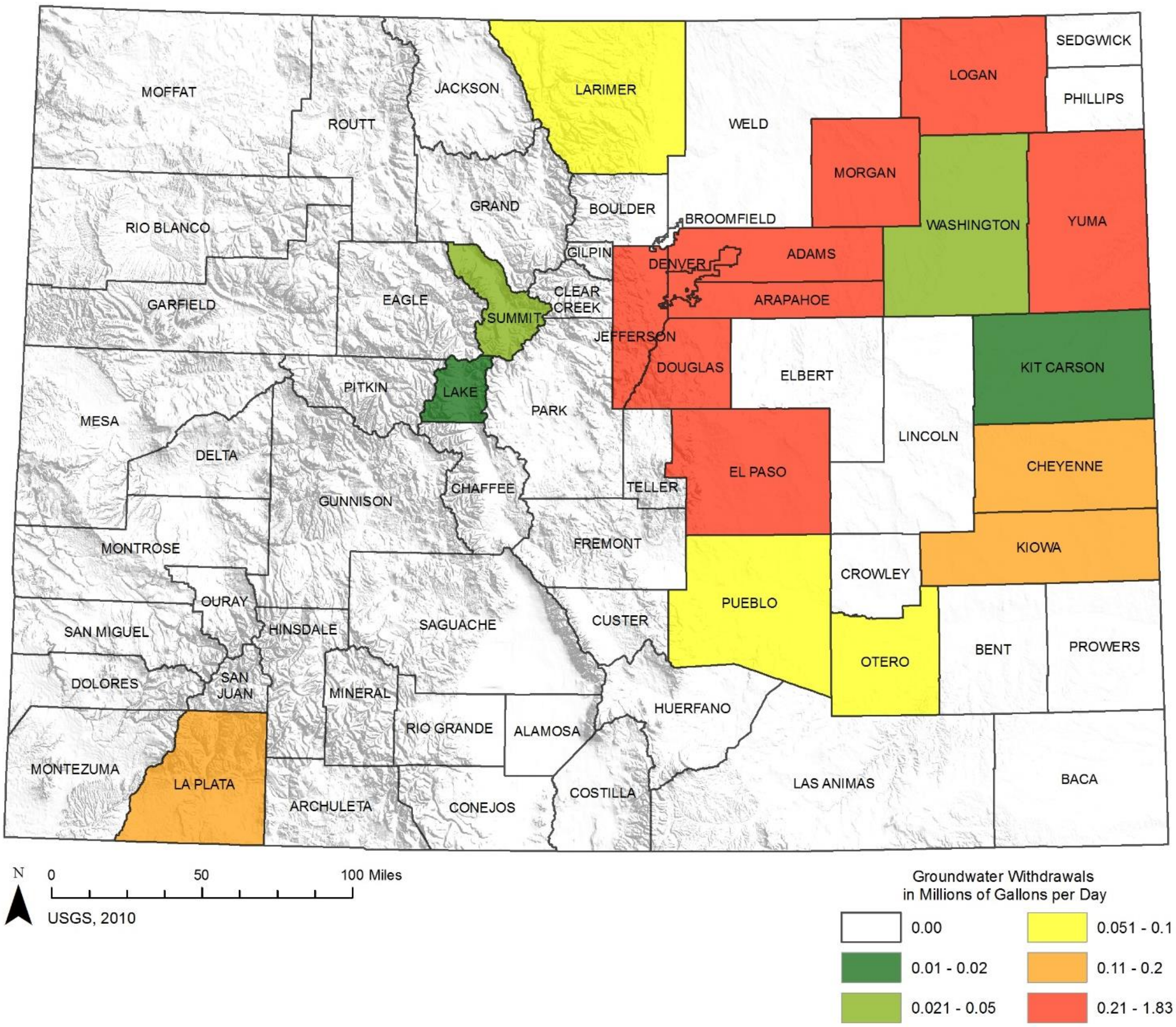
The USGS report included a table showing the estimated golf course irrigation water use by source water (i.e., surface, groundwater, potable water, or reclaimed wastewater). Although the data are available, it is not possible to make a general statement about what type of irrigation water is more vulnerable 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

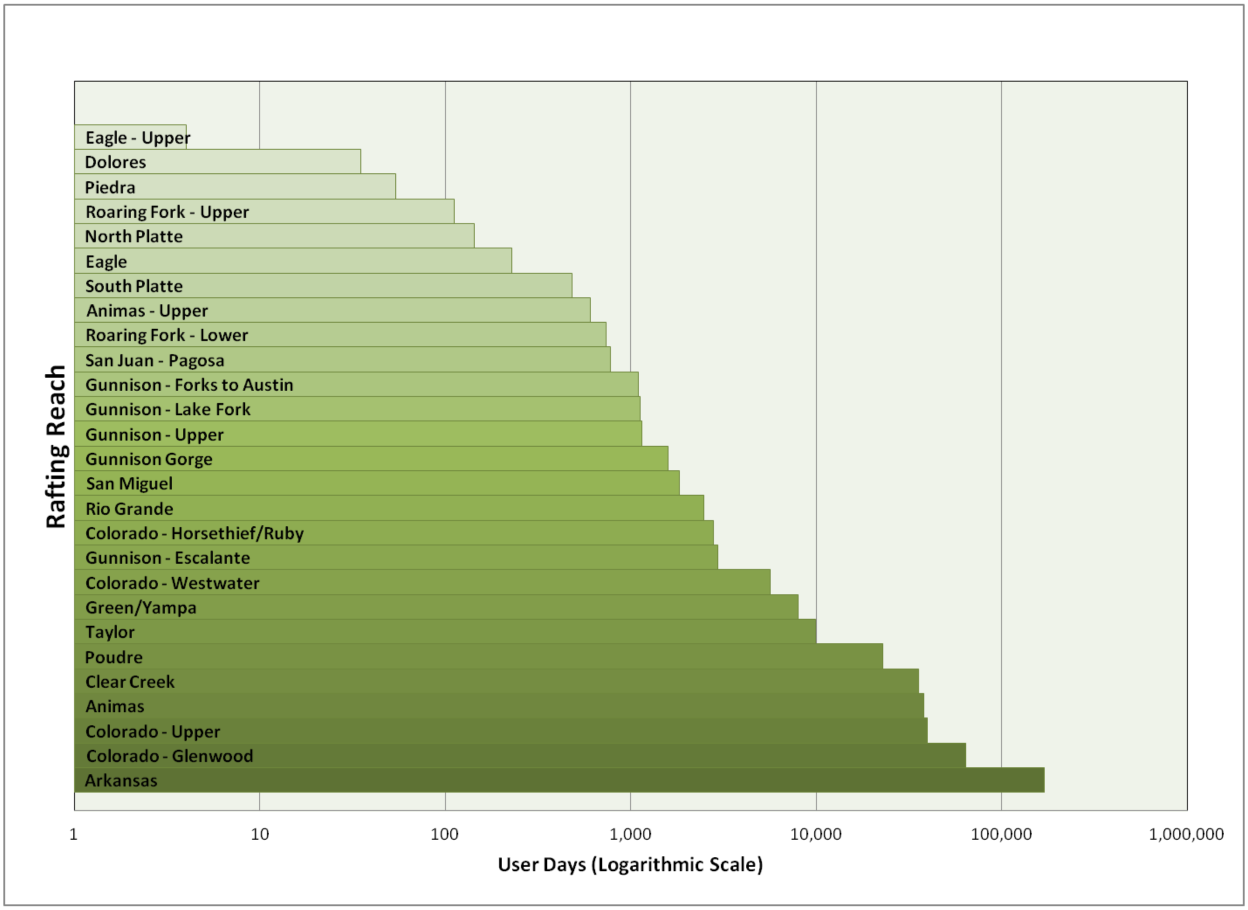
Whitewater rafting, kayaking, and canoeing take place on rivers and streams throughout Colorado. Whitewater rafting in particular is a segment of the tourism industry that has a significant presence in certain areas of the state. Commercial rafting outfitters will be the focus of this sub-sector, and 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 days[4] 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.

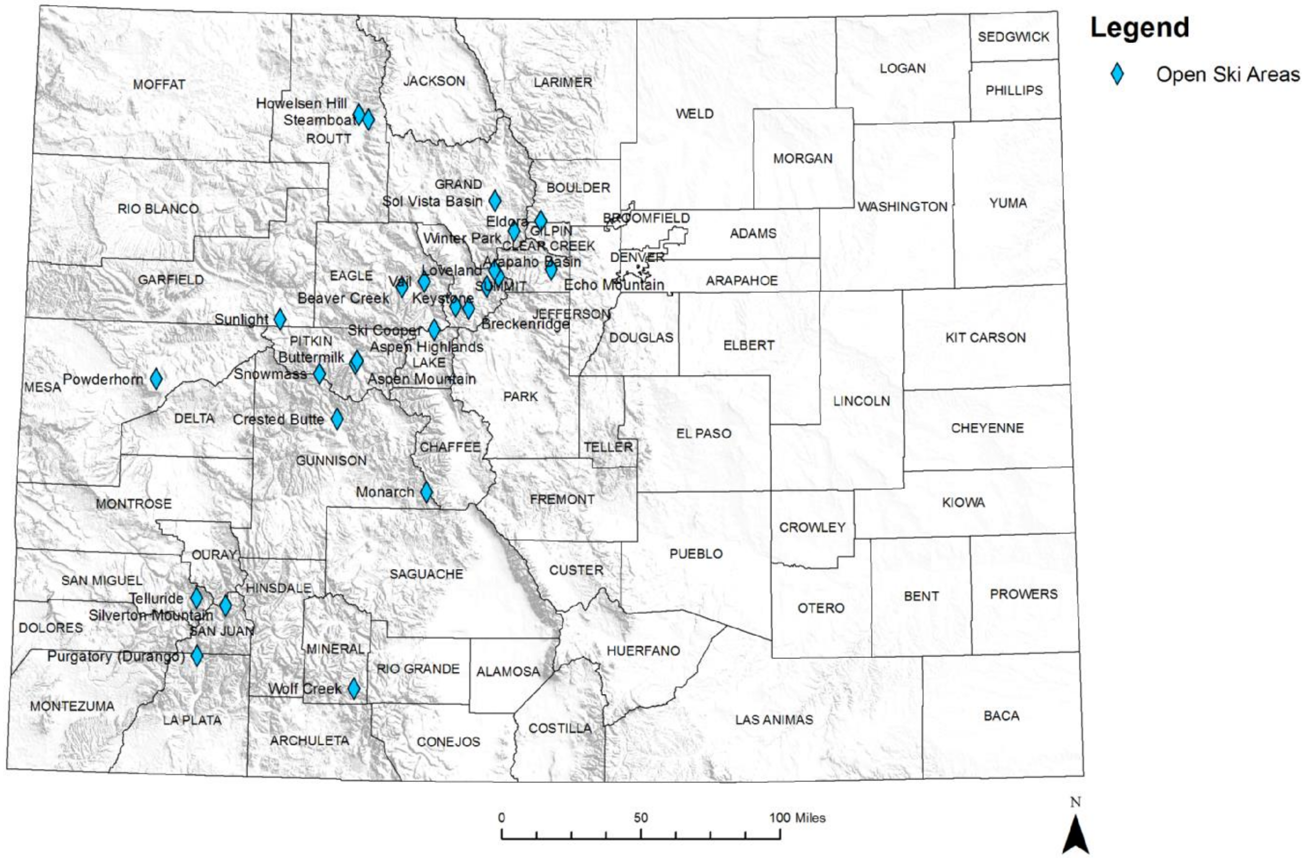
3) Cross-country and back country skiing, snowshoeing, and 10th Mountain Division hut trips. The revenue from these activities is generally much less significant in comparison to downhill skiing at established resorts.

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.

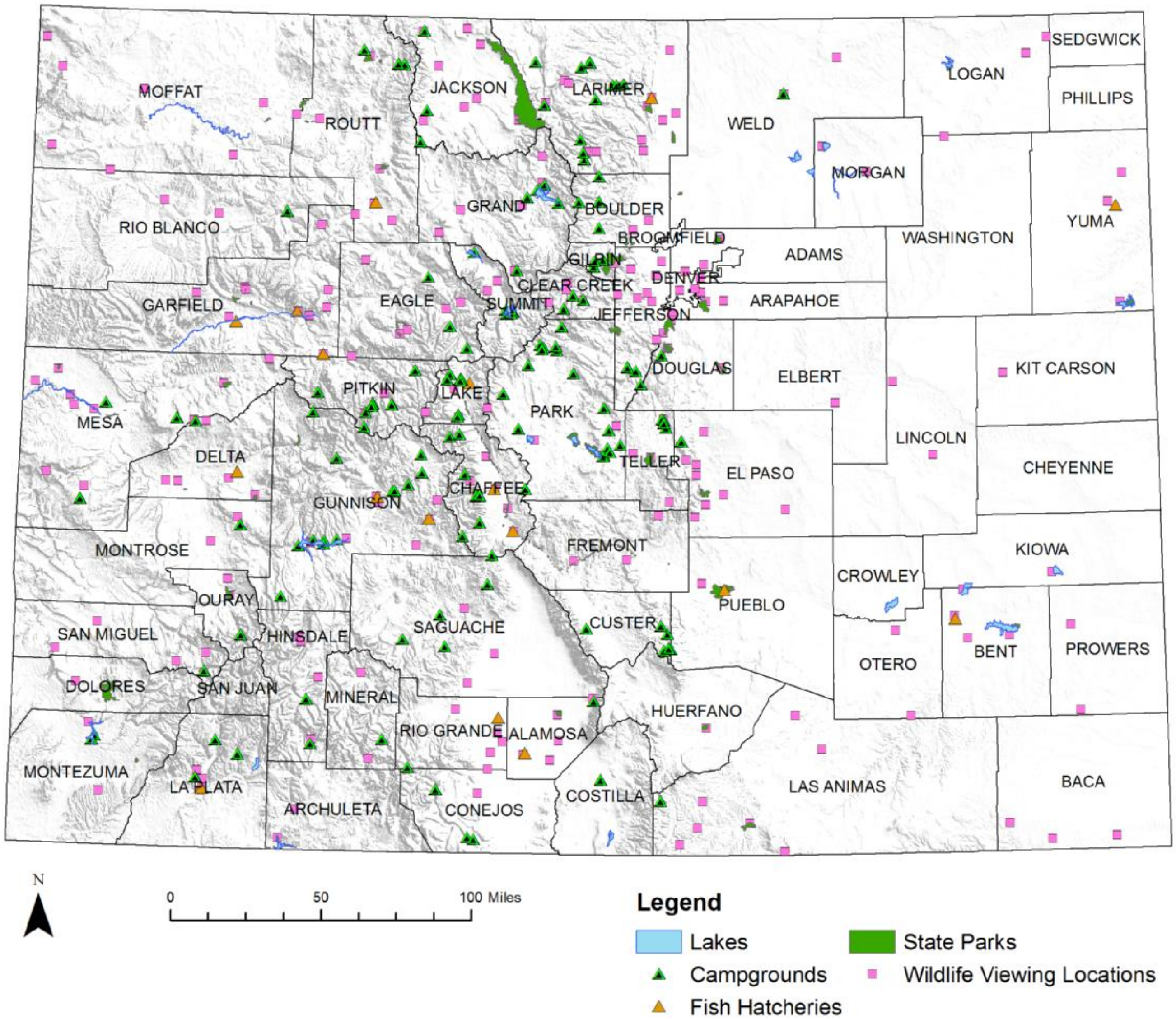
As evidenced by the previous discussion, the Recreation Sector is quite diverse, and ties into numerous other sectors of the economy and state; namely the Environment, State Assets, and Agriculture Sectors. The following sections discuss aspects of vulnerability to drought in the Recreation Sector and 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)

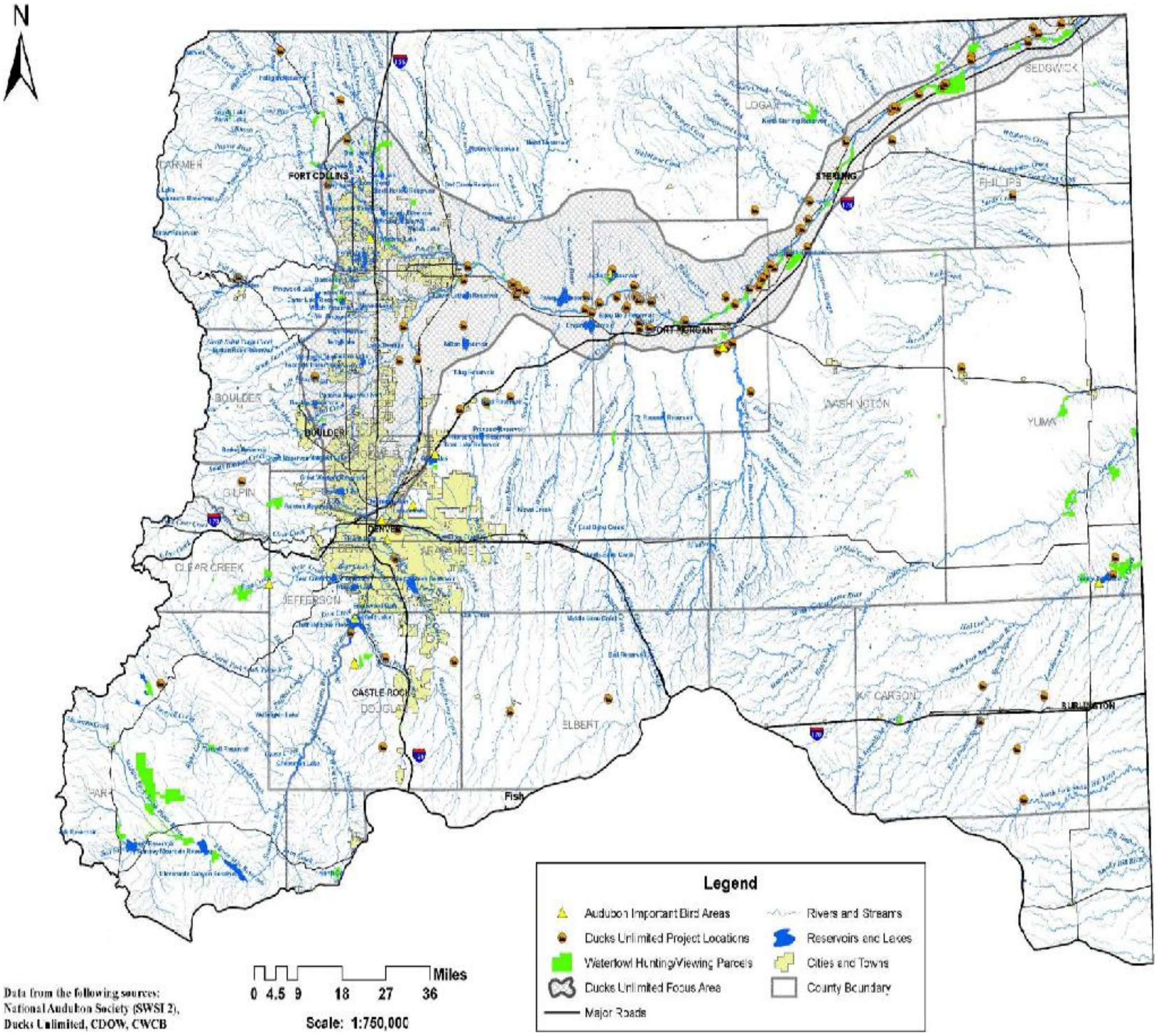
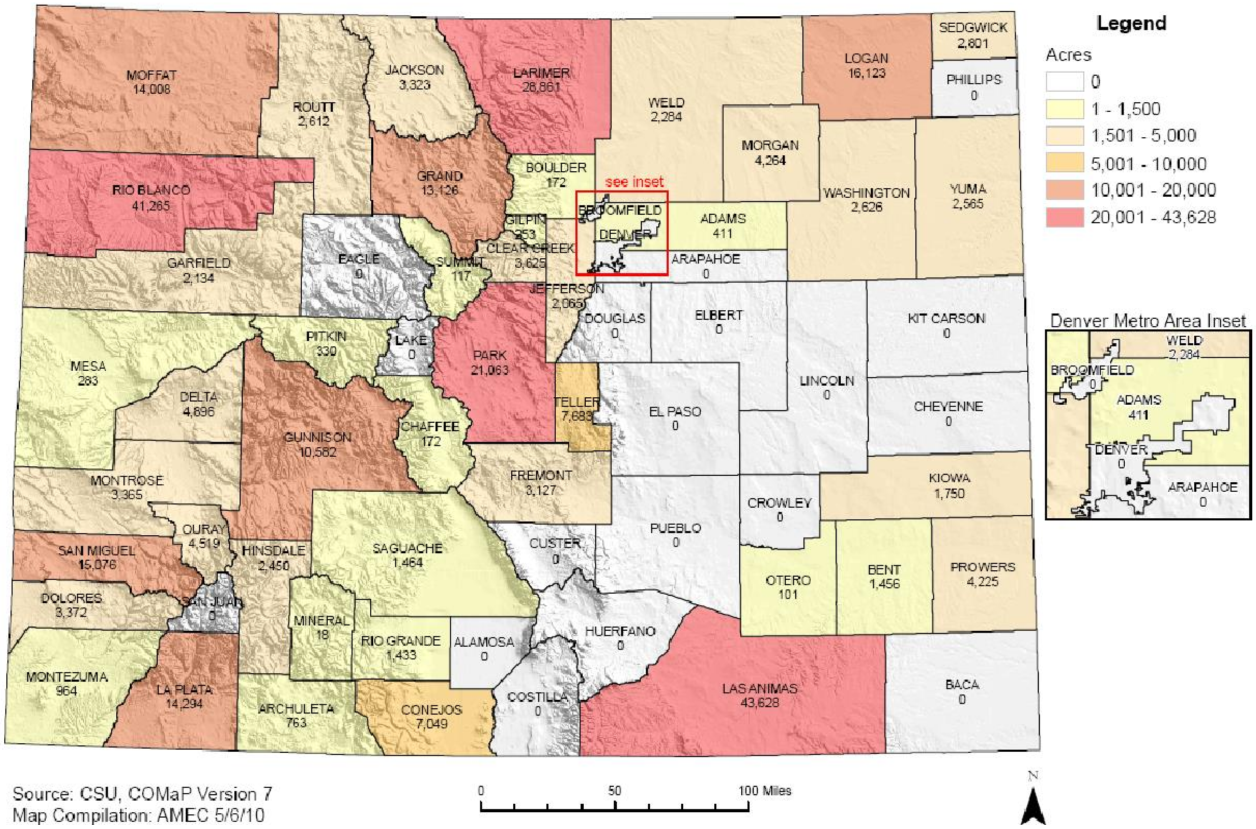


Figure 10.8 CPW Owned or Managed Lands in Colorado



Source: CSU, COMaP Version 7
Map Compilation: AMEC 5/6/10

Figure 10.9 Golf Courses in Colorado

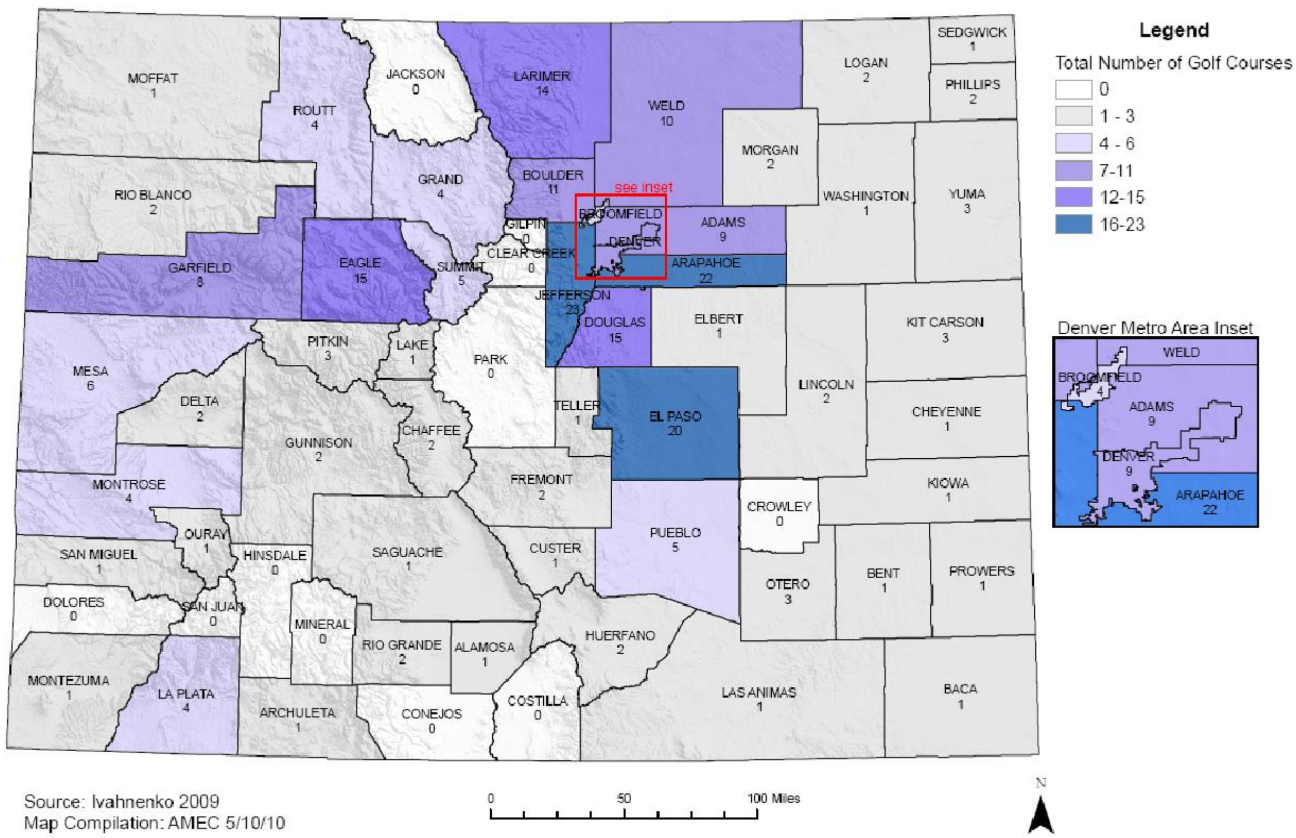
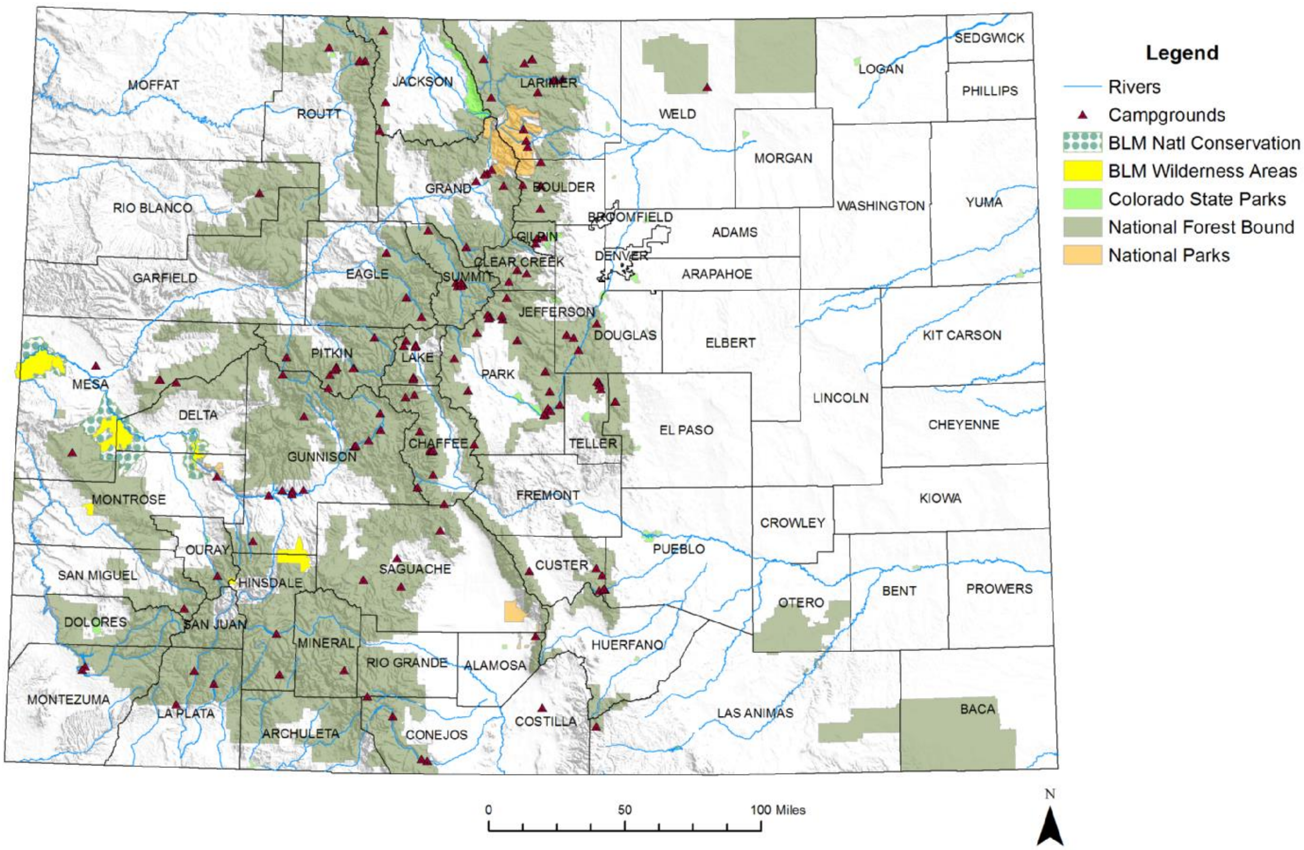
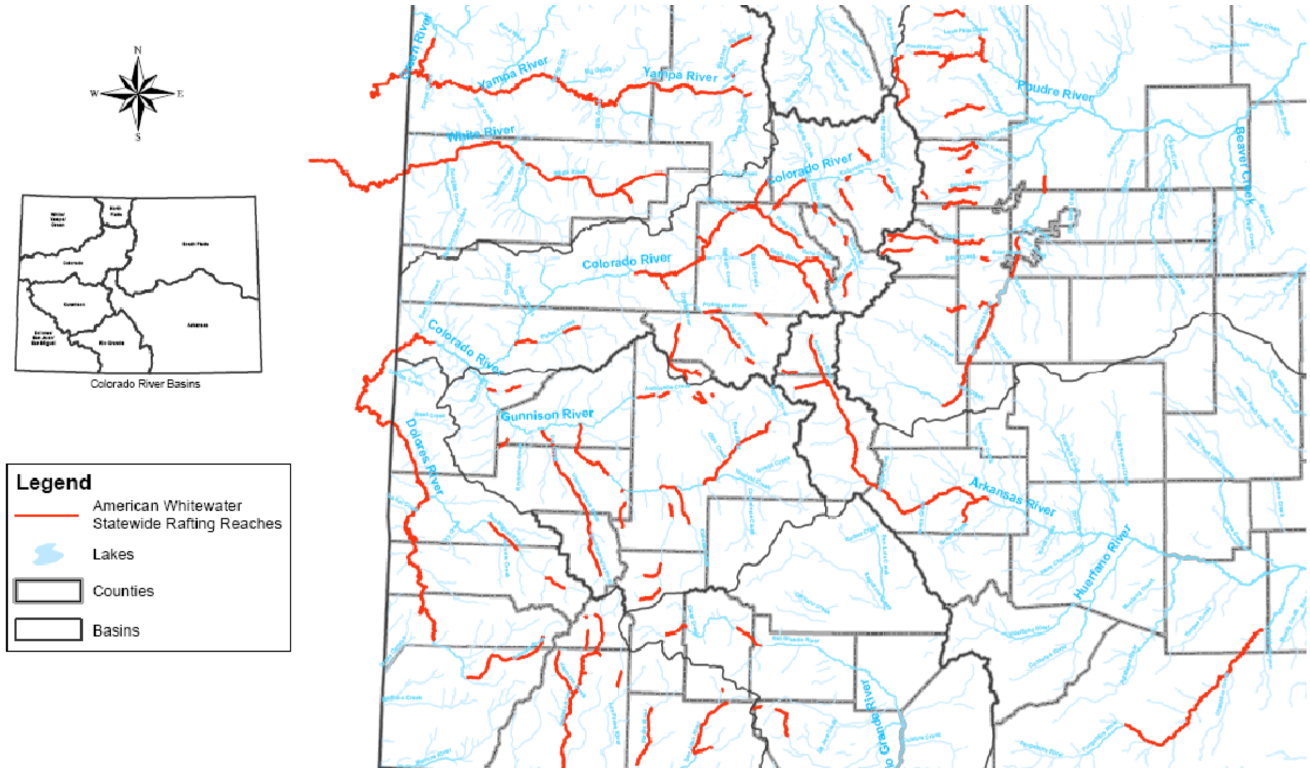


Figure 10.10 Recreation Areas in Colorado



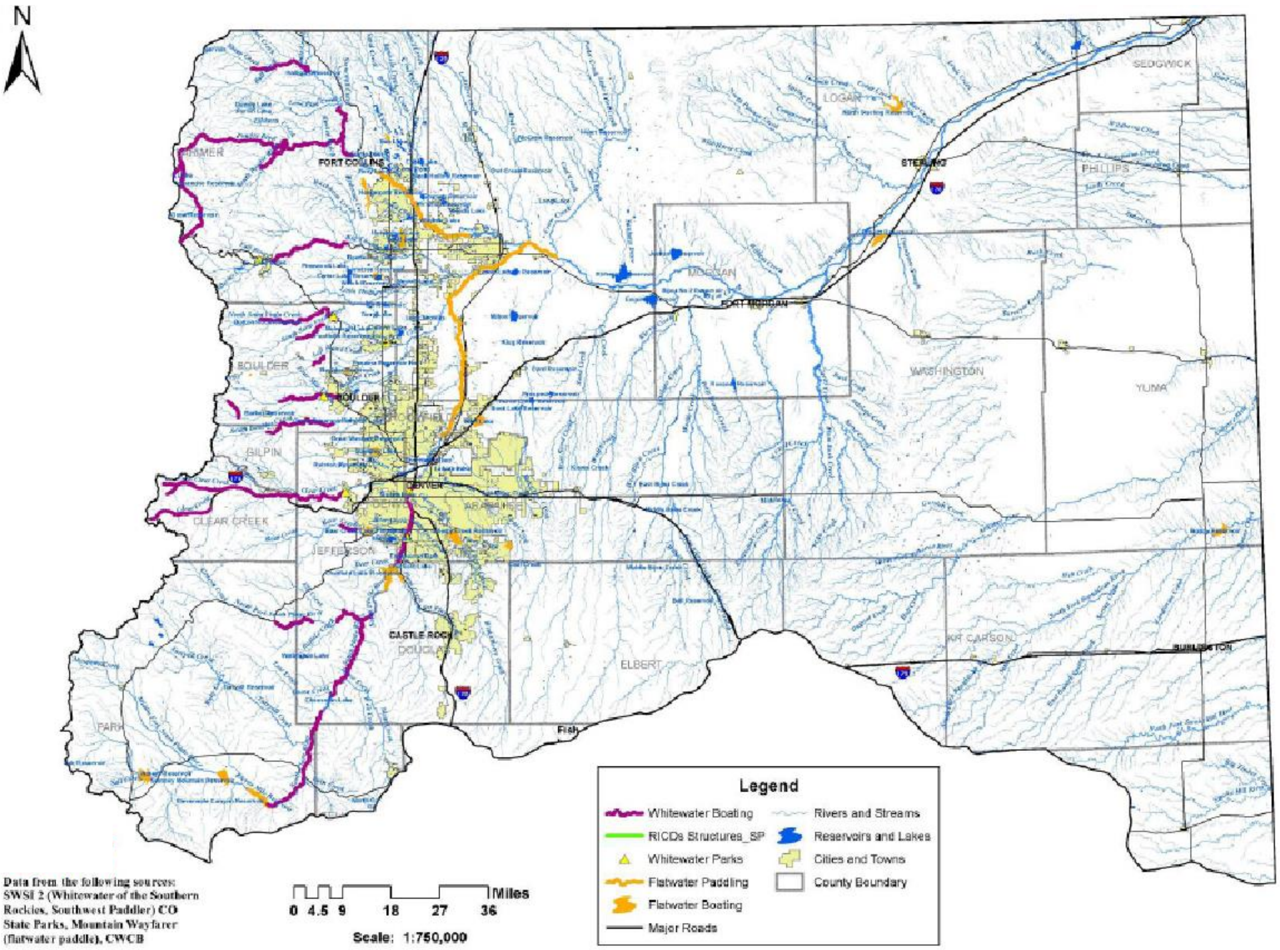
Source: BLM, NFS, State Parks

Figure 10.11 American Whitewater Statewide Rafting Reaches



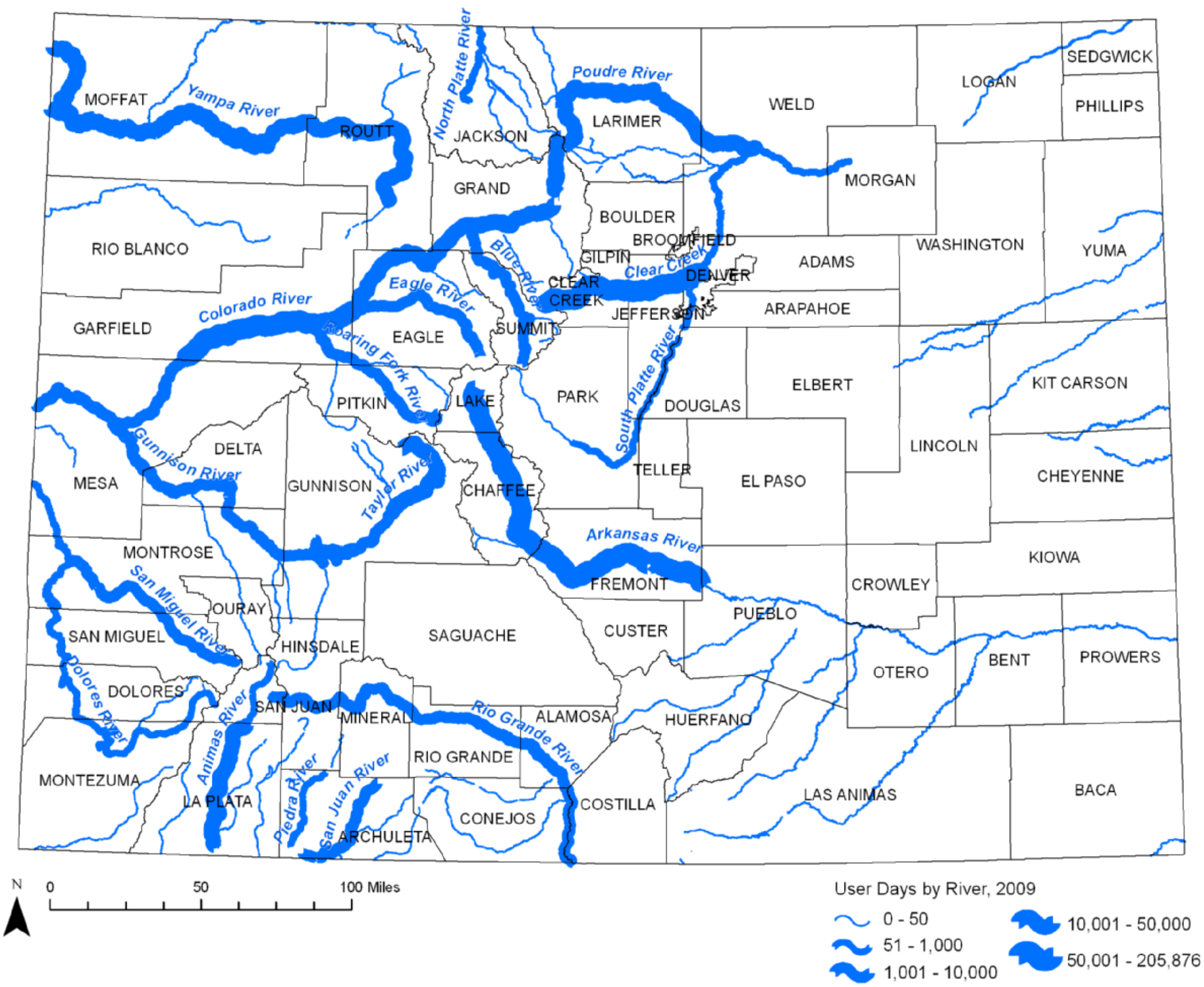
Source: SWSI Phase 2 (TNC, SWSI, CWCB, 2007)

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	Winter season drought (i.e., less-than-normal snowfall) can impact ski area revenues if potential skiers are deterred. 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. Seasonal staff could be laid off if skier visitation stays low.
Wildlife viewing	Stress to animals due to lack of water, loss of vegetative cover, and/or heat could keep them away from traditional viewing areas.
Hunting, fishing, and camping	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. Animal scarcity and/or loss of vegetative cover could detract hunters and result in decreased hunting license revenue for the CPW. With less resources (food, water, habitat) available, population production and recruitment will likely decrease for many species. 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. 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. Fish scarcity could detract anglers and result in decreased fishing license revenue for the CPW (public perception). 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. 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).
Golfing	Water scarcity and/or municipal restrictions could cause parts of course to become harder to play, go brown, or otherwise become stressed.

Sub-sector	Potential Impacts
	Drought-stressed turfgrass has diminished playability and performance, resulting in fewer golfers and a loss of revenue. 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. Golfer participation could decrease due to negative perception of course aesthetics, and/or courses could face higher operating costs to maintain existing turf. 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.
Boating	Lower reservoir and lake levels could detract boaters from visiting and/or registering their boats for a season. State Parks could experience decreased revenues due to lower visitation and registration.
Rafting	Lower streamflows could force rafting outfitters to use smaller boats, resulting in less revenue per trip. Negative public perception of drought and associated hazards (e.g., wildfires) could result in decreased rafting customers and/or cancellations.

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	Use snowmaking machines to better predict and control season opening date; this also helps mitigate against lack of natural snow later in the season. 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. 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).
Wildlife viewing	CPW feeding programs to avoid catastrophic animal loss.
Hunting, fishing, and camping	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). CPW can implement drought specific herd management principles for priority game species (CPW, 2012). Fish hatcheries can transfer fish to streams, lakes, and/or other hatcheries that are not as negatively impacted. Campsite managers can advertise areas that are not impacted (if such areas exist).

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. For the 2011/12 season, skier visits to Colorado Ski Country USA (CSCUSA) resorts were down 11.9%.	Wilhelmi et al. 2004 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 28th, 2012.	
Wildlife viewing	Documented cases of birds shifting their migratory grounds in response to environmental changes, including higher temperatures often associated with drought. 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. Animals may move to higher elevations to avoid warm temperatures during summer drought.	Audubon 2009 Audubon 2010 Kohler 2010
Hunting, fishing, and camping	The State released 16,000 extra cow elk licenses in September for fear that the elk would die over the winter anyway. 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.	Luecke et al. 2003 Schneckenburger and Aukerman 2002
Golfing	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. 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).	Watson et al. 2004 Communication with Golf Course Superintendents Association of America 2010
Boating	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. 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.	Luecke et al. 2003 Wilhelmi et al. 2004 Schneckenburger and Aukerman 2002
Rafting	Trip cancellations and significant customer declines; forced to lay off staff; increased injury among guides due to low water levels. 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. 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. The total estimated economic impact of the 2012 drought on the rafting industry was approximately $128 million	Shrestha 2009 SWSI Phase 1 2004 CROA, 2012 CROA, 2012

The 2012 Drought Assessment for Recreation & Tourism (DART) study was funded by the CWCB 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 Map[6] 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 CWCB 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.

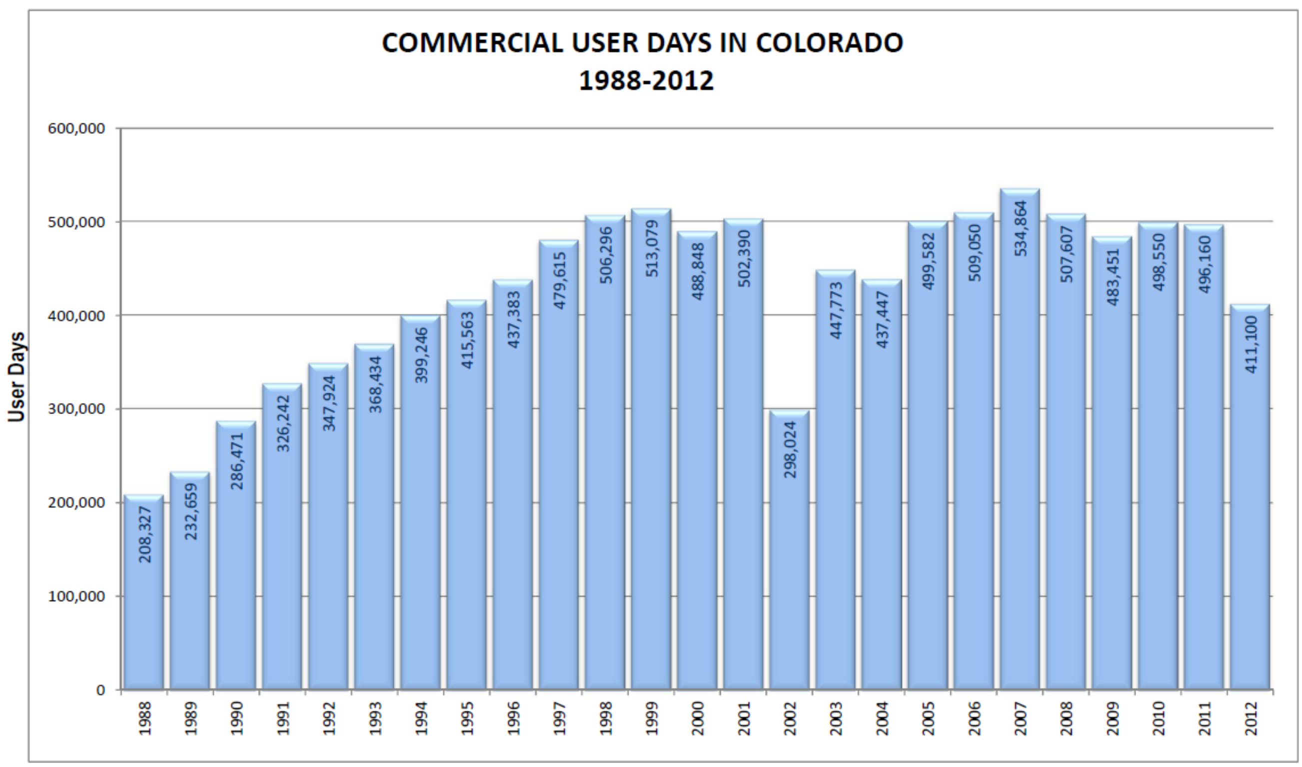
Given that there are multiple options of water sources for golf courses to obtain irrigation water (e.g., surface, ground, potable, and reclaimed), it is safe to say that diversifying the supply would provide a measure of protection against one source being cut off or depleted in a drought.

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 - Loma	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 on 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

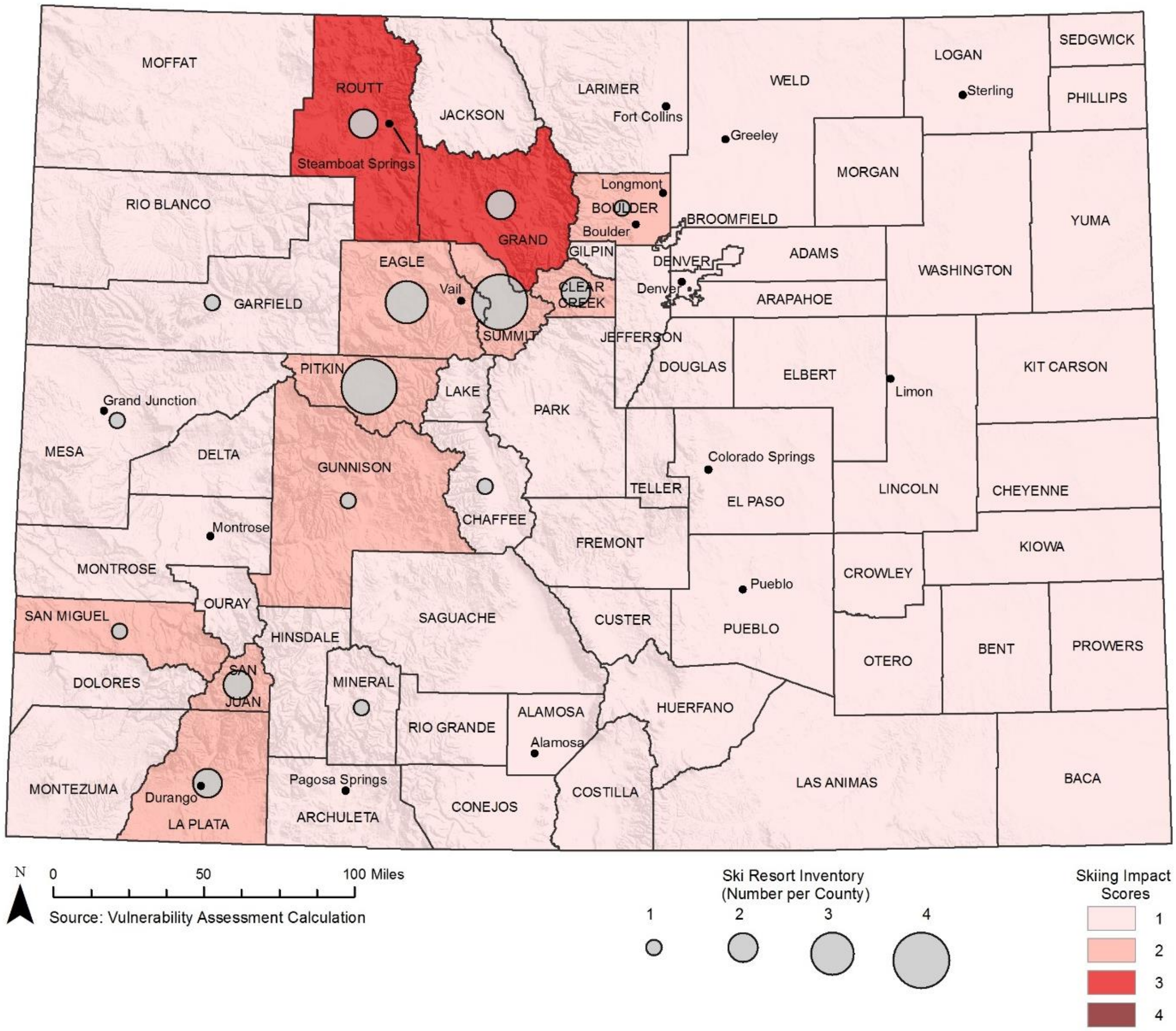


Figure updated 2018.

Figure 10.16 Wildlife Viewing Inventory and Impact Scores

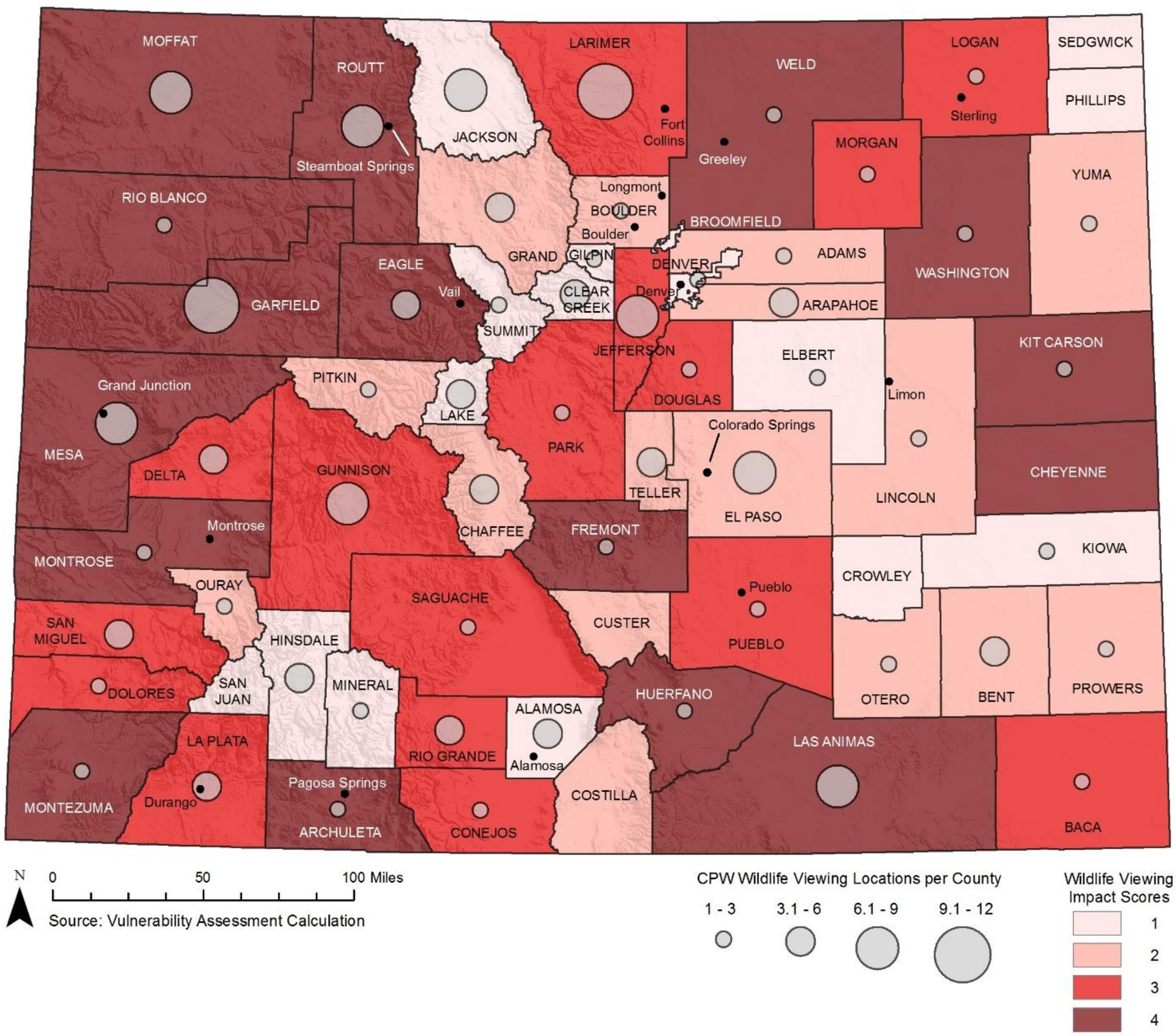


Figure Updated 2018

Figure 10.17 Hunting, Fishing, and Camping Inventory and Impact Scores

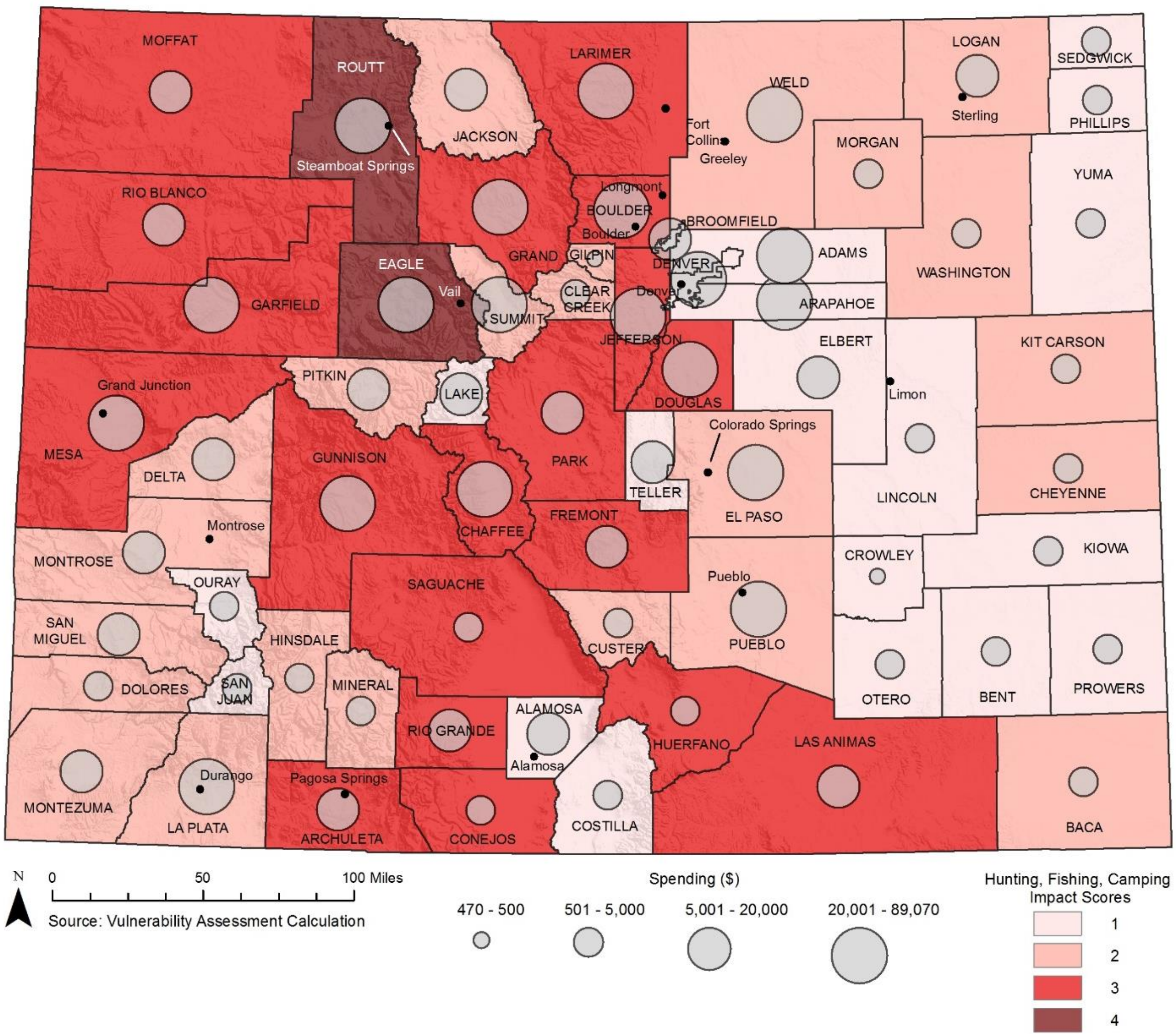


Figure updated 2018

Figure 10.18 Golf Course Inventory and Impact Scores

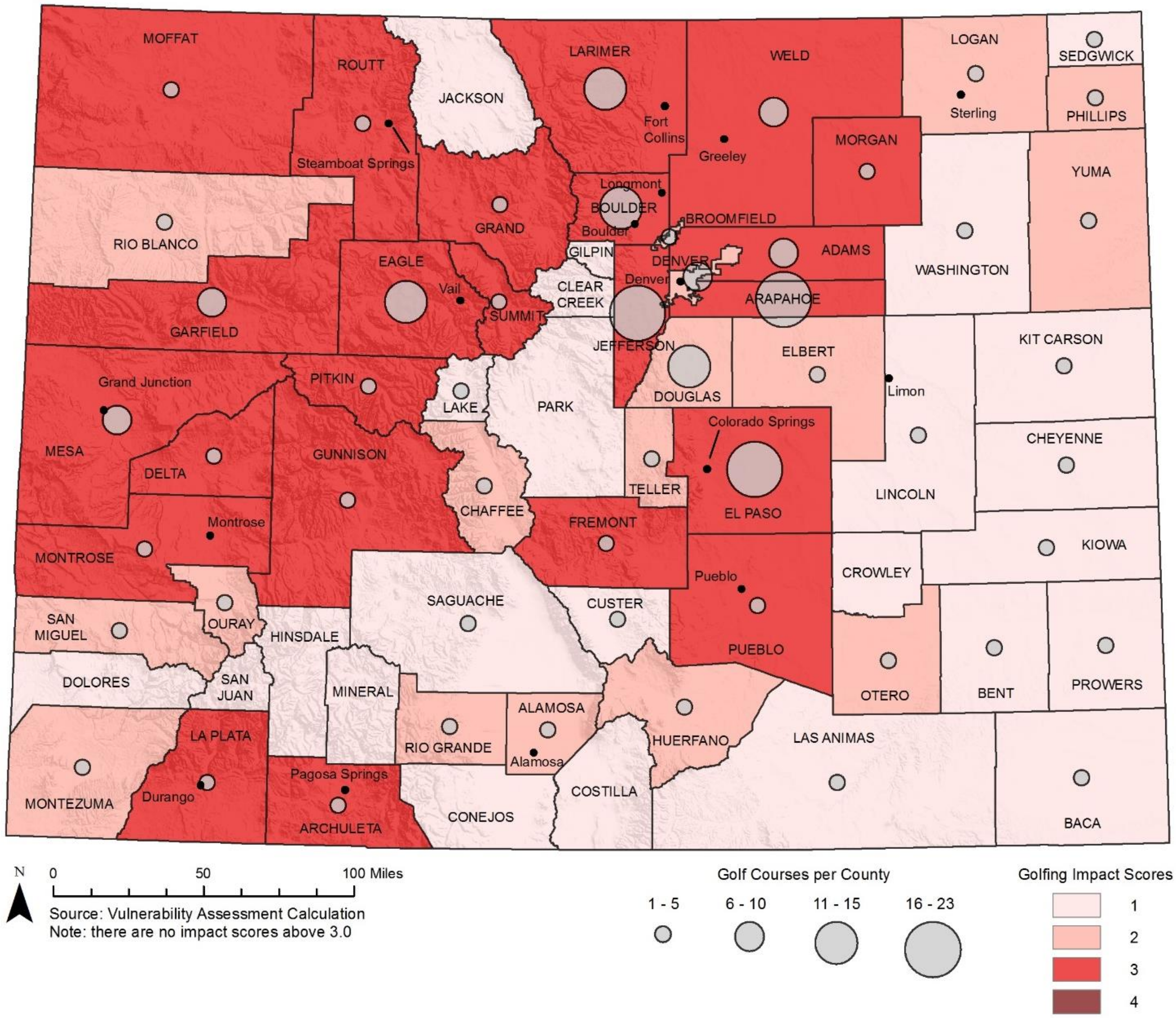


Figure updated 2018

Figure 10.19 Boating Inventory and Impact Scores

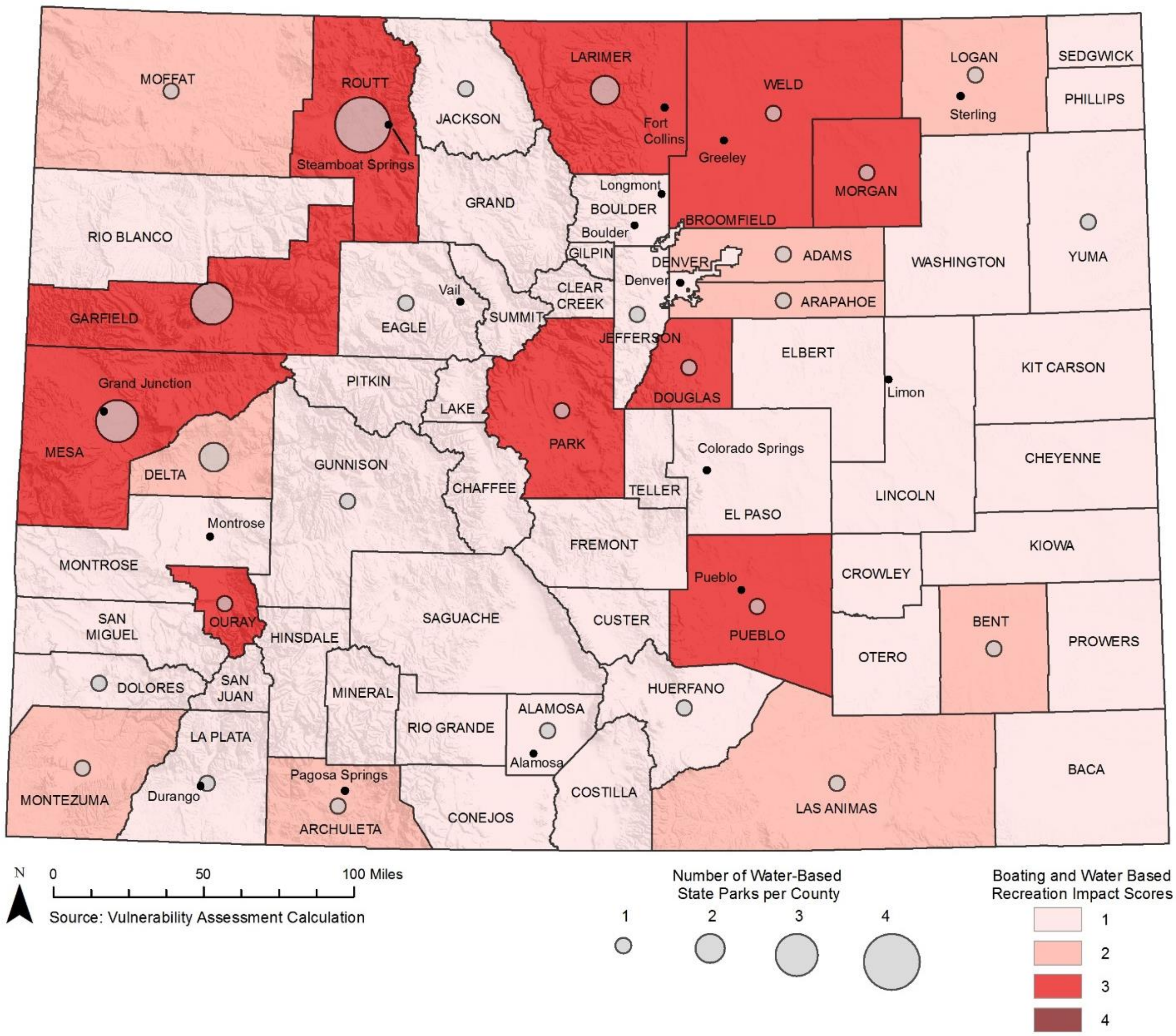


Figure updated 2018

Figure 10.20 Rafting Inventory and Impact Scores

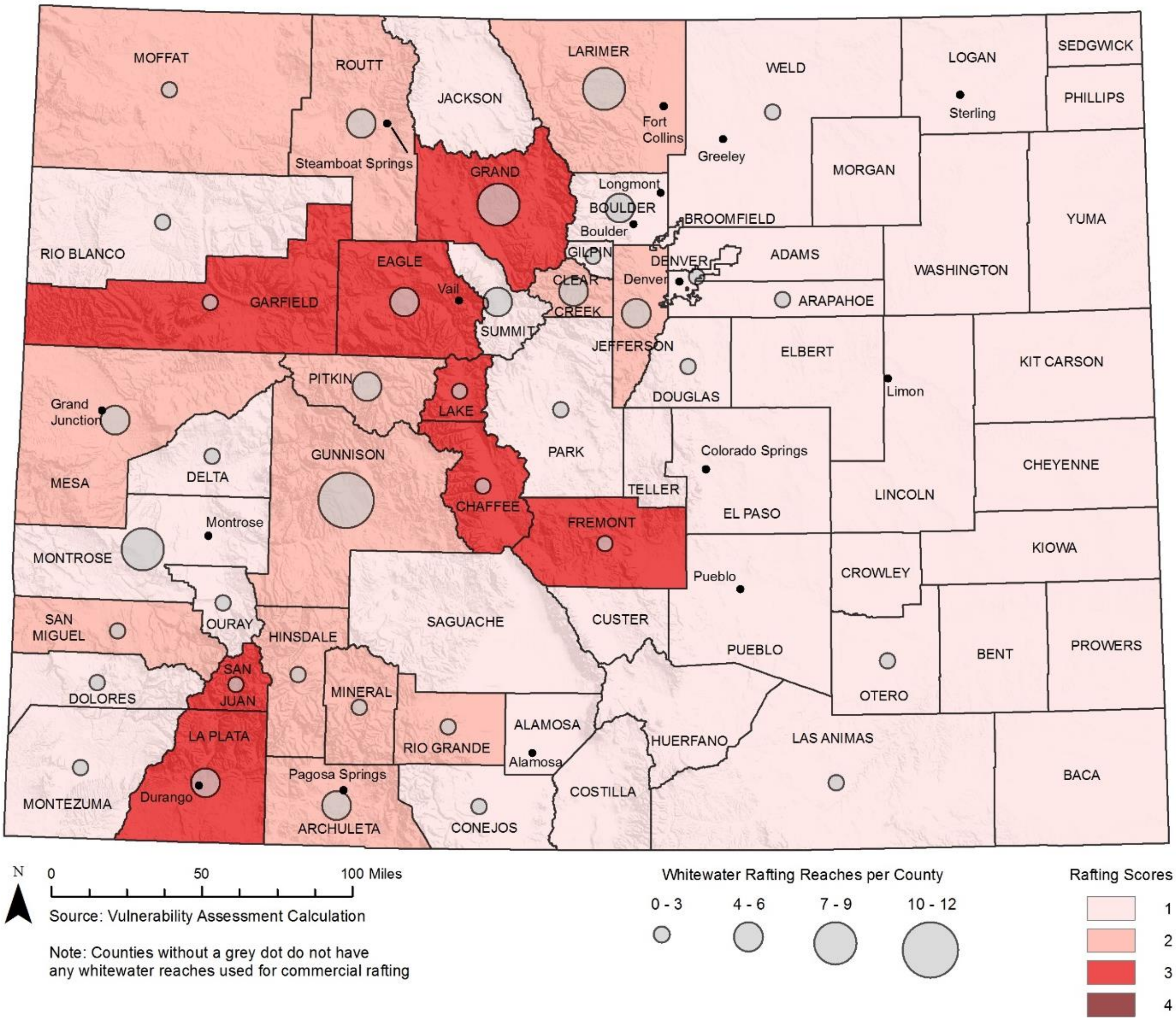


Figure revised 2018; no change to 2013 data.

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.

Figure 10.21 Overall Recreation and Tourism Vulnerability Scores

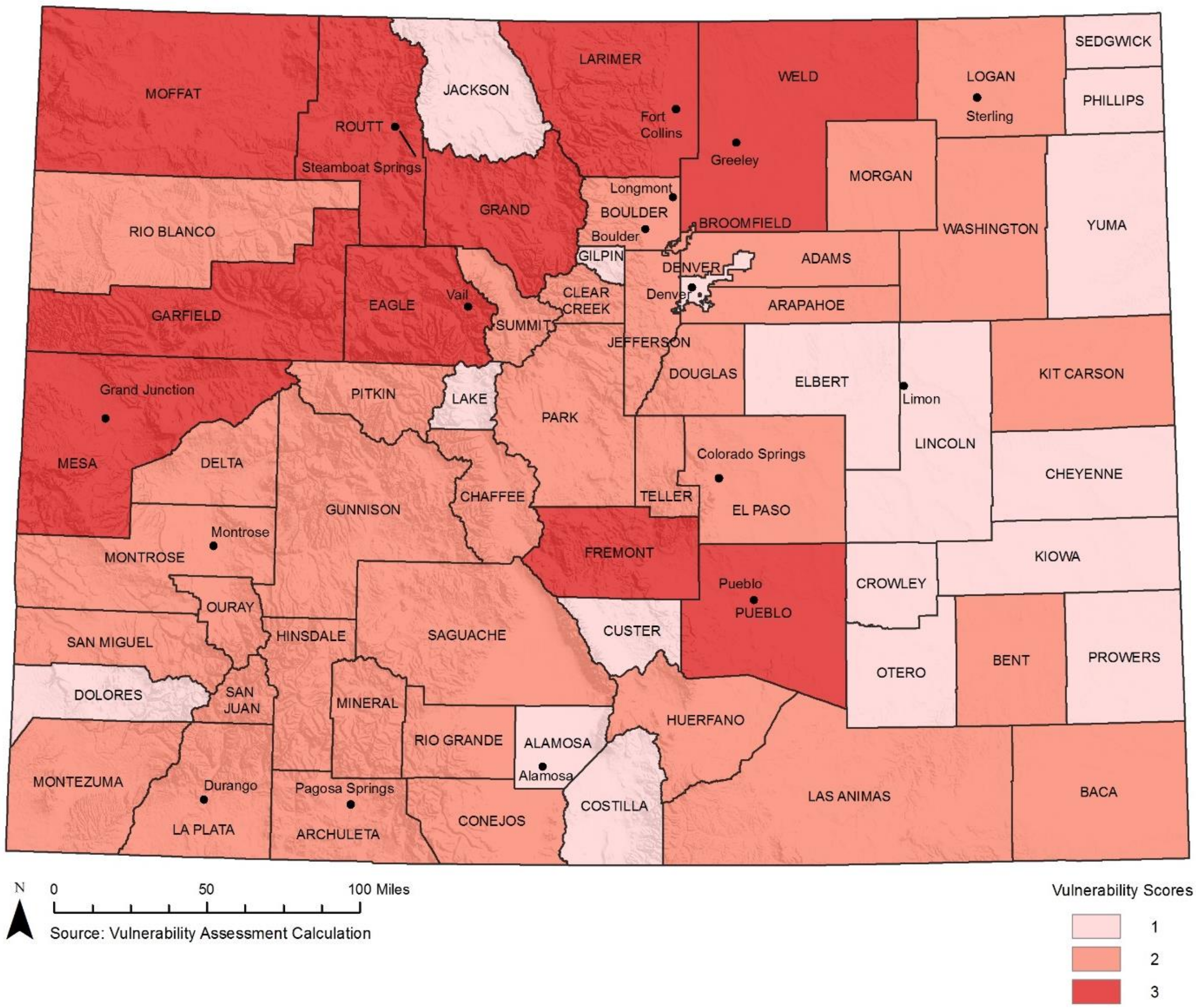


Figure updated for 2018.

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 forests[10]. 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, 2010[1]). 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	• Economic diversification • Cooperative alliances and community planning
Behavioral health impacts	• 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	• 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).

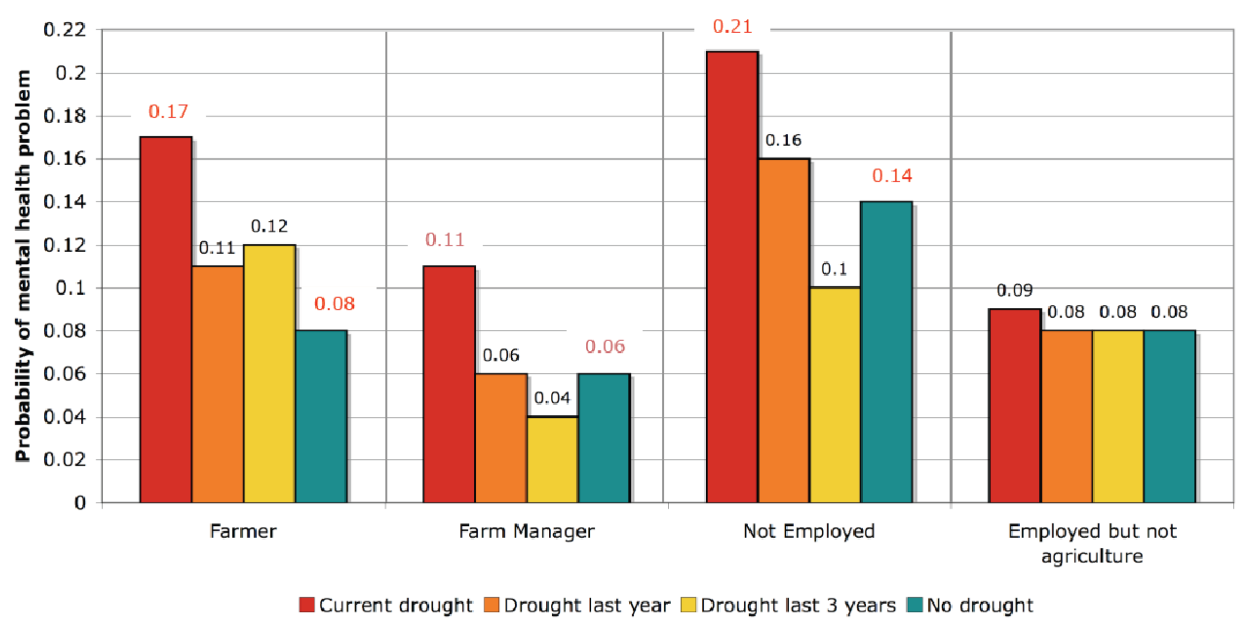
In Florida, a study was conducted to analyze the connection between St. Louis encephalitis outbreaks and drought using a dynamic hydrology model. This study found that springtime drought can force Cx. nigripalpus mosquitoes to breed in densely vegetated marsh habitats in close proximity to wild birds. 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 content 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

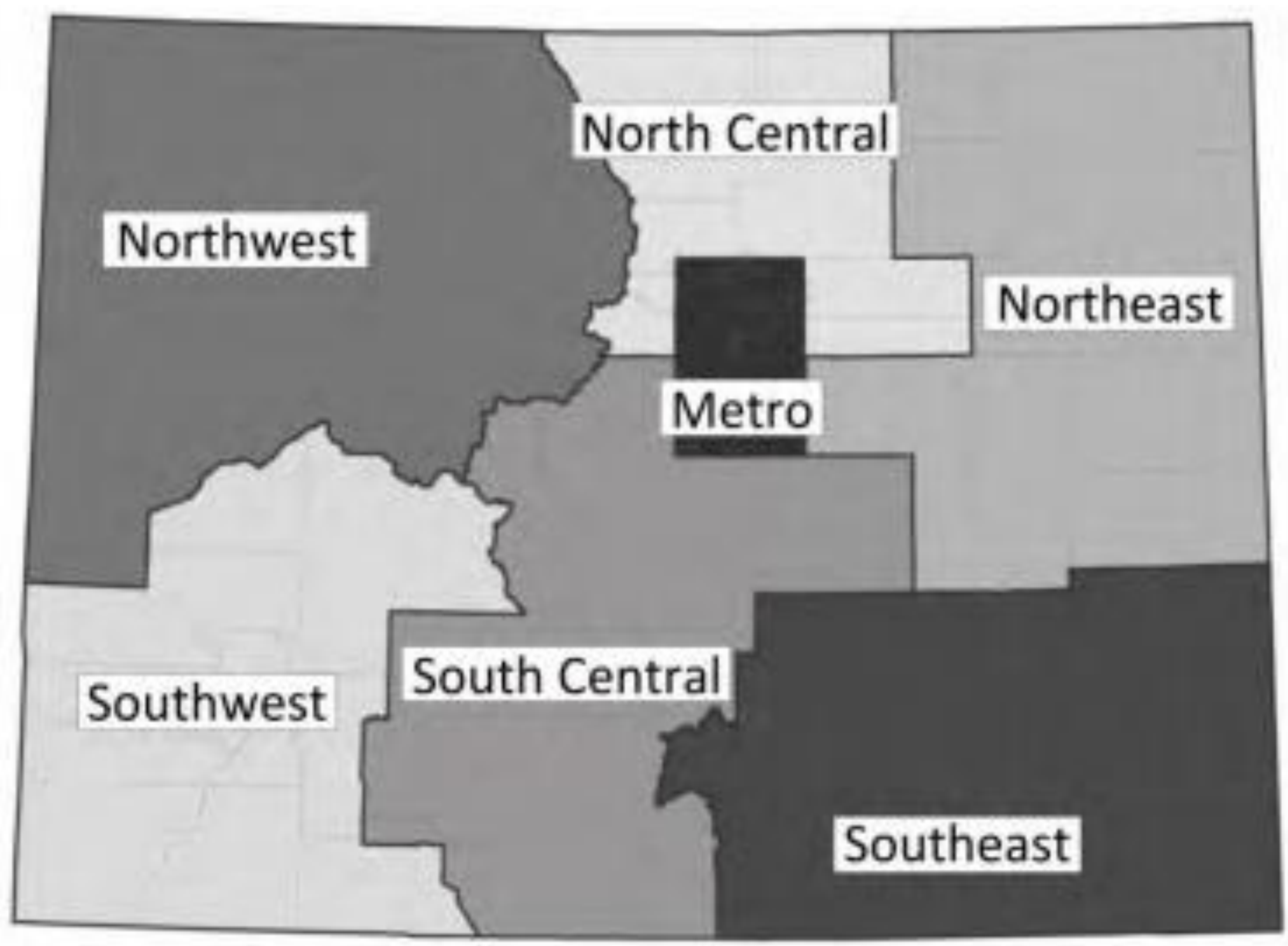
The five sub-sectors analyzed individually in this report were chosen based on importance to the economy of the State as well as water dependency. However, many industries not reliant on water are impacted by drought through their relationships with other sectors. The direct impacts of drought are just 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.

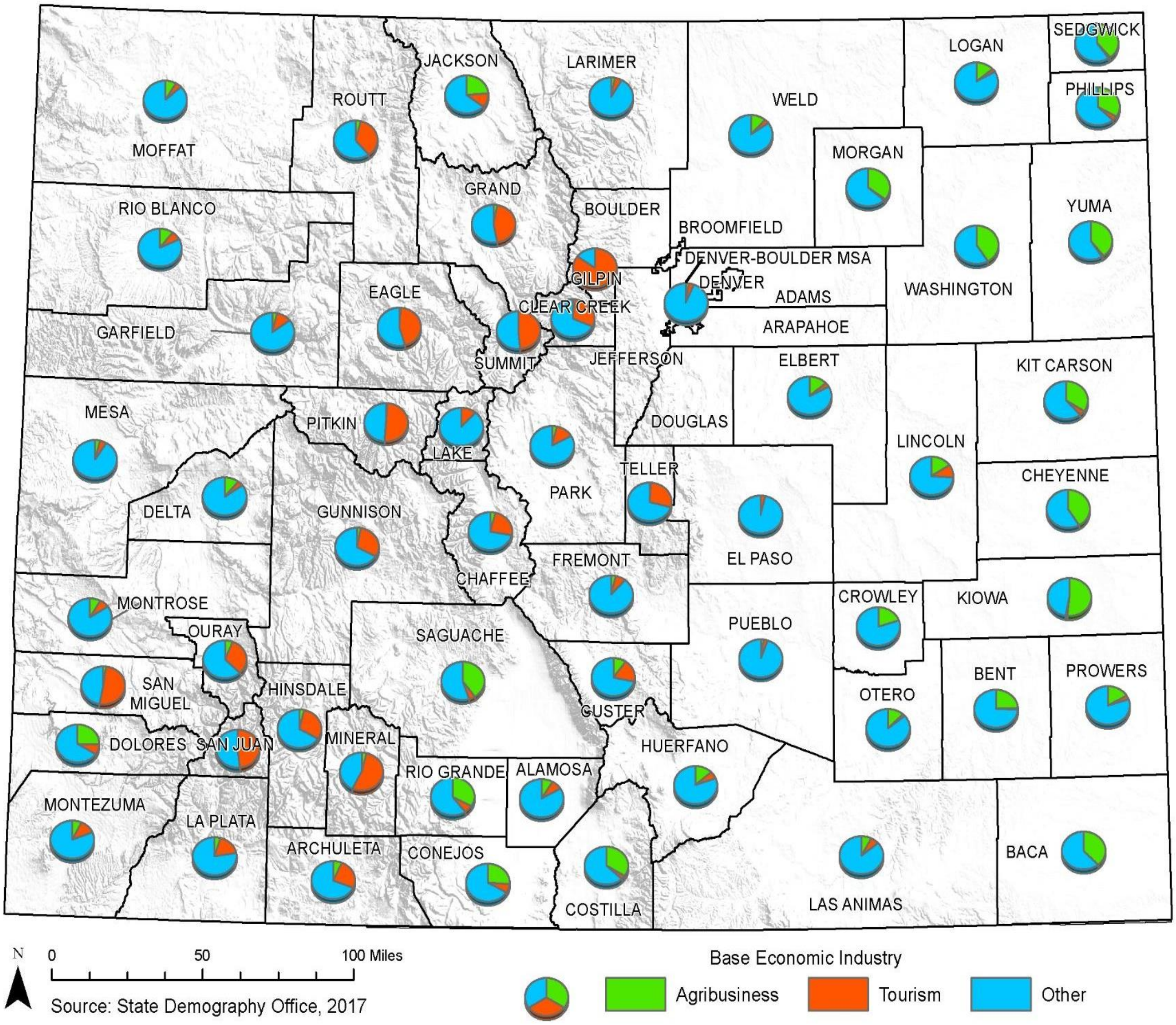
The studies discussed above provide quantitative information on how specific activities can connect to the larger economy. Results show that recreation and tourism in Colorado generate much more revenue than the licensing and park entrance fees alone. Overall spending is highest in counties with the 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…

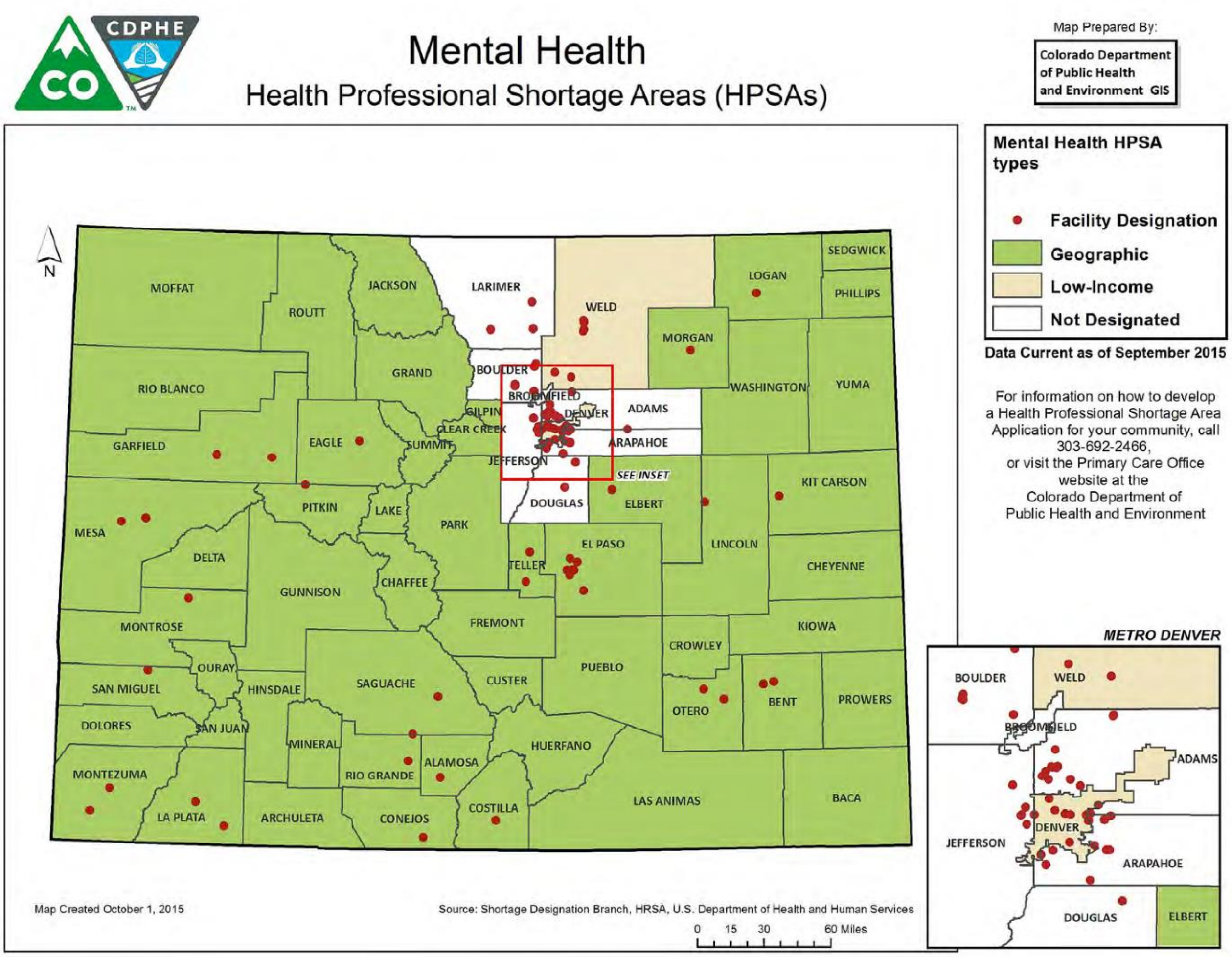
Next year, the wells may not get to pump. That would mean tens of thousands of acres of Colorado's farm ground will dry up and blow away, or there will be a lot of dryland wheat and small grains. We have farmers calling every day asking, "What should I plant? Will I have water next year?" We don't know. "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 significant 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 HSPAs 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 8^{th} most ozone-polluted urban area in America by the American Lung Association. Fort Collins was 10^{th}. Both cities saw a slight improvement in the 2017 rankings, when Denver moved from 8^{th} to 11^{th} and Fort Collins from 10^{th} to 15^{th} (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 (PM2.5) 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

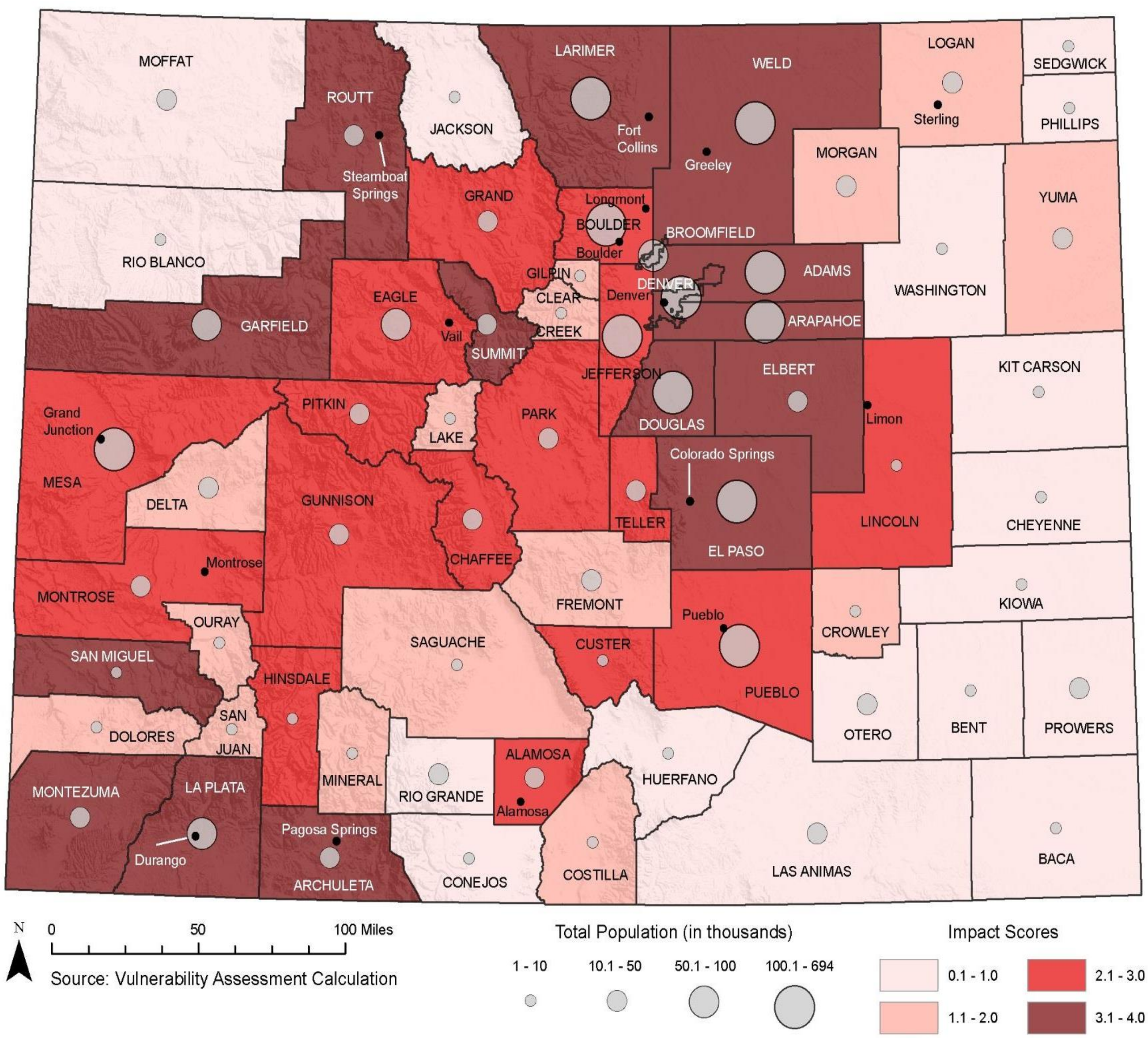


Figure 11-6 Economic Diversity Impact Score and Population Inventory by County

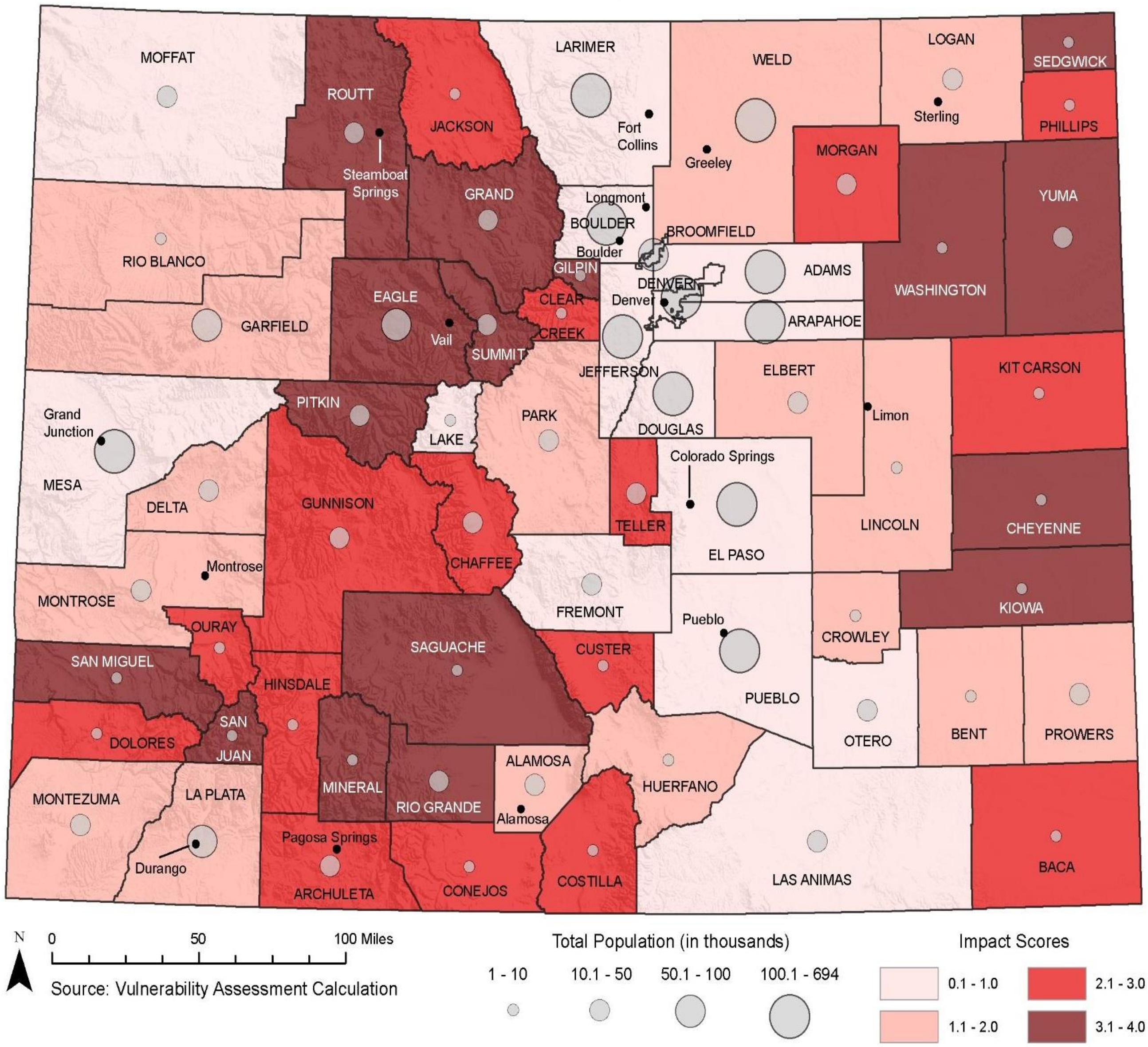


Figure 11-7 Socioeconomic Vulnerability Impact Score and Population Inventory by County

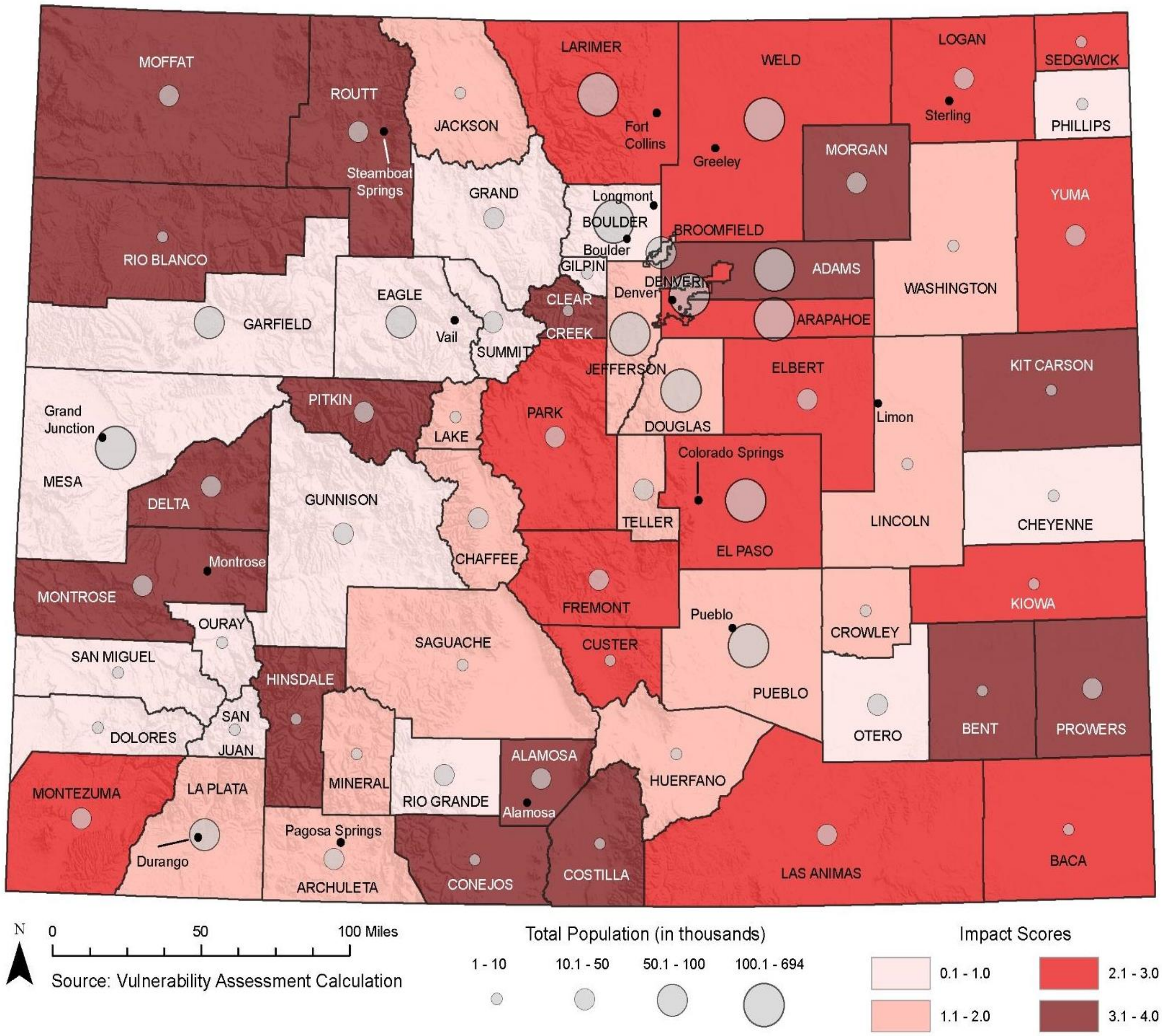
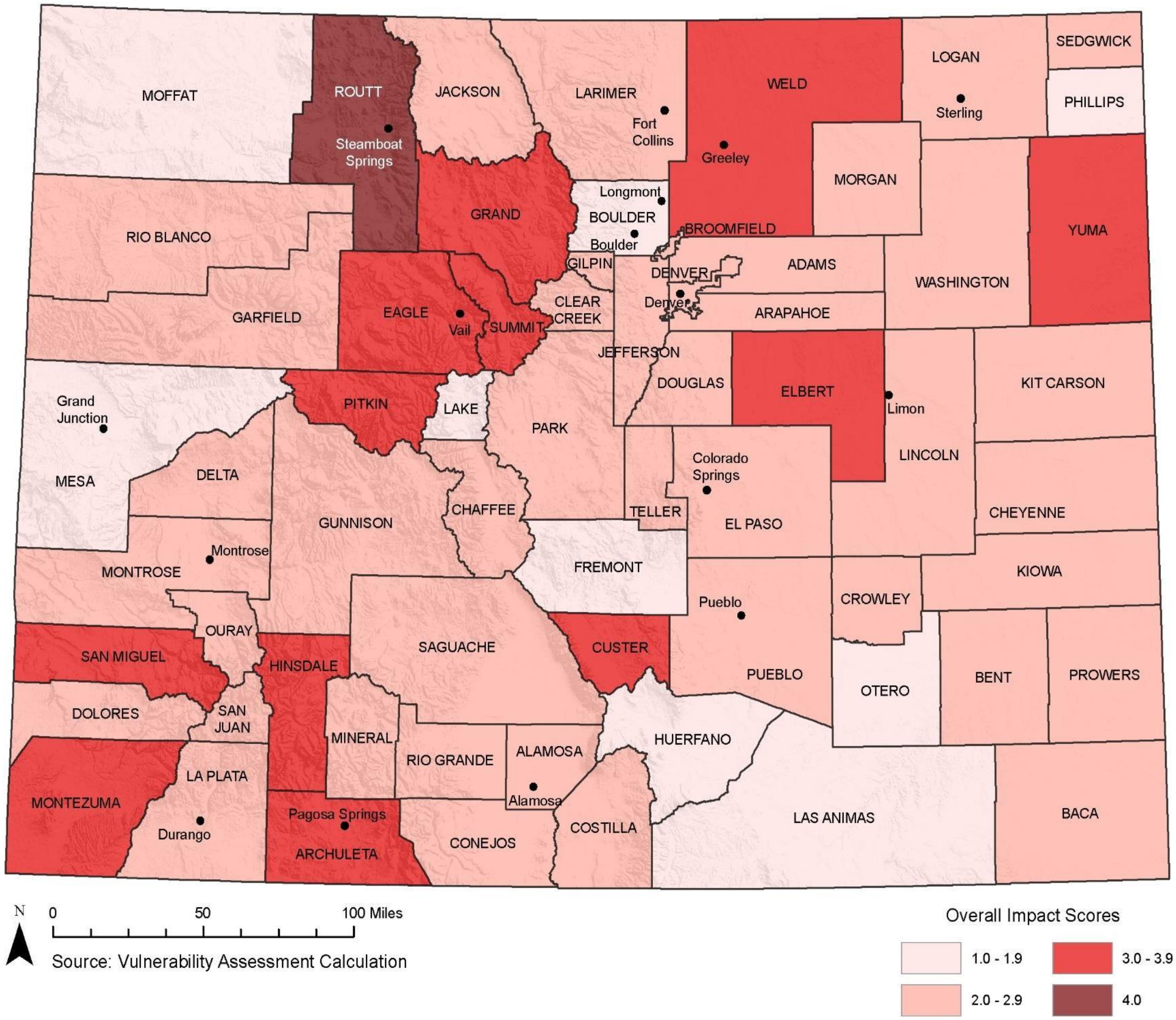


Figure 11-8 Overall Vulnerability Scores in the Socioeconomic Sector by County



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)

- 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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