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Colorado River Water Availability Study

Executive Summary

Colorado Water Conservation Board
Colorado River Water Availability Study
Phase I Report

In Association with
AMEC Earth & Environmental
Canyon Water Resources
Leonard Rice Engineers, Inc.
Stratus Consulting

March 2012

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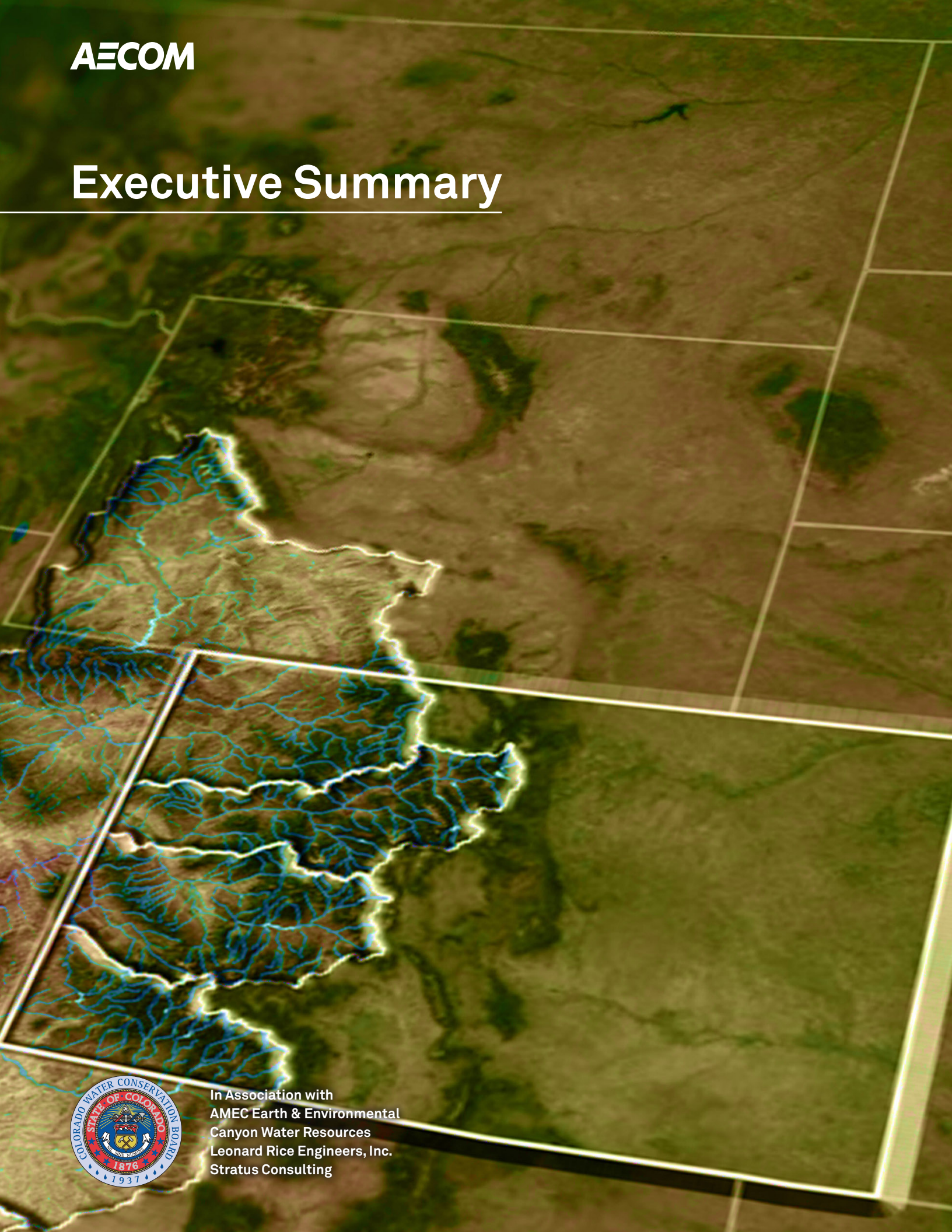

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EXECUTIVE SUMMARY

Phase I of the Colorado River Water Availability Study (the Study or CRWAS) provides an unprecedented foundation for water resources planning in Colorado. The Study, which began in 2008, combines the data and models developed by the CWCB and the Division of Water Resources over the last 15 years with new information on past droughts and wet spells and possible future changes in climatic conditions to produce the most comprehensive look to date at the Colorado River water supply in our State. Phase I of the Study provides a strong foundation for subsequent work, which will examine water availability for future water supply projects and for additional non-consumptive water needs. The Study is guided by extensive public involvement and provides a transparent examination of complex water management issues and the data, science, and computer tools applied to assess these issues. With the publication of this report and the launch of the CRWAS on-line data viewer, Colorado's water community can now fully utilize this Phase I assessment of water availability for our current supply systems and levels of water demands. State agencies and Colorado River stakeholders can now prepare for further assessments of water management strategies to meet future demands and investigate the risks associated with each of them.

Background and Objectives

Study Authorization

Colorado faces increasing demands on its water supply for both traditional consumptive uses (such as agriculture, municipal, industrial, and commercial uses) and for non-consumptive uses (such as environmental and recreational needs). Population growth; recent drought; oil, gas, and mineral development; and potential climate change broaden our concerns about the adequacy of Colorado's water supplies. Responding to these concerns, the Colorado General Assembly authorized the CRWAS through Senate Bill (SB) 07-122 and House Bill (HB) 08-1346. These bills direct the CWCB to conduct the Study: (1) in collaboration with the Interbasin Compact Committee (IBCC) and the State's river BRTs, and (2) with consideration for current and potential future in-basin consumptive and non-consumptive needs. These two directives led to broad-based and transparent public input, expanding the discussion from traditional types of consumptive water use to encompass environmental, recreational, and aesthetic uses of water.

A Study Team led by AECOM and including AMEC Environment & Infrastructure, Canyon Water Resources, Leonard Rice Engineers, Inc., and Stratus Consulting began work in late 2008, leading to a first draft of this report in March 2010. Recognizing the importance and interest in the Study, the CWCB set a 4-month public comment period and conducted extensive additional public outreach and technical analysis to respond to the broad range of comments received. To date, more than 60 public presentations and workshops about the CRWAS have been held with various groups including the CWCB's Board of Directors, IBCC,Basin Roundtables (BRTs), Colorado Water Congress, and many others. The input and direction received from broad-ranging interests refined the focus and approach of the Study. It now provides more relevant and responsive information to Colorado water users, managers, policy makers, and stakeholders about current and potential future hydrologic conditions in the Colorado River tributaries that sustain our State's critical economic sectors and natural ecosystems. The Study is a source of useful water management information, but it is not intended to prescribe policies. Each organization, agency, and individual can interpret the Study results from its own perspective, considering its own assessment of the possible future conditions, its role in water

management, the resources it has to adapt to alternative potential future conditions, and its tolerance for risk.

Study Phasing

Working closely with the IBCC, the CWCB is conducting the Study in multiple phases. Phase I (the subject of this report) is an assessment of water availability based on existing levels of water use (see Figure ES-1). For Phase I, the analysis of water availability focuses on current levels of water demands served by water rights now in use ("perfected" or "absolute" water rights). Phase I also focuses on interpretations of current operating and management practices for water diversion, storage, and conveyance facilities. For example, in scenarios where potential changes in climate conditions could affect the magnitude of water demands served by current water rights and irrigation systems, Phase I allows for the diversion of water up to the decreed maximum in the current water right. The difference between the crop's needs under new climate conditions and water diverted under the Phase I simulations is reported as a shortage.

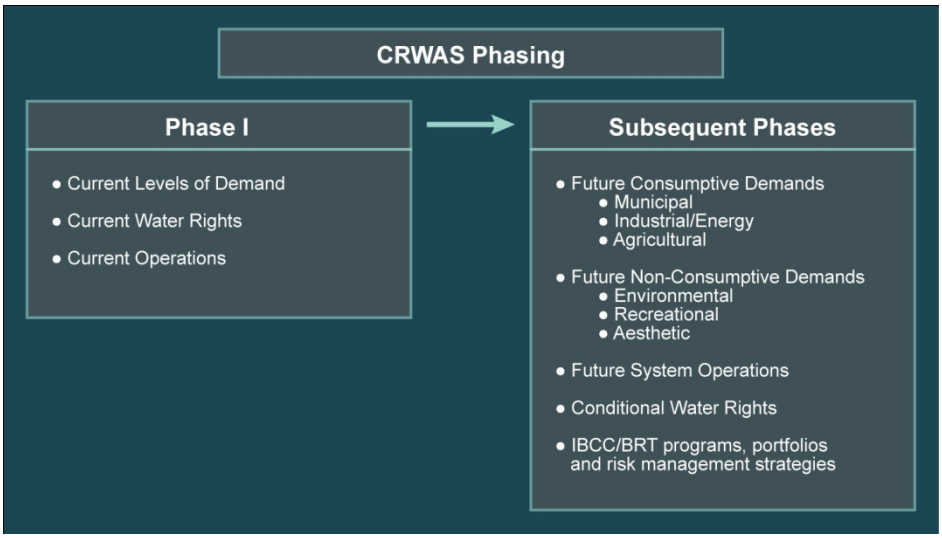


Figure ES-1 – CRWAS Phasing

The process of defining the potential future water demands , both consumptive and non-consumptive, that will be analyzed in subsequent phases of the CRWAS is currently underway through the State's IBCC processes coordinated by the CWCB. The primary focus of future phases will likely be to simulate the hydrologic effects of the various water demand scenarios, water supply portfolios, and potential changes to existing project operation. Subsequent phases will lay the foundation for individual or collective assessments of risk and potential strategies to manage or minimize risk. Regardless of the scope of future phases, the information, tools, and modeling results from Phase I will continue to support a broad range of CWCB programs and responsibilities, including continuing assessments of:

- Streamflows and reservoir storage to support water supply
- Flood protection and management
- Instream flow protection
- Water conservation
- Endangered species recovery
- Intra-state, interstate, and federal issues and programs

As shown in Figure ES-2, there are many ongoing programs and processes that the CWCB performs or directs in close collaboration with other State agencies and programs. In addition to other State, federal and local agencies, the CWCB is coordinating closely with the IBCC and BRTs in reviewing the Study's methods and results.

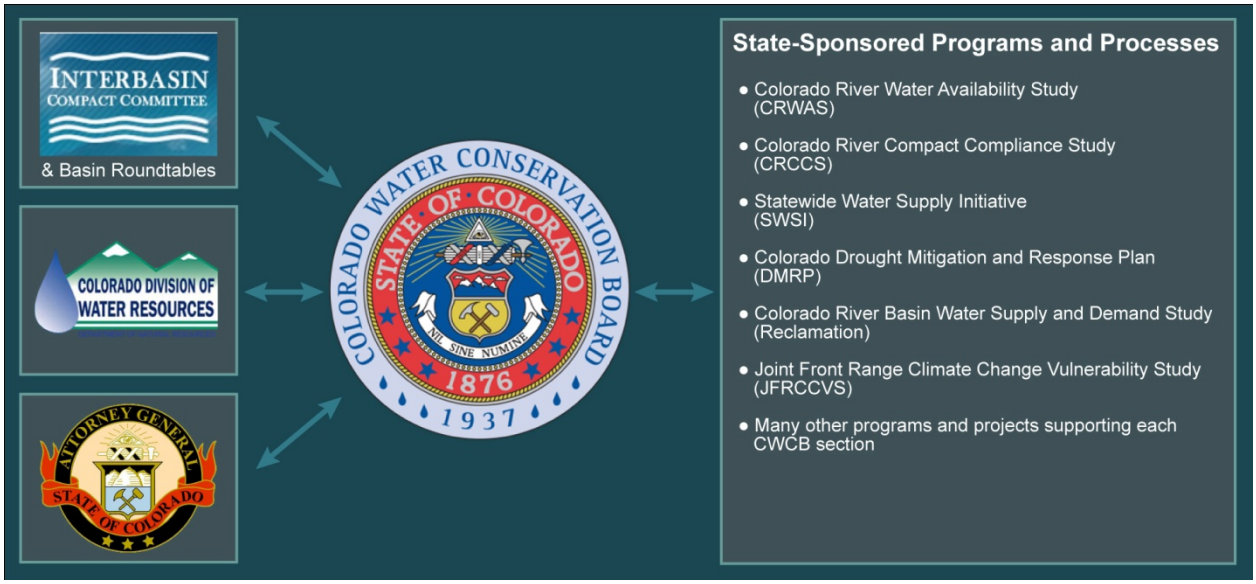


Figure ES-2 – State-Sponsored Water Management Programs Supported by the CRWAS

Study Area

The Study Area for the CRWAS encompasses the major tributary river basins of the Colorado River in the State of Colorado. Figure ES-3, presents the Study Area in accordance with the basins defined for the four West Slope BRTs. Elsewhere in this report, the basins comprising this Study Area are also referenced using the nomenclature of the Colorado Decision Support System (CDSS) for consistency in displaying modeling results. The CDSS consists of data and tools developed Statewide, plus models developed under basin-specific DSS efforts. The Colorado River DSS (CRDSS) models were developed for the Yampa, White, Upper Colorado, Gunnison, and San Juan/Dolores basins. The term CDSS is used throughout this document to refer to both the larger CDSS effort, and the basin-specific development.

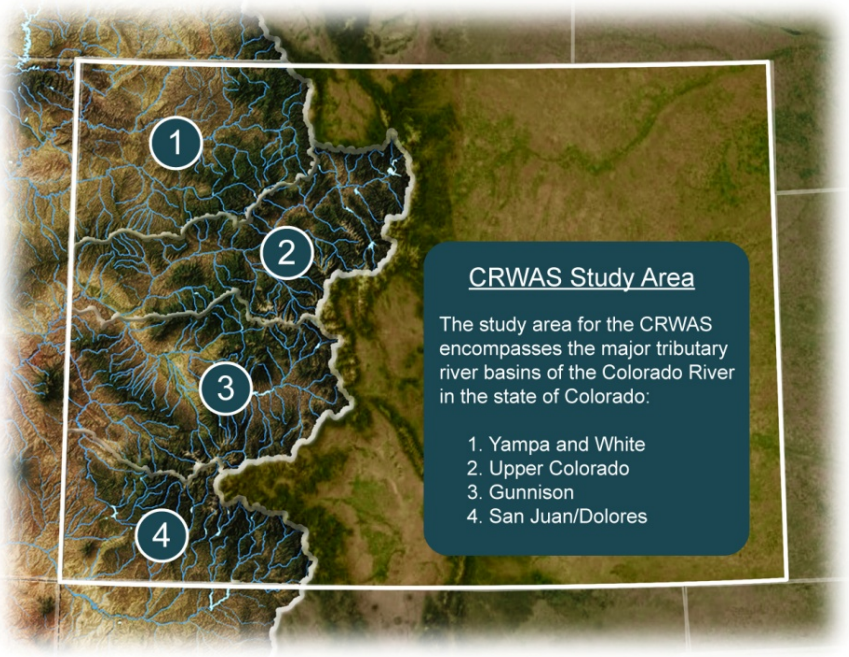


Figure ES-3 – CRWAS Study Area

Unique Attributes of the CRWAS

Studies considering the effects of climate change on water resources are being conducted world-wide; including two studies that have been completed, or are near completion, that cover a portion of the geographical area covered by the CRWAS. The Joint Front Range Climate Change Vulnerability Study (JFRCCVS), published in February 2012 by the Water Research Foundation, was undertaken to examine the potential effects that climate change may have on the supplies available to several Front Range municipal water agencies. The overlapping geographical area for the JFRCCVS and the CRWAS is the Colorado River main stem in Colorado and its tributaries. The U.S. Bureau of Reclamation is moving to finalize the Colorado River Basin Water Supply and Demand Study (CRBS) in the summer of 2012. This study completely encompasses the geographic area of the CRWAS and extends downstream to cover the entire Colorado River Basin. The primary purpose of the CRBS is to "define current and future imbalances in water supply and demand in the Basin and the adjacent areas of the Basin

States that receive Colorado River water over the next 50 years (through 2060), and to develop and evaluate adaptation and mitigation strategies to resolve those imbalances." Each of these studies inform stakeholders how water supplies may vary under changing climate conditions.

The JFRCCVS accomplished its goal of identifying changes to natural flow at 18 river locations for five climate projections representing 2040 and five representing 2070. As discussed in more detail in Section 2.3.4, the CRWAS investigated the same scenarios for 2040 but chose different projections for 2070 that better represented its study area. The JRCCVS scope did not include investigating how climate change may affect basin demands, nor did it investigate how climate change may affect future agricultural water consumption, affect water available to satisfy other specific water uses, or affect operations of existing water supply systems.

The CRBS identified changes to natural flow at 29 locations throughout the entire Colorado River basin reflecting estimated annual change through 2060, including locations in seven states, for all 112 available climate projections. They developed relationships based on degree increases in temperature and annual changes in precipitation to adjust their aggregated irrigation demands to reflect climate change. Finally, they used the Colorado River Simulation System (CRSS) model with the revised natural flows and demands to identify supply and demand imbalances in both the Upper Colorado and Lower Colorado river basins. Although the CRSS model does not include specific water rights or non-federal project operations in Colorado, it does represent the critical operations of Lake Powell and Lake Mead.

The State of Colorado has developed tools that allow the CRWAS to go well beyond both the JFRCCVS and the CRBS studies to investigate how climate change may affect water availability at the water user and water rights level, and how climate change may affect reservoir use and operations. The approach adopted by CRWAS may be the most detailed look at how specific water users may be impacted by climate change performed to-date anywhere in the world. This was made possible because of the availability of the CDSS model datasets previously developed for the Colorado River in Colorado. CDSS model datasets have not been fully developed for either the South Platte or the Arkansas River basins; therefore were not available for use in the JFRCCVS.

The existing CDSS consumptive use model (StateCU) datasets represent 100 percent of the current estimated irrigated acreage and irrigation practices at the ditch level. The existing CDSS water allocation model (StateMod) datasets represent the current water rights and administrative agreements, water user demands, and basin operations superimposed on natural flows throughout the Study Area. The availability of these datasets allowed the CRWAS to revise crop demands at the ditch level, using StateCU, to reflect current acreage and crop types and potential changes to growing seasons based on more locally estimated climate change parameters. Diversion demands, again at the ditch level, were adjusted to reflect crop demands. StateMod was then used to superimpose streamflows and climate-altered water use using Colorado's current water rights, administrative rules and agreements, and operational practices. The results provide detailed information on consumptive use; shortages; physical streamflow; and water available for future use at more than 2,000 locations throughout the Study Area. In addition, reservoir use (storage and releases) are provided for more than 60 federal and non-federal reservoirs throughout the Study Area.

Each of these three complementary studies help inform stakeholders how water supplies may vary under changing climate conditions. The JFRCCVS focuses on potential changes in natural flows that may affect Front Range municipal water providers and the CRBS focuses on potential

changes in natural flows and federal reservoir operations throughout the seven-state Colorado River basin; The CRWAS includes effects on natural flow but extends the analysis to consider resulting changes in crop consumptive use, federal and non-federal reservoir operations and remaining water availability for consumptive and non-consumptive purposes.

Technical Approach

Water availability studies like the CRWAS compare water supply and demand based on the "supply-and-demand equation":

Water Available for Future Uses = Supply – Demand

Supplies and demands vary from day to day. They vary seasonally and they vary in dry years and wet years. Complex computer models are used to track the water supplies in streams and reservoirs and to reflect the actions of water managers as they operate supply systems to minimize shortages and as they deal with increasing competition for water among cities, industry, agriculture, recreation, and the environment. The flexibility of water managers to minimize shortages is constrained by the terms of their water rights, operation plans and water exchange agreements.

A primary challenge in conducting a comprehensive water availability study is developing the tools (computer models) needed to: (1) mimic natural phenomena as water flows through drainage basins, and (2) simulate the operations of stream diversion structures and reservoirs, and (3) represent flows returning to streams from cities, farms, and industry, - all operating under the umbrella of Colorado's Prior-Appropriation Doctrine. Fortunately for the CRWAS, the State of Colorado had the foresight to invest in the development of comprehensive computer tools over the past 15 years that allow this study to be performed with relative efficiency and in great detail. The CDSS, with its integrated databases and simulation models, is likely the most comprehensive, transparent, and geographically extensive system for water supply analyses available anywhere in the U.S.

The health of Colorado's forests is very important to regional ecological conditions that have potential effects on water supplies. Phase I of the CRWAS reviewed the practicality of modeling the hydrologic effects of recent and on-going changes in our forest lands as part of the Study's focus to assess long-term water supply availability.

The U.S. Forest Service (USFS), in conjunction with the CWCB and the North Platte River Basin Roundtable, is conducting a multi-year study to collect information regarding the forest change processes that most influence the hydrology of disturbed forests in Colorado. Given that the focus of Phase I of the CRWAS is to evaluate long-term water availability, it is appropriate to re-assess quantifying the impact of forest change on water availability when results of the USFS work are available and the science of forest change assessment is more advanced.

The March 2010 Draft CRWAS Phase I Report provided quantitative estimates of the amount of consumptive use, above existing levels, that can occur within Colorado under certain Colorado River Compact assumptions ("water available for future consumptive use"). After careful consideration, the Study Team and the CWCB agreed that the preliminary analyses of the March 2010 Draft Report would be replaced with a summary of the complexities, challenges, and uncertainties inherent in estimating the magnitude of water available for future consumptive uses in Colorado. This summary is presented in Section 2.2.6 of the main report.

Phase I of the CRWAS is composed of two primary analysis components: 1) CDSS Refinements and 2) Water Availability Assessments as follows.

Continuing CDSS Refinements

The CRWAS leveraged the State's investment in the Colorado Decision Support System (CDSS) modeling tools. Through extensive public outreach and direct collaboration with water suppliers and managers, the models were reviewed and refined to further enhance general confidence in the models' ability to simulate streamflows and project operations, and to provide important information for future assessments of non-consumptive water needs. The refinements were thoroughly documented to support subsequent CRWAS phases and other future State water resource modeling and planning initiatives. The CDSS proved fully capable of simulating current water uses (demands) and alternate hydrologic cases to provide a broad range of results including physical streamflow, consumptive use, and water available to meet future demands throughout the Study Area under Colorado's Prior Appropriation Doctrine.

Water Availability Assessments

Phase I considers and compares three different conditions for water supply:

1. **Historical Hydrology** – Traditionally, water supply agencies have used recorded historical information on water supply as an indication of likely future conditions, the premise being that history tends to repeat itself. This Study uses a 56-year period to represent historical hydrology (1950 through 2005). This period includes both very wet and very dry years, contains the most reliable historical data upon which to base comparisons of the effects of climate change, and uses information that Colorado River stakeholders can relate to through their own experiences.

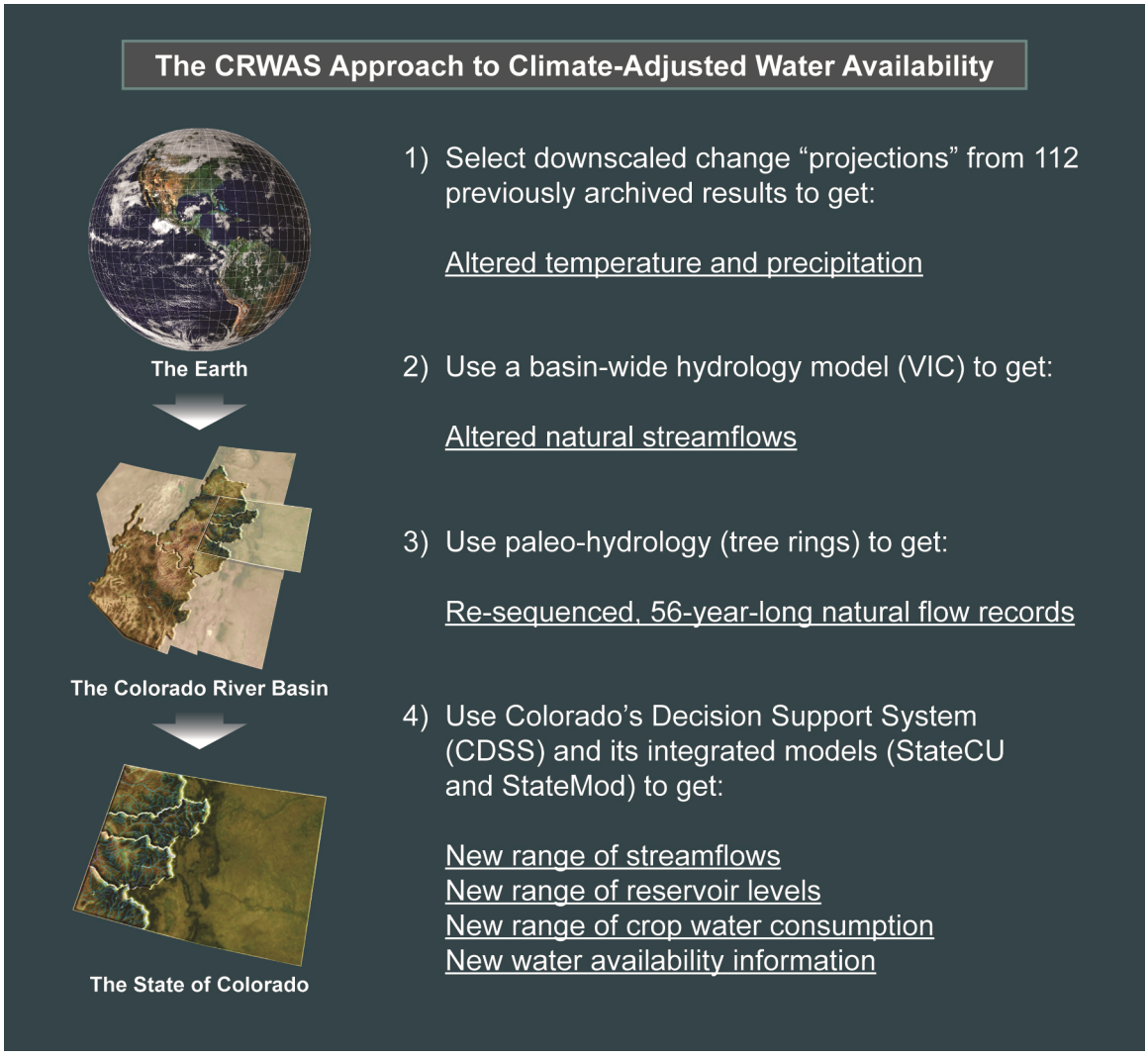
2. **Extended Historical Hydrology** – Also referred to as "paleo-hydrology", this approach extends historical records using information from more than 1,200 years of previously published tree-ring records. The lengths of the wet and dry periods have significant effects on water availability for future use. Phase I of the CRWAS reviews alternative methods for correlating annual tree growth with streamflow and concludes that a "re-sequencing" approach best serves the needs of the Study. This approach focuses on the probabilities of transitioning back and forth between wet and dry years. It does not use the tree-ring data to increase or decrease the magnitudes of the maximum and minimum natural flows in the historical records, it simply rearranges the years, resulting in longer wet and dry periods.

3. **Climate-Adjusted Hydrology** – This approach assesses the magnitude of future water supply availability considering the effects of projected changes to climate. This Study reviews many methods to incorporate information from the climate projections that are available for the Colorado River basin. After coordinating with the State's CCTAG and the Joint Front Range Climate Change Vulnerability Study (JFRCCVS), the CRWAS uses five projections for each of the 2040 and 2070 planning horizons (ten total). A hydrology model is used to translate projected changes in temperature and precipitation to changes in natural flows throughout the river basin. Colorado's consumptive use model, StateCU, is used to estimate altered crop water needs resulting from higher temperatures and longer growing seasons. Figure ES-4 provides an overview of the process used to estimate the possible effects of climate change.

Table ES-1 summarizes the technical approach for all aspects of the CRWAS Phase I work including the effects of climate-adjusted hydrology.

Approach to Evaluating the Effects of Climate Change

Approach: The CRWAS approach to evaluate the effects of potential climate change on our State's water availability begins by using previously developed climate change projections. A hydrology model is then used to estimate effects on streamflow. The process includes consideration of extended historical hydrology and concludes with applying the State's sophisticated water planning models to simulate the response of our existing water rights and water supply systems to meet our water demands.



Result: Interested parties can use results to consider both historical hydrologic conditions and the potential effects of climate change in planning their future capital expenditures and risk management strategies.

Figure ES-4 – Adjusting Historical Hydrology to Consider Potential Climate Change

Table ES-1 – Phase I Technical Approach Summary

Historical Hydrology	**Data and Tools:** CDSS (StateCU and CDSS Natural Flows) **Results:** Historical Natural Flows, Modeled Streamflows, Consumptive Use, Reservoir Levels and Water Availability **Includes natural flow hydrology observed for period 1950–2005**
Extended Historical Hydrology	**Data and Tools:** Extending Paleo Datasets **Results:** Extended Natural Flows, and Wet/Dry Spell Statistics **Extended record dating from AD 762 (more than 1,200 years)** • Provides estimated natural flow traces. Flow magnitudes taken from historic flow record (1950-2005). • Flow sequences developed using statistical models applied to tree-ring data. • Provides a wider variety of year-to-year flow sequences than historical record. • Re-sequencing – Future sequences of wet and dry years cannot be predicted; therefore, 100 different 56-year hydrologic traces were developed. All are considered equally probable.
Climate-Adjusted Hydrology	**Data and Tools:** Variable Infiltration Capacity (VIC) Model **Results:** Climate-Adjusted Temperature, Precipitation, and Natural Flows **Based on the selection of five climate projections for each of the 2040 and 2070 planning horizons** • Used same five 2040 projections selected in the JFRCCVS; however, obtaining five appropriately distributed projections for CRWAS study conditions required different projections for 2070. • Each of the selected downscaled climate projections is treated as equally probable. • Temperature and precipitation changes were translated into effects on natural flow using the VIC hydrologic model. Flow sequences (dry/wet spells) were derived from those seen in the paleohydrology flow record.

Table ES-1 – Phase I Technical Approach Summary (cont.)

Climate-Adjusted Irrigation Demands	**Data and Tools:** CDSS (StateCU) **Results:** Climate-Adjusted Irrigation Demands **Superimposes historical or projected mean monthly temperature and total monthly precipitation on current irrigated acreage and crop types to estimate crop irrigation requirements (CIR).** • StateCU uses temperature-based monthly Blaney-Criddle approach, incorporating available locally calibrated coefficients to determine CIR. • Temperature triggers allow growing season start and end dates to reflect changes under varying climate conditions.
Water Allocation Modeling	**Data and Tools:** CDSS (StateMod) **Results:** Climate-Adjusted Streamflow, Water Availability, Reservoir Operations, and Consumptive Use **Reflects historical or projected climate-based natural flows, crop demands, and irrigation head gate demands.** • Uses current M&I demands, transmountain exports, reservoir capacities, and basin operations. • StateMod allocates historical or projected natural flows to meet demands based on Colorado water rights, current administrative agreements, and current reservoir operations. • Model provides physical streamflow and water available for future demands at 2,000+ locations throughout the Study Area. Includes reservoir use, diversions, and consumptive use.

Technical Findings

The detailed technical approaches presented in the preceding section were developed in a transparent manner considering the input and direction of CWCB staff and Directors, IBCC and BRT members, the State's CCTAG and many representatives of many non-governmental organizations and stakeholders. A major finding for the CRWAS is that the methodology adopted, that built on existing data; existing models; and existing procedures, is a valid technical approach uniquely suited for the study. The use of readily-available down-scaled climate projection information, the robust VIC hydrology model, and the CDSS processes, models, and data sets provide a comprehensive way to assess water availability and operational effects for historic, extended historic and climate-adjusted hydrologies.

CRWAS findings are presented for the three alternative hydrologic cases: historical hydrology from the 1950 through 2005 study period, alternate historical hydrology incorporating information from tree-rings to allow an extended view of variability, and alternate hydrology associated with potential future climate conditions. Average monthly hydrograph charts and low flow comparison charts are presented in the report and appendices. In addition, these findings can also be accessed, viewed, and downloaded through the CRWAS Data Viewer

(http://cwcb.state.co.us) where time series flow charts can be tailored to a user's specific interests. This accessibility of results for each hydrology scenario analyzed at locations throughout the basin specifically addresses the feedback received during the CRWAS public outreach efforts. The information is available for water users and providers to: (1) access model results at specific locations of interest; (2) perform statistical analyses based on selected hydrology and locations and (3) make decisions on which hydrologic datasets to use for planning purposes.

Study results for historic hydrology are provided in combination with climate-adjusted hydrology in the main report and in the appendices, for the following parameters:

- Temperature
- Precipitation
- CIR
- Natural Flow
- Modeled Streamflow
- Water Available to Meet Future Demands
- Modeled Reservoir Storage
- Modeled Consumptive Use

The ensemble of 100 56-year-long natural flow traces that constitute the extended historical hydrology is characterized by statistical analyses that allow comparison to the historical record.

Table ES-2 summarizes general technical findings of CRWAS Phase I, comparing conditions for the 2040 and 2070 climate projections with historical conditions.

Table ES-2 – Primary Phase I Findings Based on 2040 and 2070 Climate Projections

Temperature

- Increase is less than the Study Area average increase at northern climate stations (e.g., Grand Lake, Yampa, and Hayden)
- Every climate projection shows an increase in average annual and monthly temperature
- 2070 temperatures are higher than 2040

2040	• Study Area average annual increases range from 1.8 °F to 5.2 °F
2070	• Study Area average annual increases range from 4.8 °F to 8.1 °F

Precipitation

- Generally increases in the winter months and decreases in the summer months
- Average winter increases are larger in the northern portion of the Study Area, and smaller in the southwestern portion of the Study Area
- Increase in temperatures causes a shift from snow to rain in the early and late winter months

2040	• Study Area winter average changes by 102% to 116% of historical • Study Area April through October average changes by 82% to 105% of historical
2070	• Study area winter average changes by 99% to 127% of historical • Study Area April through October average changes by 93% to 99% of historical

CIR

- Increases for each of the climate projections throughout the Study Area
- Increases are primarily due to higher temperature and lower irrigation-season precipitation, which increase:
    - the number of days in the growing season for perennial crops, and
    - the crop demand for irrigation water
- Peak continues to occur in the same month as it has historically

2040	• Study Area average annual CIR increases by 1.9 to 7.4 inches for individual climate scenarios. • Study Area average annual growing season increases by 8 to 32 days
2070	• Study Area average annual CIR increases by 5.1 to 10.9 inches for individual climate scenarios. • Study Area average annual growing season increases by 21 to 46 days

CIR for Study Basins

- Every Study Basin shows an increase for all climate scenarios
- The White River basin shows the largest percentage increase
- The Yampa River basin shows the smallest percentage increase

Table ES-2 – Primary Phase I Findings Based on 2040 and 2070 Climate Projections (cont.)

Natural Flow

Historical Hydrology

- The longest (historic) wet spells range from 4 to 16 years in length, with only 4% longer than 7 years
- Historic dry spells range from 3 to 11 years in length with 95% being 5 or 6 years long
- Moving from north to south, historic dry spells generally become shorter and historic wet spells generally become longer

Extended Historical Hydrology

- The return interval of historic wet and dry spells vary widely from location to location
- Return intervals are shorter for locations that have shorter historic spells and longer for locations that have longer historic spells.
- At 90% of the sites, the return interval of the historic dry spell ranges from about 8 to about 200 years, and the return interval of the historic wet spell ranges from about 13 to about 100 years
- In very general terms, locations with shorter historic spells should expect longer spells and vice versa

Climate-Adjusted Hydrology

- At over 80% of the sites, the majority of climate cases suggest a decrease in annual flow for both 2040 and 2070
- Annual flow is more likely to increase in parts of the Yampa River basin and in some higher elevation watersheds
- Annual flow is more likely to decrease in southwestern watersheds and at lower elevations
- At 75% of locations, all climate cases showed a shift toward earlier runoff, and at all locations, some climate cases showed a shift toward earlier runoff
- Higher peak flows may be beneficial for riparian health; however, lower flows in late summer and fall may impact other non-consumptive needs

2040	• At three locations, all climate cases showed increases in average annual flows. At the remaining 224 locations, the climate cases contained the historic average annual flow • Runoff shifts earlier by an average of 8 days
2070	• At 17 locations, all climate cases showed increases in average annual flows. At 74 locations, all climate cases showed a decrease in average annual flows. At the remaining 136 locations the climate cases contained the historic average annual flow • Runoff shifts earlier by an average of 14 days

Table ES-2 – Primary Phase I Findings Based on 2040 and 2070 Climate Projections (cont.)

Modeled Streamflow

2040	• Flows are generally higher than historical in May and June and lower in July through March • Flows are generally lower than historical in three of the five climate projections, but generally higher than historical in two projections • The historical annual low-flow values generally fall within the range of projected low-flow values
2070	• Some 2070 projections show greater average annual modeled streamflow compared to 2040 projections • Locations in the northern portion of the Study Area and higher elevation locations in the upper Colorado basin generally show increases in average annual modeled streamflow • The historical annual low-flow values generally fall within the range of projected low-flow values in the Yampa, White, and Colorado basins. However, the range of projected low-flow values is generally lower than historical low-flow values for locations in the Gunnison basin and in the southwestern portion of the Study Area • The historical annual low-flow values in the northern portion of the Study Area generally show a wider range between the five individual 2070 climate projections than between the five individual 2040 climate projections • The historical annual low-flow values in the central and southern portions of the Study Area generally show a narrower range between the five individual 2070 climate projections than between the five individual 2040 climate projections

Water Available to Meet Future Demands

- Upstream locations on main rivers and smaller tributaries generally have less flow available to meet future demands as a percent of modeled streamflow than gages farther downstream that include more tributary inflow

2040	• Most locations show less water availability for three of the five climate projections. However, for one of the projections, the locations selected to display CRWAS results show more water available • The climate projections generally indicate more water availability in April and May, corresponding to the shift in the natural flow hydrographs • The historical annual minimum water availability values generally fall within the range of projected minimum water availability values for 2040 throughout the Study Area
2070	• Most locations in the Study Area show less water availability for four of the five climate projections. The exception is the southwestern portion of the Study Area, which generally shows less water availability for all five projections • The range of projected annual minimum water availability values is generally larger in 2070 compared to 2040 in the northern portion of the Study Area, but smaller in the central and southern portions of the Study Area • The historical annual minimum water availability values generally fall within the range of projected minimum water availability values for 2070 in the northern and central portion of the Study Area

Table ES-2 – Primary Phase I Findings Based on 2040 and 2070 Climate Projections (cont.)

Modeled Reservoir Storage

- Earlier peak runoff, reduced flows during the peak irrigation season, and increased crop demands result in more use of reservoirs (more reservoir fluctuation)

2040	• Reservoirs are generally drawn down to lower levels, and generally fill to historical levels
2070	• Reservoirs are generally drawn down to lower levels, and do not fill to historical levels, except in the northern portion of the Study Area

Modeled Consumptive Use

- Average annual consumptive use in the Yampa, White, Upper Colorado, and Gunnison basins is greater for every climate projection. Average annual consumptive use in the San Juan basin is less for every climate projection
- Total consumptive use for the Study Area is greater than for historical climate conditions for most climate projections
- Although modeled consumptive use generally increases, not all crop demands are met in any basin. Similar to historical conditions, there continue to be water shortages on tributaries and in the late irrigation season for the projected conditions

2040	• Projected consumptive use increases in most months in every basin except the San Juan. Projected consumptive use in the San Juan generally increases in spring months only
2070	• Projected consumptive use increases in April, May, and June for every basin, with the exception of the San Juan basin. Projected consumptive use is higher in every month in the White River basin • Projected consumptive use for the 2070 projections is higher than for the 2040 projections in every basin except the San Juan.

Conclusions and Recommendations

Phase I of the CRWAS responds to the General Assembly's direction to the CWCB to provide information on how much additional water is available from the Colorado River basin to meet the State's future consumptive and non-consumptive water needs. In accordance with IBCC input in the scoping process, Phase I presents water availability based on current levels of water use, existing water supply systems, and current interpretations of operating and management practices.

An important aspect of the Phase I work is that it is transparent and accessible. Analysis methods and refinements to modeling tools were reviewed extensively with BRT representatives, including the owners and operators of the major water supply systems. Results are presented for three alternative hydrologic cases, including those based solely on historical hydrology. This process allows individuals and agencies to consider a broad range of potential future hydrologic conditions in their water management decisions.

Because of that transparency, the tools, and the detailed database of natural flows, water use and modeled conditions provided by Phase I will serve as a foundation for future Study phases and other analyses, by the State and others. Subsequent CRWAS phases would likely consider potential new water supply projects, additional non-consumptive water demands and revised water management strategies intended to meet those demands to the greatest degree with consideration for acceptable risk.

Important conclusions and recommendations of the Phase I Study are summarized in four general categories: Technical; Study Processes and Supporting Accomplishments; Utilization of Phase I Results, and Future Analyses.

Technical Results

The technical approach and findings presented in the previous sections document the geographic breadth and engineering sophistication of the CRWAS. The datasets and modeling tools of the State's CDSS proved to be well-suited for addressing current water management operations and the effects of potential future hydrologic conditions. Extensive streamflow, reservoir storage, consumptive use and other important data are now available throughout the Study Area for current water management operations superimposed on historical hydrology, extended historical hydrology and climate-adjusted hydrology.

1. **Historical Hydrology -** The analysis of Historical Hydrology results in new water resource data throughout the Study Area based on the latest adjustments to the CDSS models. Historical hydrology has long been used in estimating the reliable yields of Colorado water supply systems. The magnitude and duration of droughts in relation to the wet periods that refill reservoirs are critical in analyzing our ability to meet current and future consumptive and non-consumptive water needs. The longest wet spells in the 56-year record (referred to as the "historic spell") range from 4 to 16 years in length across the 227 locations in the Study Area where natural flows are determined, with only 4 percent of historic wet spells longer than 7 years. Historic dry spells range from 3 to 11 years in length with 95 percent of dry spells being 5 or 6 years long. Moving from north to south, historic dry spells generally become shorter and historic wet spells generally become longer.

2. **Extended Historical Hydrology -** The Extended Historical Hydrology showed that the length, intensity and frequency of wet and dry spells vary significantly across the Study Area. The expected frequency with which a dry or wet spell of length equal to the historic spell will return also varies considerably from location to location, so conclusions about the expected recurrence of spells must be made on a site-specific basis. In general, the Extended Historical Hydrology shows that significantly longer dry periods occurred prior to recorded history.

3. **Climate-Adjusted Hydrology -** For the Climate-Adjusted Hydrology, some projections of future conditions show increased flows at the majority of locations compared to historical conditions; however, most projections show reduced flows. Projected flows generally show a shift toward earlier runoff. At most locations and for most projections, future conditions show an increase in precipitation in the winter and a decrease in precipitation during the summer. All projections show an increase in temperature. Decreased precipitation and increased temperature during the growing season lead to increased crop irrigation requirement. This, combined with a tendency for runoff to occur earlier, contributes to increased fluctuation in reservoir contents and, generally, lower end-of-year contents. The projections also indicate that the southern part of the State may be generally drier (less Natural Streamflow, Modeled Streamflow, and Water Available to Meet Future Demands) than northern parts of the State.

Readers are encouraged also to review the details presented in Table ES-2, the main report and its appendices as well as the on-line CRWAS Data Viewer to gain a more complete understanding of water availability in the Study Area.

Study Processes and Supporting Accomplishments

1. **IBCC and BRT Involvement** – Interaction with the IBCC and the BRTs provided essential context for the work performed, especially concerns regarding the Study's methods and outcomes. The interaction helped mold the Study and ensure that the results of the initial CRWAS process provide a strong foundation for future work. The interaction and educational workshops also facilitated improvements, and enhanced trust in the State's CDSS planning tools.

2. **Public Outreach** –General public input also shaped the Phase I study. Numerous meetings, including but extending well beyond the official IBCC and BRT meetings, provided important forums for sharing the complex issues and tools of the CRWAS. Formal comments provided by more than 30 entities on the Draft CRWAS Phase I Report helped improve the Study and its results. These comments were carefully considered by the CRWAS Team and, in response, the CWCB authorized extensive additional outreach workshops and the preparation of a 115-page response matrix. The response matrix provides the State and its water stakeholders with valuable documentation about water management concerns and supports statewide communication and collaboration in water planning. As the Study transitions into additional phases, a similar level of outreach may be an important part of intrastate dialogue to guide water supply and demand analyses for a variety of potential planning scenarios. Public outreach should continue to include education and review of CDSS models; ongoing refinements are recommended to advance the value of the State's analysis tools.

3. **Access to Data and Modeling Results** – Water availability is highly dependent on the characteristics of a particular use—the priority and magnitude of its water rights, the physical supply available at its location and the capacity of its facilities. No single report can provide enough detail to address the thousands of Colorado water uses within the Colorado River Basin. Through the CRWAS public outreach activities, it became clear that stakeholders required simplified access to all of the detail of the CRWAS data and modeling results in order to use the Study results effectively. An online CRWAS Data Viewer now provides a means to quickly and easily:

    - Explore over 2,000 CRWAS model locations on interactive maps.
    - View and compare streamflows, reservoir contents, diversions and other data for the 5,500 final CRWAS model runs representing historical, alternate historical, and climate projected conditions.
    - Download CRWAS model data in user-friendly spreadsheet format for stakeholders to prepare additional analyses and tailor their own presentations.

    The CRWAS Data Viewer allows anyone with internet connection to easily access hundreds of gigabytes of CRWAS information without having to download and learn new and complex software. This application will help stakeholders consider their own assessments of future opportunities and risks. The CRWAS Data Viewer and corresponding User Manual are available through an internet link on the CWCB website. During CRWAS public outreach workshops, CWCB received positive feedback on the usefulness of the CRWAS Data Viewer. This application should be updated, as necessary, to respond to initial public use and to allow continued public use through subsequent phases of the CRWAS and other state programs.

Utilization of Phase I Results

1. **Support for other State Programs** – As listed on Figure ES-2, the many ongoing State-sponsored programs and processes are interconnected with each other and with the CRWAS. Hydrologic data and modeling tools from CRWAS Phase I and subsequent phases will support many other State programs and processes. CRWAS can also support several of Governor Hickenlooper's goals for the IBCC and BRTs in further implementation of the Water for the 21st Century Road Map including:

    - Increase education, specificity, support, engagement, and regional cooperation in the IBCC framework.
    - Support common understanding of statewide water problems and solutions.
    - Support interchange of ideas between State, water providers, and project proponents.
    - Support BRT portfolio development and assist in identifying methods to meet regional needs.

2. **Availability of Results for Historical Hydrology** – Traditionally, water supply agencies have relied extensively on historical information on water supply as an indication of likely future conditions, the premise being that history tends to repeat itself. Because the CRWAS also includes analyses for paleohydrology and climate change hydrology, much of the focus in public outreach meetings and in presenting Phase I results necessarily focused on aspects of these less-familiar topics. The data and modeling results for today's level of demands superimposed on historical natural flows are presented in Phase I of the CRWAS and available through the CRWAS Data Viewer.

This information provides the foundation on which stakeholders' can assess their future water management strategies.

3. **Perspectives on Climate Change Projections** – Phase I of the CRWAS compares the effects of three alternative water supply cases (historic hydrology, extended historical hydrology, and climate-adjustedhydrology). Phase I results and models allow Colorado River water managers, policy makers, and stakeholders to consider wide ranging hydrologic scenarios and base their water management decisions on their own risk management strategies. With the CRWAS information, they can base their planning decisions on their own level of confidence in the historic hydrology, paleohydrology, or climate-adjusted hydrology.
4. **Perspectives on Uncertainty** –The CRWAS addressed the uncertainty in projections of future climate conditions by selecting five climate "cases" for each future time frame. The projections were selected to cover approximately 80 percent of the range of conditions projected by the 112 readily available climate model runs. The results of the CRWAS analyses, which are based in part on the selected projections, reflect the uncertainties in climate modeling. The range of results is large—in some cases and locations the selected climate projections lead to higher streamflows and in some cases they lead to lower streamflows; and this is a realistic reflection of the state of climate science at this time.
5. **Foundation for Water Resource Planning –** Phase I is not prescriptive, with no grand conclusions suggesting that water managers take specific actions. Instead, Phase I provides a tremendous amount of data about a variety of possible future hydrologic conditions, allowing study users the freedom to interpret the data in context with their own programs, priorities and water management systems. Based on comments received on the previous draft report, many water agencies may focus on historic hydrology in the planning and financing of major capital investments but may also consider, in a more qualitative fashion, the impact of potential climate change on these decisions. This approach anchors the policy-making process in the context of the historical hydrology while still considering vulnerabilities that may be faced if the future hydrologic conditions prove to be significantly different than they have been in the past.

Future Analyses

1. **Stakeholder Interest in Assessment of Water Availability under Future Demands –** Phase I results are based only on current water uses (current irrigated acreage, M&I demands, and non-consumptive water demands). In the Study presentations and workshops, and in written comments submitted on the previous draft report, many stakeholders expressed interest in the analysis of water availability considering future levels of consumptive and non-consumptive water demands, and analysis of potential water supply solutions including new water supply projects, new non-consumptive use programs and protections, and new water management strategies - all supporting a more robust assessment of risk management strategies.

2. **Alternative Transbasin Water Demands affected by Climate Change** – Climate change in eastern Colorado may affect demands for Colorado River water. In Phase I of the CRWAS, transbasin demands were not adjusted to reflect the effects that climate change may have on current levels of demand in the South Platte River and Arkansas River basins. As the State continues its programs to develop Decision Support Systems for the South Platte and Arkansas River basins, the methods adopted in the CRWAS

may be appropriate to estimate projected climate-adjusted water availability for these adjacent river basins.

3. **Consider Alternative Water Management Strategies and Interpretations of Existing Operational Agreements** – Phase I results indicated that, under hydrologic conditions not experienced in the historic period, existing operational agreements, management plans, and annual reservoir operation plans may need to be interpreted in the context of these potential changed conditions. Subsequent phases of the CRWAS will provide opportunities to assess the effects of a broad range of reasonable interpretations and consider alternate operational strategies, including formal and informal agreements, affecting water management in the Study Area.

4. **Collaboration with Other Studies and Incorporation of Independent Reviews of Methods and Results** – Phase I demonstrated the benefits of independent input received from the IBCC, the BRTs, and other stakeholders and groups. Colorado is in an enviable position in terms of its resident professional expertise in water resource planning and management, its existing CDSS modeling tools, and the extensive climate change expertise in the state. Future CRWAS phases should continue to build upon the multiple CWCB / IBCC programs. Use of the CCTAG as a cost-effective and independent technical reviewer should continue, which will enhance the credibility of the State's programs like the CRWAS.

Final Thoughts for Colorado River Stakeholders

Phase I of the CRWAS provides Colorado River stakeholders with updated computer models and important new information on historic and future water availability. The CRWAS provides twelve different water supply scenarios based on historical hydrology, paleohydrology, and the ten climate change projections. The broad range of projected conditions poses a daunting challenge to planning. There is no single way to move forward with planning for water supply under profound uncertainty, but researchers and water resources managers are already developing planning approaches that begin to address the new types of uncertainty about long-term conditions. Scientists have been able to provide only very general (and sometimes contradictory) guidance about how to interpret projections of future conditions, but water managers have begun to consider practical ways to address uncertainty, and some useful resources are referenced in the body of this report.

Phase I results can be used by stakeholders to consider a broad range of potential future hydrologic conditions, better understand uncertainty in water management decisions, and support the development of specific policies and programs. It is recommended that each stakeholder entity interpret Phase I work from its own perspective, considering its own assessment of the possible future conditions, its role in water management, the resources it has at hand with which to adapt to alternative potential futures, and its tolerance for risk.