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4. Water Supply

Introduction

Colorado's water supply consists of both surface water and groundwater sources. Surface water and groundwater supplies are dependent on complex interactions among geography, weather, and legal constraints, all of which influence how much water is available for beneficial uses. Groundwater accounts for approximately 17 percent of water use, while surface water supplies the remaining 83 percent. Colorado's rivers and streams, which are highly variable both seasonally and annually, provide surface water and replenish alluvial groundwater supplies. Groundwater and surface water are subject to different management institutions, which are described in Chapter 2. The quality of surface water and groundwater also influences the amount available for different types of uses.

Waters of Colorado

Colorado's geography is diverse, with terrain that ranges from the low-lying plains of Holly (3392 feet) to the high peak of Mt. Elbert (14,440 feet), the highest peak in the contiguous Rocky Mountain states. The entire state resides above 3300 feet, with a mean elevation of 6800 feet, the highest of any state.[1] This variability influences precipitation amounts and patterns experienced across the state.

Many major rivers originate in the high Rocky Mountains and collectively account for 70 percent of Colorado's surface water. These rivers flow east, west, north, and south from Colorado's mountains and plains out of the state, through 18 downstream states and Mexico, into the Gulf of Mexico or the Pacific Ocean. Four major river systems begin in Colorado: the Arkansas, the Colorado, the Platte, and the Rio Grande.[2]

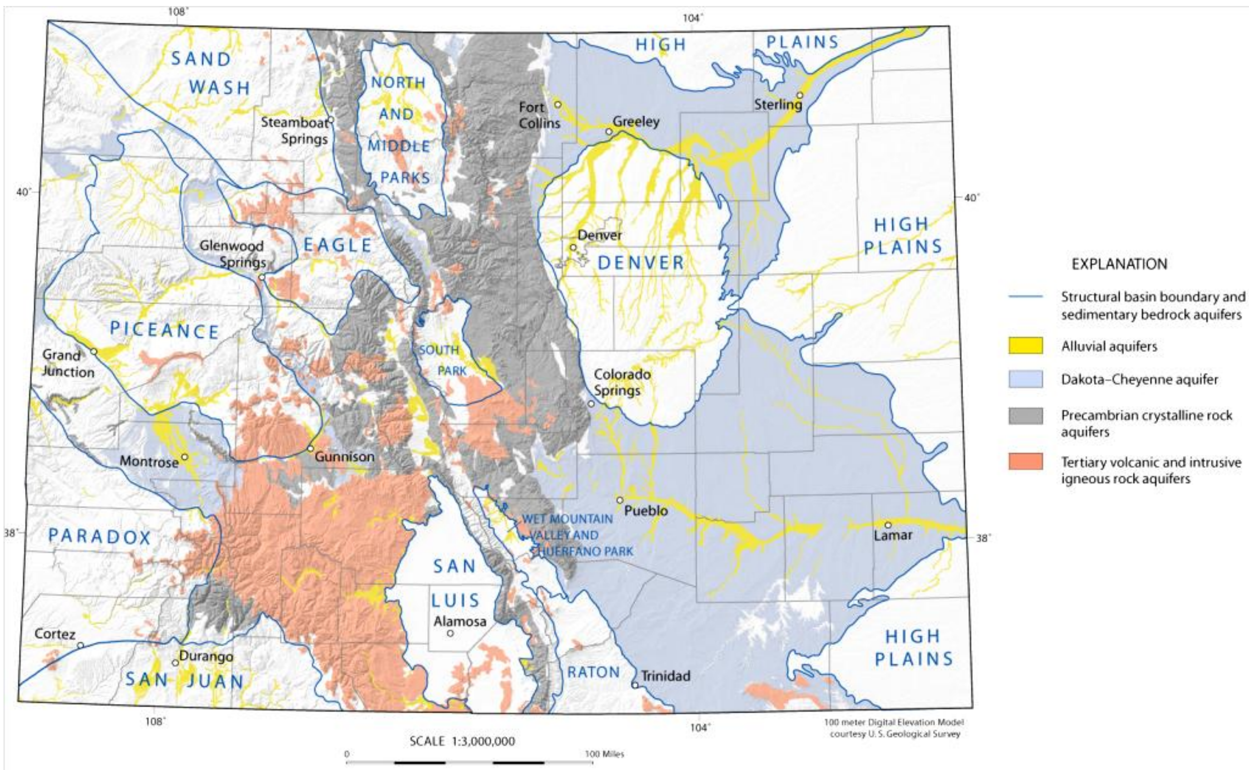
Colorado has eight primary river basins that span the state: South Platte; North Platte; Arkansas; Rio Grande; Gunnison; Colorado; the Northwest Basin composed of the Yampa, White, and Green Rivers; and the Southwest Basin composed of the Dolores, San Juan, and San Miguel Rivers. The Republican River also begins in Colorado. These basins are dependent on winter snowpack and spring runoff to replenish and sustain their flow, which on average produces approximately 15 million acre-feet of water annually. Of that, we consume roughly 5 million acre-feet, and approximately 10 million acre-feet flows out of Colorado to neighboring states.

The western side of the Continental Divide contains 70 percent of the surface water and 11 percent of the population.[3] The eastern side of the Continental Divide consumes 70 percent of the state's water.[4] As a result, many reservoirs on the western slope service communities and demands along the Front Range and eastern plains.[a] Water managers rely on networks of reservoirs, pumps,

[a] The western slope includes the Gunnison, Colorado, Yampa/White/Green river basins, and the basin of the Southwest, composed of the Dolores, San Juan, and San Miguel Rivers. The Rio Grande, North and South

tunnels, and ditches to store and move water and to meet demands at peak times. They also need to comply with relevant environmental mitigation requirements to maintain ecosystem health. Demand-management strategies can help alleviate stress on the system under both normal operating conditions and during shortages, as further discussed in Chapter 6.3.

Figure 4-1: Principal Aquifers and Structural Basins of Colorado



Groundwater plays a major role in the statewide water supply. Nineteen of Colorado's 64 counties and about 20 percent of the state's population rely heavily on groundwater.[5] Most of the groundwater use occurs in the eastern part of the state and in the Rio Grande Basin. The western slope has not developed groundwater to the same extent.

Groundwater resources exist throughout the state in alluvial, sedimentary, and crystalline rock aquifers (Figure 4-1).[6] Alluvial aquifers occur along many of the state's streams and are usually tributary to the stream, in which case the groundwater is administered as part of the stream system. Alluvial aquifers in designated groundwater basins are an exception to this and fall under the management and control of the Colorado Ground Water Commission. Designated groundwater basins include eight areas in the eastern part of the state that rely primarily on groundwater, having minimal to no surface water supplies (Figure 4-2). Sedimentary aquifers occur throughout the state, and include multi-aquifer systems such as the Denver Basin and Dakota-Cheyenne

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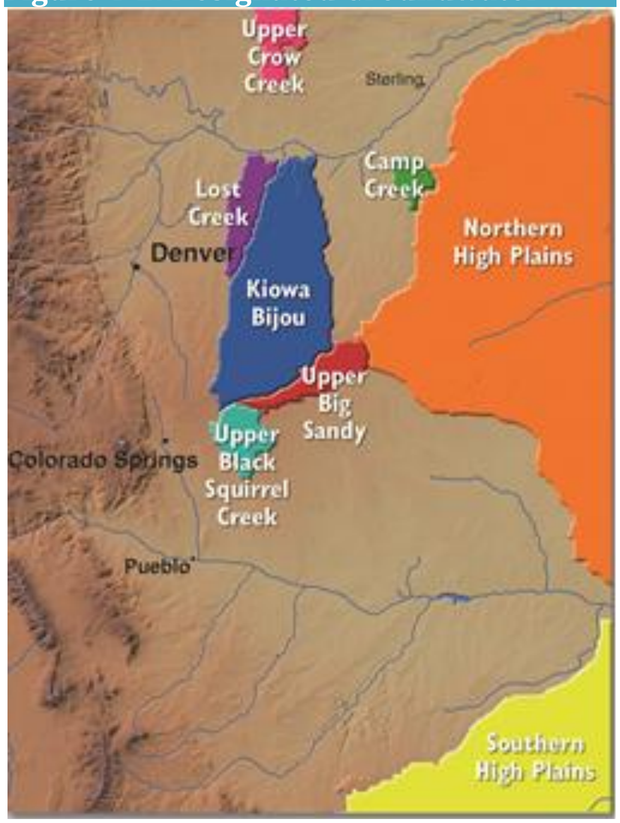
Platte, Arkansas and the Republican River basins are included in the calculations for the eastern slope. If the Rio Grande Basin is included in the western slope, then western slope water increases closer to 80 percent, which is the figure traditionally used. Nevertheless, since the Rio Grande is not truly west of the continental divide, 70 percent is a more accurate figure.

aquifers. Crystalline rock aquifers are found in most of the foothills and mountainous areas of the state. Primarily recharged by snowmelt into fractures in the rock, these aquifers have a low storage capability and are usually limited to domestic use.

Groundwater aquifers offer benefits through their natural infrastructure and protection from evaporation. Nevertheless, relying on groundwater as a primary supply may be challenging because of uncertain and varied natural recharge rates. In some aquifers such as those in the Denver Basin, the natural recharge rate is very low compared to extraction rates so that it is considered a non-renewable resource.

Figure 4-2: Designated Groundwater[5]



Both alluvial and bedrock aquifers offer potentially significant groundwater storage capability. Total capacity potentially available statewide is approximately 10 million acre-feet of alluvial aquifer storage and more than 150 million acre-feet of bedrock aquifer storage. Many potential storage sites, however, are located far away from significant recharge water sources, and there are only a few applications of managed groundwater storage in Colorado, mostly located in the Denver Basin aquifers. Colorado developed rules allowing for recharge and long-term storage in the nontributary Denver Basin aquifers, but there are currently no comparable rules for storage in alluvial aquifers. Groundwater recharge for augmentation purposes is differentiated from groundwater recharge for storage purposes. Recharge in shallower unconfined alluvial aquifers is physically easier than in the deeper confined bedrock aquifers (i.e. surface spreading vs. injection). In contrast to recharge for augmentation, storage in alluvial aquifers may be more difficult to manage because of the transient nature of groundwater flow in tributary alluvial aquifers, making storage in alluvial aquifers potentially more short-term. While groundwater storage has its advantages (e.g. lack of evaporation), it also has its challenges, including slow recharge rates and difficulty controlling the recharged water, retrieving the water, and delivering it to the customer.

Variability in Water Supplies

Precipitation varies in both amount and distribution across the state and is influenced by the elevation and the orientation of the mountains and valleys (Figure 4-3). While portions of the state, such as the San Luis Valley, receive just seven inches of precipitation annually, other portions, for example Wolf Creek Pass, average more than 60 inches. Colorado receives 17 inches of precipitation, on average, each year. In general, the mountains receive more precipitation than the eastern plains, and winters are typically wetter than summers. Despite high precipitation during the winter months, demand for water is highest in the summer months and the growing season.[7]

Figure 4-3: Average Precipitation in Colorado 1981-2010 (inches)

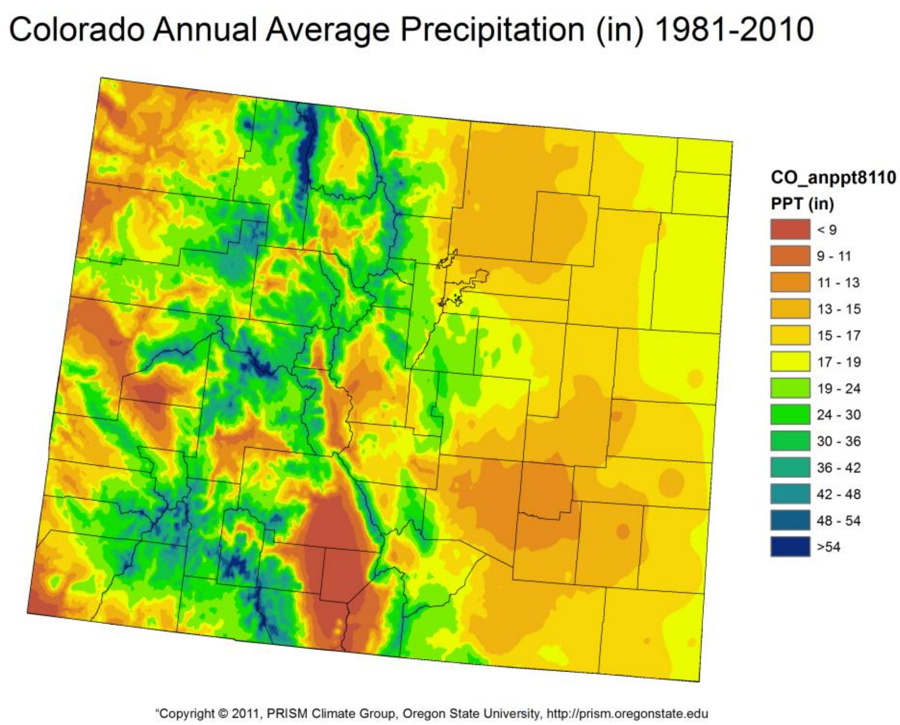
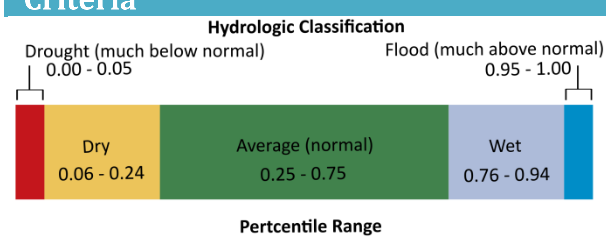


Figure 4-4 Hydrologic Classification Criteria



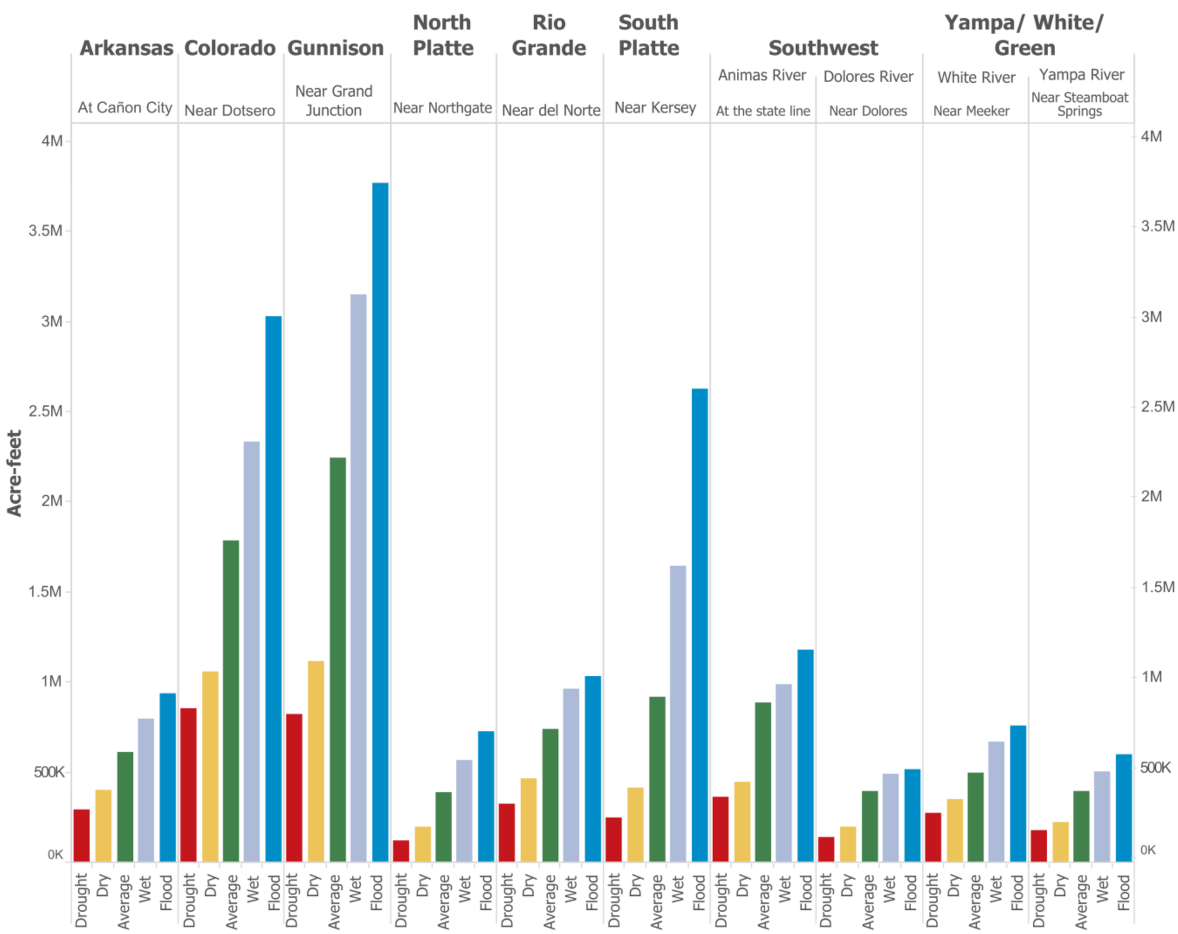
Percentile range used to define drought, dry, average, wet, and flood condtions.

Our state's variable precipitation patterns have resulted in considerable hydrologic fluctuation with floods and drought possible within the same year. In 2011 and 2013, Colorado experienced both extreme flooding and severe droughts during the same periods. These variations from basin to basin may differ by thousands of acre-feet. Furthermore, basin streamflow is not equally distributed across the state, so a low flow in one basin may be greater than a high flow in another, as is the case with the Colorado River and the Southwestern Basins (Figure 4-5).

For the purposes of this plan, hydrologic classifications are assigned based on percentile ranking: drought, dry, average, wet and flood (Figure 4-4). Drought and dry periods have substantial and lasting effects on water supplies and availability for years, while wet years offer relief with as much as six times the amount of annual water supplies compared to dry years (e.g. lower South Platte).

Both extremes can affect water supplies and availability throughout the state for years (Figure 4-5). They also have other consequences, such as wildfires and negative economic effects.

Figure 4-5 Annual Flow Values for Varying Conditions at Select Gages (Acre-Feet per Year)



Annual flow values for drought, dry, average, wet and flood conditions for 10 locations across the state. This graphic illustrates the variability that exists both within basins and between basins of the state and shows the upper-most threshold of the percentile range for each of the selected gages. As this was an independent analysis, values may differ slightly from volumes reported in the individual basin implementation plans.

For example, in 2002, the driest single year on record, Colorado suffered several severe wildfires. The largest of these fires, the Hayman Fire, raised levels of nitrate and turbidity in streams in the burn area that remained elevated for five years after the event.[8] Another example, in 2013, the West Fork Complex fire damaged watersheds and diminished water quality in the Rio Grande Basin. Substantial hillside and stream erosion results from such events. Increased levels of debris in reservoir affect not only water quality, but also the operations of water supply and treatment infrastructure.[9]

Figure 4-6: Average Monthly Flows by Hydrologic Classification

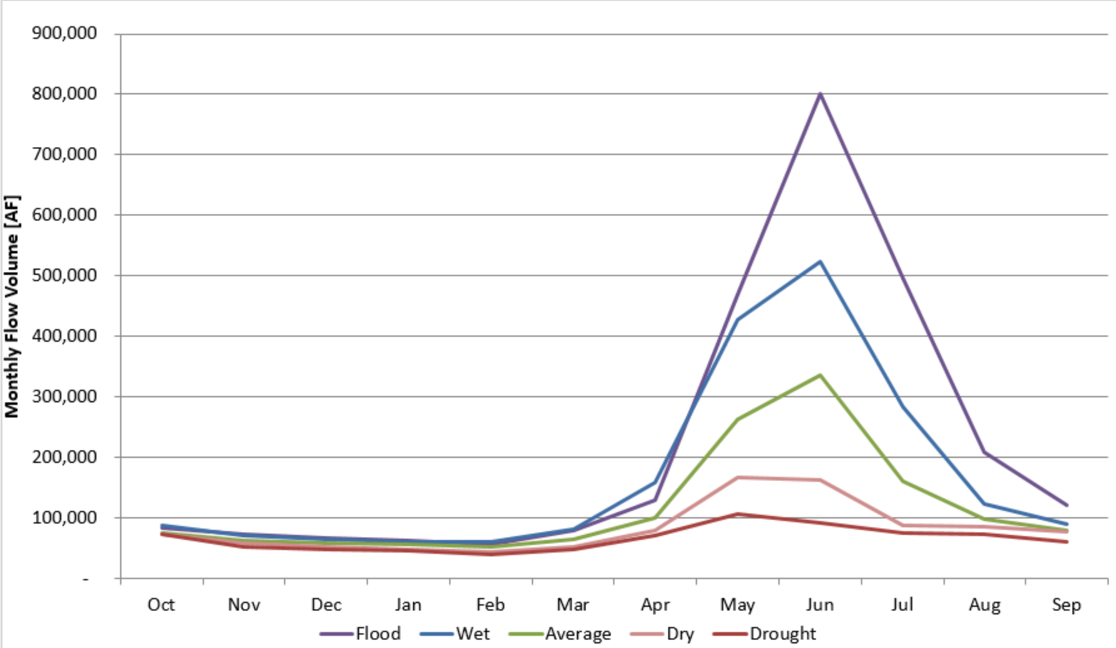


Figure 4-6 uses the same hydrologic classifications as Figure 4-5, but shows average monthly flow volumes on the Colorado River at Dotsero to illustrate the wide variance that can exist among classifications, especially during the runoff season.

The Colorado Water Conservation Board coordinated field data and assisted in developing reports on the substantial hillside and stream erosion that takes place following medium and high intensity wildfires.[10]

Wildfires can affect Colorado's economy and may cost the state millions of dollars in response and recovery efforts alone. They may also impact water providers' budgets as well. The 1996 Buffalo Creek and 2002 Hayman fires cost Denver Water $20 million in wildfire-related dredging and maintenance at their Strontia Springs reservoir, without complete resolution of the problem. [11] In 2012, another year of statewide drought, Colorado Springs Utilities, and the City of Fort Collins also incurred costs from separate wildfires in the watersheds that supply their municipal water. These naturally-occurring events can greatly affect the amount of water supplies that are available for use.

Aside from the effects of wildfire, drought can also have substantial fiscal effects resulting from decreased water availability. In 2012, it is estimated that lost revenues resulting from the drought in the agricultural sector alone exceeded $409 million statewide.[12] When secondary and tertiary economic effects to local communities are factored in, the loss increases to $726 million statewide.[13] Drought can also negatively influence air quality, water delivery infrastructure, wildlife, the environment, recreation, and tourism. Drought is unique in that it can last for weeks, months, or years; and the longer a drought persists, the larger its effect. For instance, a municipality may be able to weather a single-year drought by using reservoir storage and drought response measures, but if the storage is not replenished, subsequent years become increasingly more difficult to manage. The same is true in the agricultural sector; ranchers forced to cull herds in response to drought may need decades to recover their stock, or may never recover at all. Both the Rio Grande and the Arkansas Basins have been dry most of the past decade with only three above-average precipitation years since 2000.[14] The Colorado River Basin has experienced the driest 14-year period since 1963 with above-average flows in only three of the last 14 years.[15]

On the other end of the variability spectrum are floods—too much moisture can result in overflowing reservoirs and extensive damage. In the fall of 2013, widespread flooding occurred in some regions of the state after receiving as much as 19 inches of rain in a few days. In these areas, the events were equivalent to nearly a full year of precipitation. As many as 88 weather stations exceeded 24-hour precipitation records and the hardest hit areas received more than 600 percent of average precipitation for the month.[16] Entire communities were inundated with water.

The September 2013 floods resulted in loss of life, power, homes, businesses, and roads. Initial estimates of economic losses have reached $2.9 billion.[17] This event caused Halligan Reservoir to rise 30 feet, capturing nearly 6000 acre-feet of water in just over 24 hours. Halligan Reservoir transformed from nearly an empty vessel to a full supply in a matter of days. Unfortunately, flows were so high that many storage facilities lost the infrastructure necessary to store the excess water. Floods not only cause community damage, but also affect agricultural operations and water supply because of damaged delivery systems. Flooding events can leave water supply infrastructure, such as diversions and headgates, completely disconnected from their historical source of water. These effects may take weeks, months, or years to fully repair, and some damage may be too great to ever repair economically.

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Figure 4-7: Wet and Dry Year Flows at Select Gages

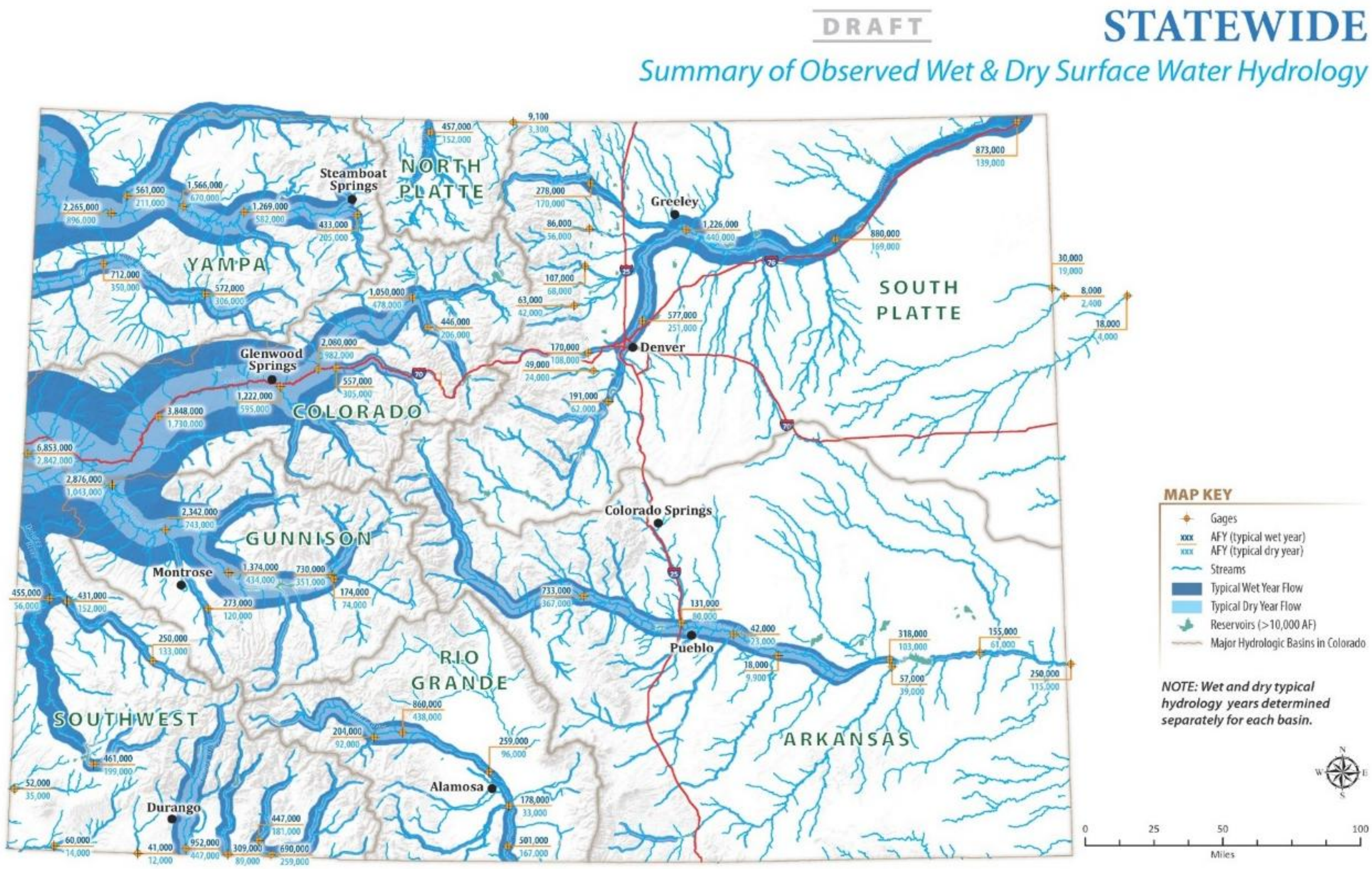


Table 4-1: Summary of Projected Changes and Potential Effects to Water Resources for Colorado[18]

Element	Projected changes and potential effects	Studies that have assessed this vulnerability for Colo.
Overall surface water supply	Most projections of future hydrology for Colorado's river basins show decreasing annual runoff and less overall water supply, but some projections show increasing runoff. Warming temperatures could continue the recent trend towards earlier peak runoff and lower late-summer flows.	Colorado Water Conservation Board (CWCB) (2012); Bureau of Reclamation (BOR) (2012); Woodbury et al. (2012)
Water infrastructure operations	Changes in the snowpack and in streamflow timing could affect reservoir operations, including flood control and storage. Changes in the timing and magnitude of runoff could affect the functioning of diversion, storage, and conveyance structures.	CWCB (2012); BOR (2012)
Crop water demand, outdoor urban watering	Warming temperatures could increase the loss of water from plants and soil, lengthen growing seasons, and increase overall water demand.	CWCB (2012); BOR (2012)
Legal water systems	Earlier and/or lower runoff could complicate administration of water rights and interstate water compacts, and could affect which rights holders receive water.	CWCB (2012)
Water quality	Warmer water temperatures could cause many indicators of water quality to decline. Lower streamflows could lead to increasing concentrations of pollutants.	Environmental Protection Agency (EPA) (2013)
Groundwater resources	Groundwater demand for agriculture could increase with warmer temperatures. Changes in precipitation could affect groundwater recharge rates.	
Energy demand and operations costs	Warmer temperatures could place higher demands on hydropower facilities for peaking power in summer. Warmer lake and stream temperatures, and earlier runoff, could affect water use for cooling power plants and in other industries.	Mackenick et al. (2012)
Forest disturbances in headwaters region	Warmer temperatures could increase the frequency and severity of wildfire, and make trees more vulnerable to insect infestation. Both have implications for water quality and watershed health.	
Riparian habitats and fisheries	Warmer stream temperatures could have direct and indirect effects on aquatic ecosystems, including the spread of non-native species and diseases to higher elevations. Changes in streamflow timing could also affect riparian ecosystems.	Rieman and Isaak (2010)
Water- and snow-based recreation	Earlier streamflow timing could affect rafting and fishing. Changes in reservoir storage could affect recreation on-site and downstream. Declining snowpacks could affect winter mountain recreation and tourism.	BOR (2012); Battaglin et al. (2011); Lazar and Williams (2008)

Uncertainties Affecting Supply

In addition to the high hydrologic variability we face as a state, climate change and dust on snow events present additional complexities and uncertainties. In recent decades, Colorado experienced warming and will likely continue to do so in the future. Average yearly temperature increased by 2°F in the last 30 years, and 2.5°F in the last 50 years across the state. This affects the timing of snowmelt and peak runoff, which occur earlier, and there is an increase in heat waves and wildfires. Climate projections show Colorado warming an additional 2.5°F to 5°F by mid-century, with summer temperatures increasing more than winter. While projections are less clear whether precipitation will increase or decrease, warming temperatures that drive physical processes, such as evapotranspiration, are projected to result in an earlier run-off, longer irrigation season, and a decrease in annual stream flow, especially in the state's southern basins. Even moderate increases in precipitation will not be sufficient to overcome the drying signal. All of these changes are likely to substantially affect water available for beneficial use in Colorado in the coming decades. Table 4-1 illustrates the potential water-related effects of climate change in different areas and sectors; while Table 4-2 highlights projected effects of increased temperatures on a wide array of indicators, as described in the 2014 Climate Change in Colorado Report.

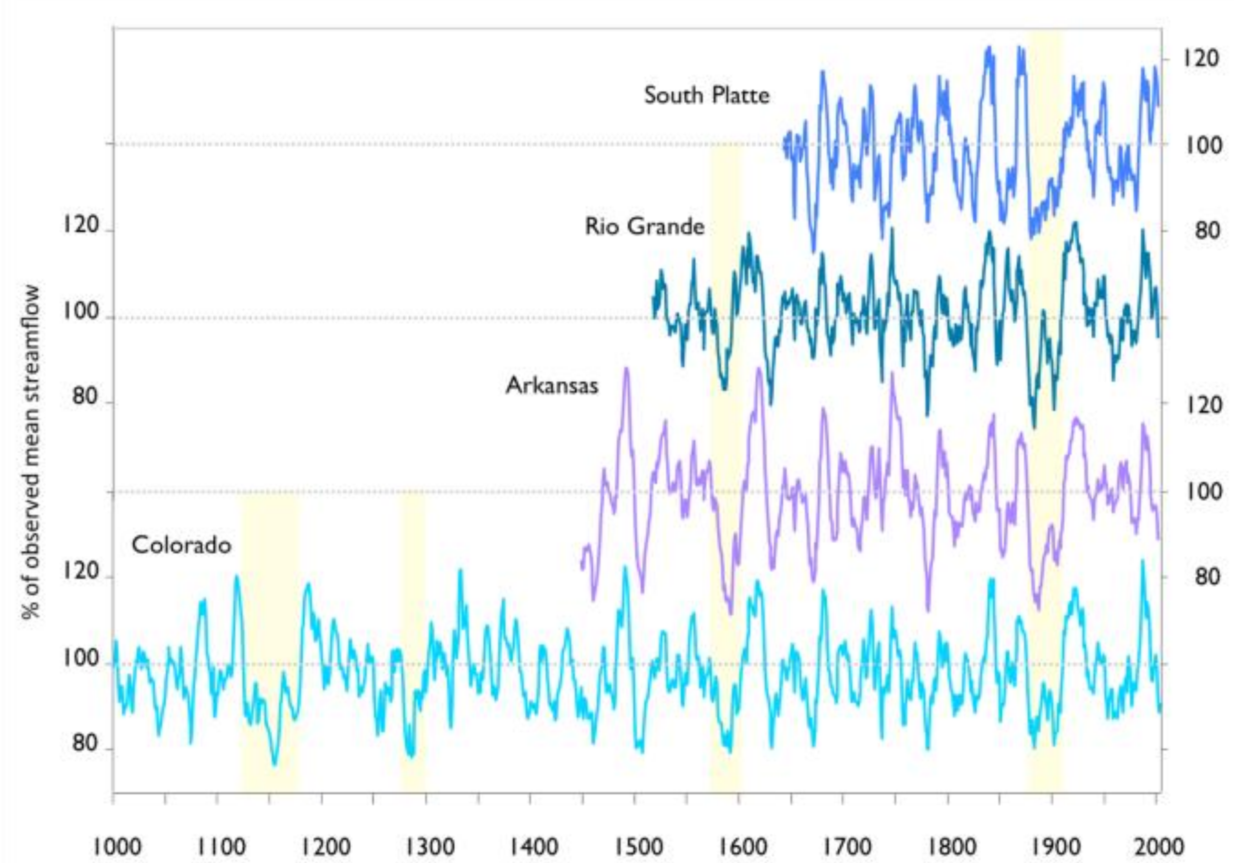
Table 4-2 Projected Climate and Hydrology Changes[19]

Indicator	Effect of Climate Change
Annual Streamflow	Decrease in most of the climate projections
Peak Runoff Timing	Earlier in all projections
Crop Water Use	Increases
April 1 Snowpack	Decreases in most projections
Palmer Drought Severity Index	More drought
Heat Waves	More frequent
Cold Waves	Less frequent
Frost Free Season	Longer

Colorado is accustomed to dealing with variability and drought over the last 150 years, yet tree ring reconstructed streamflows indicate that the state has endured longer lasting and more severe droughts than we have seen in our relatively brief observed record. In fact the 20th century is unique in that there were two prolonged wet periods and no multi-decadal droughts.[20] Figure 4-8 shows multiple droughts (shaded highlights) that exceed the intensity and duration of our observed record.

As described in Section 6.1, the scenarios developed by the IBCC will help the state prepare for whatever future may unfold, those include three scenarios that have a climate different from what was observed during the 20th century, including two scenarios that experience "hot and dry" conditions and one scenario with hydrology and climate "between 20th century observed and hot and dry." Figure 4-9 illustrates where these scenarios fall in comparison to the current, or 20th century observed.

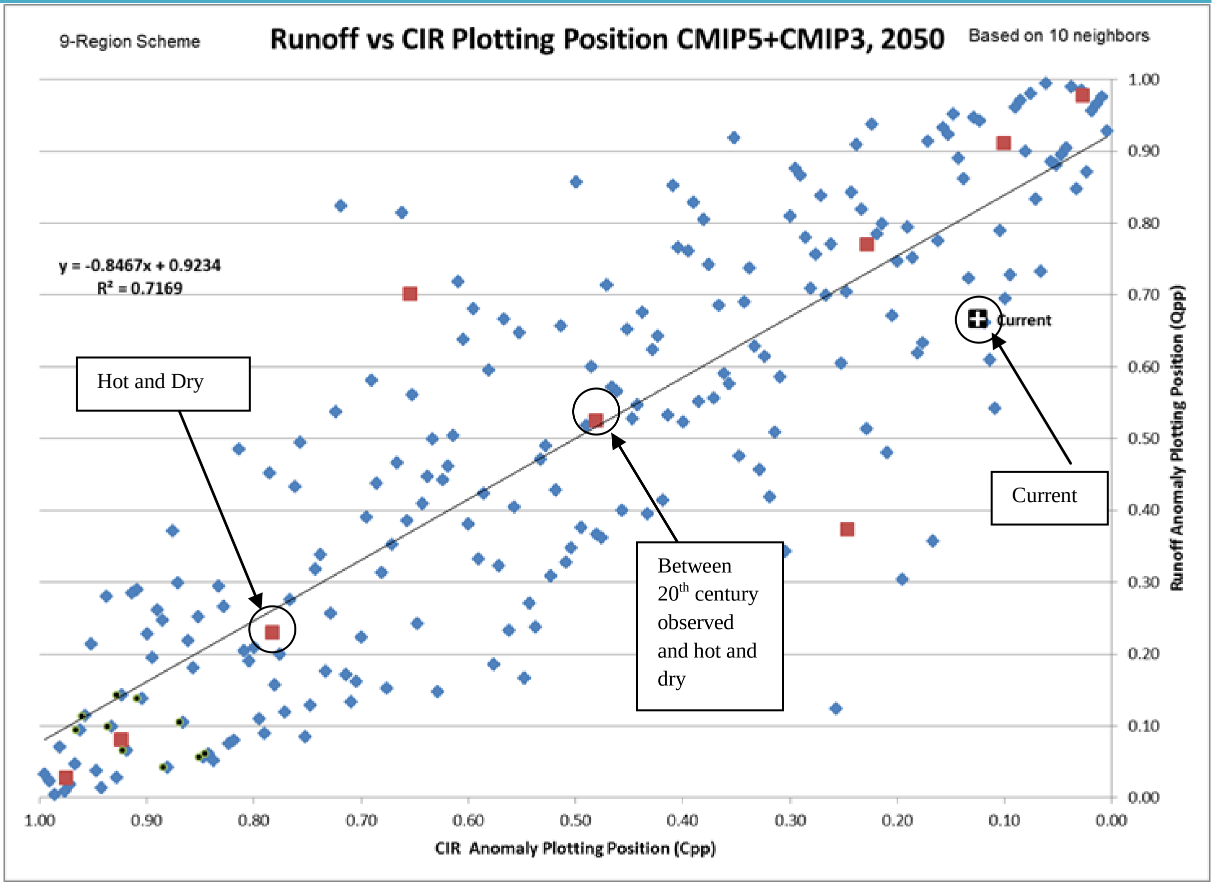
Figure 4-8 Tree-ring Reconstructed Water-year Streamflows for Four Major River Basins of Colorado[21]



Tree-ring reconstructed water-year streamflows as percent of observed mean, showing the 10-year running average, for four gages representing major Colorado basins: the Colorado River at Lees Ferry, AZ (762–2005, here shown from 1000–2005), the South Platte River at South Platte, CO (1634–2002), the Rio Grande at Del Norte, CO (1508–2002), and the Arkansas River at Salida, CO (1440–2002). All four records show the occurrence of droughts before 1900 that were more severe and sustained than any modern droughts. The yellow shading highlights several notable multi-decadal paleodroughts, in the mid-1100s, the late 1200s, the late 1500s and the late 1800s. The 20th century was unusual in having two persistent wet periods and no droughts longer than 10 years. (Data: TreeFlow web resource; http://treeflow.info)

Having quantitatively defined the scenarios, the data were used to determine the effect on streamflow. Figure 4-10 below illustrates projected depleted flows for 2050 in acre-feet per year at eleven different sites around the state. In some scenarios, projected flows are less than zero, indicating that some users, both senior and junior, would be unable to obtain their historical supply of water.[22] Both the Arkansas and the Rio Grande Rivers are projected to experience these conditions under both climate scenarios; the South Platte is projected to experience these conditions under the "hot & dry" climate scenario. While these basins are accustomed to calls dating back well into the 19th century, climate change has the potential to substantially alter the amount of water available to even those with well-established senior water rights. Continued monitoring, research, and planning is critical to determining whether future supplies will fulfill future demands and continue to fulfill *current* demands. Addressing these challenges will require collaboration and innovative solutions.

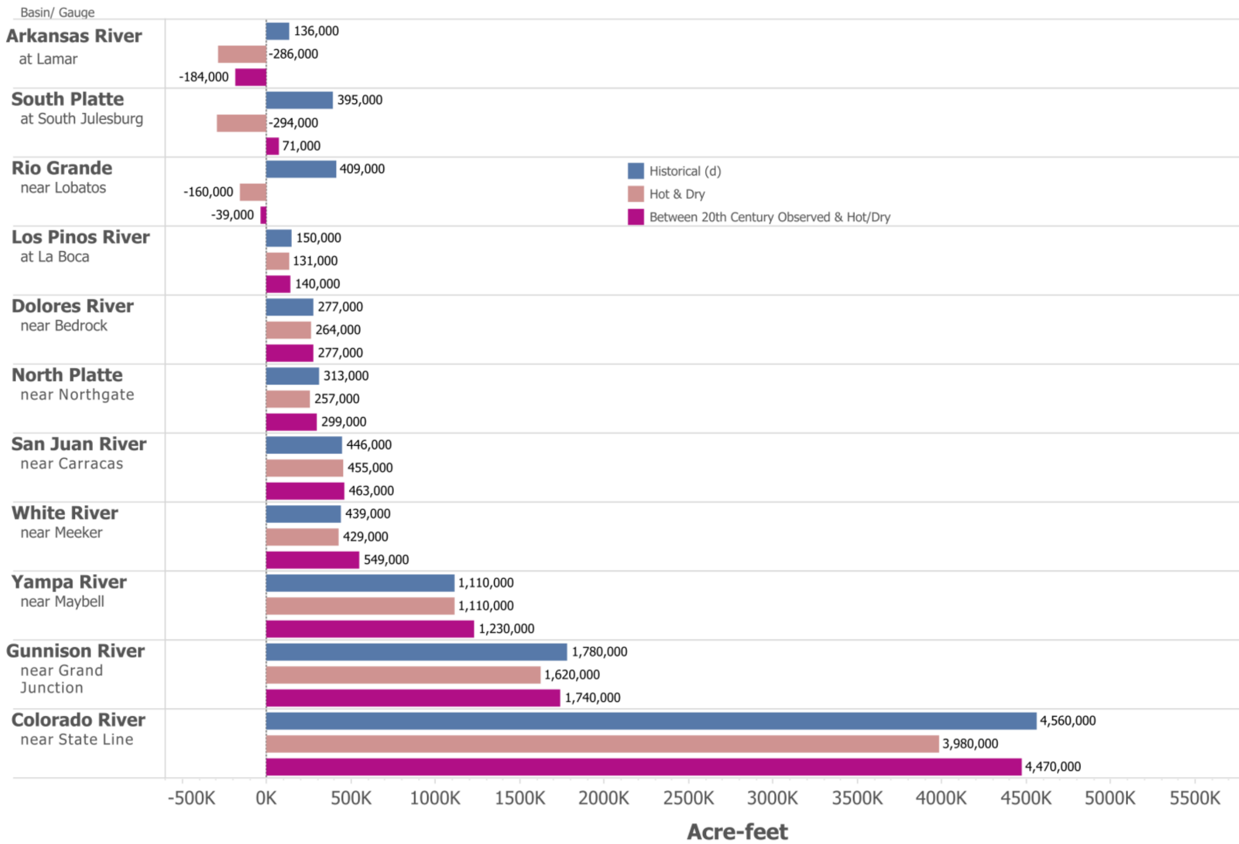
Figure 4-9 Plot of Runoff vs. Crop Irrigation Requirements Utilizing the Bureau of Reclamation Archive



Hot and dry is defined as the 75th percentile of climate projections for crop irrigation requirement (water use), and the 25th percentile for natural flows. In other words, only 25 percent of projections have lower natural flows and 25 percent of projections have a higher crop irrigation requirements. Between 20th century observed and hot & dry is defined at the 50th percentile for both natural flows and crop irrigation requirements. This scenario is the middle of the range in terms of severity. Historical or current conditions, which is no change in runoff or crop irrigation requirement fall at roughly the 9th and 67th percentiles; this means that 91 percent of runs show increases in crop irrigation requirement and about two thirds show reductions in runoff.

In addition to the work the state did on climate change, several of the basin roundtables also incorporated the uncertainties posed by climate change into their Basin Implementation Plans. Many basins now recognize that previous assumptions used for planning purposes are no longer sufficient because of climate change. For example, the Colorado Basin recognizes that relying on previous firm dry yields will not provide reliability for the future and is therefore encouraging water providers update their master plans accordingly (and consider interconnected water systems to help mitigate the influences of climate change). The South Platte, Arkansas and Rio Grande Basins all recognize they must plan for a decrease in water supplies because of the effects of climate change, the latter of which highlighted that they expect to see their water resources reduced by as much 30 percent in the next 50 to 100 years. In response, the Arkansas Basin is looking into conjunctively using tributary and non-renewable sources to alleviate the effects of reduced yields from climate change and the potential for dry up of non-tributary sources.

Figure 4-10: Projected Depleted Flows for 2050 (acre-feet per year)



Projected depleted flows for 2050 in acre-feet per year at eleven different sites around the state using the aforemntioned classifications of historical, hot and dry and between 20th century observed and hot and dry.

Almost all Basin Implementation Plans, including that of the North Platte, specifically address the need to continue to monitor the effects climate change will have on the respective basins. The Gunnison Basin, for example, referenced throughout their plan the need to study effects of climate change as a means to achieve their primary and complementary basin goals and identify actions to protect existing uses. The *Research and Public Education on Anticipating, Mitigating and/or Adapting to Climate Changes*, is one way they propose to meet this goal. Education and outreach is another goal indentified by several basins. The Southwest Basin, for example, committed to educating their roundtable members on climate change as a way to better refine their present and future water planning efforts.

Several basins, including the South Platte/Metro, Yampa/White/Green, Arkansas, and Southwest, incorporated scenarios or projected and potential effects of climate developed by the state into their own planning processes.

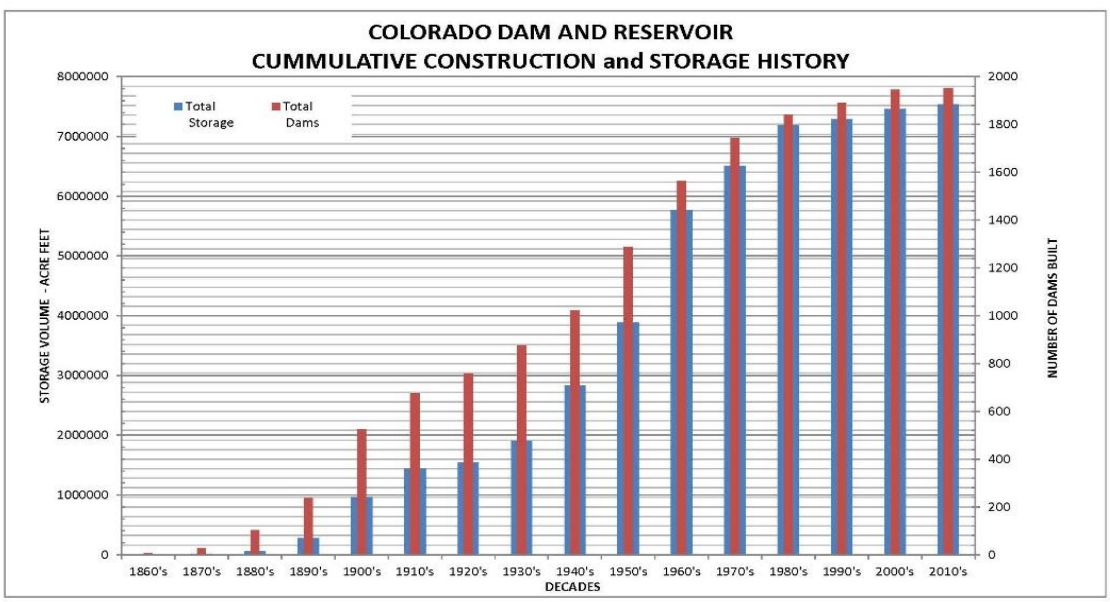
Dust on Snow Events

So called "Dust-on-snow" events also introduce uncertainty into managing water supplies. Dust-on-snow events occur when wind deposits dust from southwestern deserts (and other loose-soil surfaces lacking vegetation) onto mountain snowpack. This increases the effect of solar radiation, which speeds up snowmelt and leads to earlier spring runoff. Studies have shown that dust events can advance snowmelt timing, enhance snowmelt runoff intensity, and decrease snowmelt yields.[23] Dust-on-snow events can result in peak runoff occurring three weeks earlier than normal; this shift is independent of climate change, which may also result in earlier snowmelt patterns.[24] Since 2005, when dust tracking began, 91 events have occurred. Ten of these dust-on-snow events occurred in the 2013 water year, when Colorado observed the heaviest deposition to-date.[25] While the severity of future dust-on-snow events is uncertain, if events continue at recently-observed rates, they will affect Colorado's present and future water supply by decreasing flows by 5 percent, on average. On the Colorado River, this reduction would result in a decrease of 750,000 acre-feet of water, or twice the amount of water the City of Denver uses annually.[26]

The Role of Storage

While our snowpack is our greatest storage "facility," to meet the year-round needs of agriculture, municipalities, recreation, and the environment, we have constructed numerous reservoirs to hold water during plentiful times and release water during heightened demand or periods of drought. Nearly half of the state's storage capacity is located on the western slope in the Colorado River Basin and its tributaries.[27] Colorado's total storage capacity is approximately 7.5 million acre-feet within 1953 reservoirs (Figure 4-11). Approximately 4.2 million acre-feet of the state's total storage is in 113 federally-owned reservoirs.

Figure 4-11: Colorado Dam and Reservoir Cumulative Construction and Storage History



Colorado's water infrastructure, including water storage, is critical to maintaining stable water supplies. Water-storage infrastructure allows Colorado to use its legal entitlements before water flows out of the state. In addition, water-storage infrastructure is essential in assisting with flood control, supporting all types of use (agricultural, environmental, municipal, and industrial) in periods of drought, complying with interstate compacts, and augmenting stream systems to allow water use by water users that would otherwise not have a right to divert in the prior appropriation system. Most storage projects were developed in the middle of last century. Both construction of new infrastructure and storage have remained relatively static over the last 30 years (Figure 4-12). In fact, construction of storage has declined so much that our current rate of building storage capacity resembles that of the Great Depression.

Figure 4-12: Colorado Dam and Reservoir Construction History and Volume by Decade

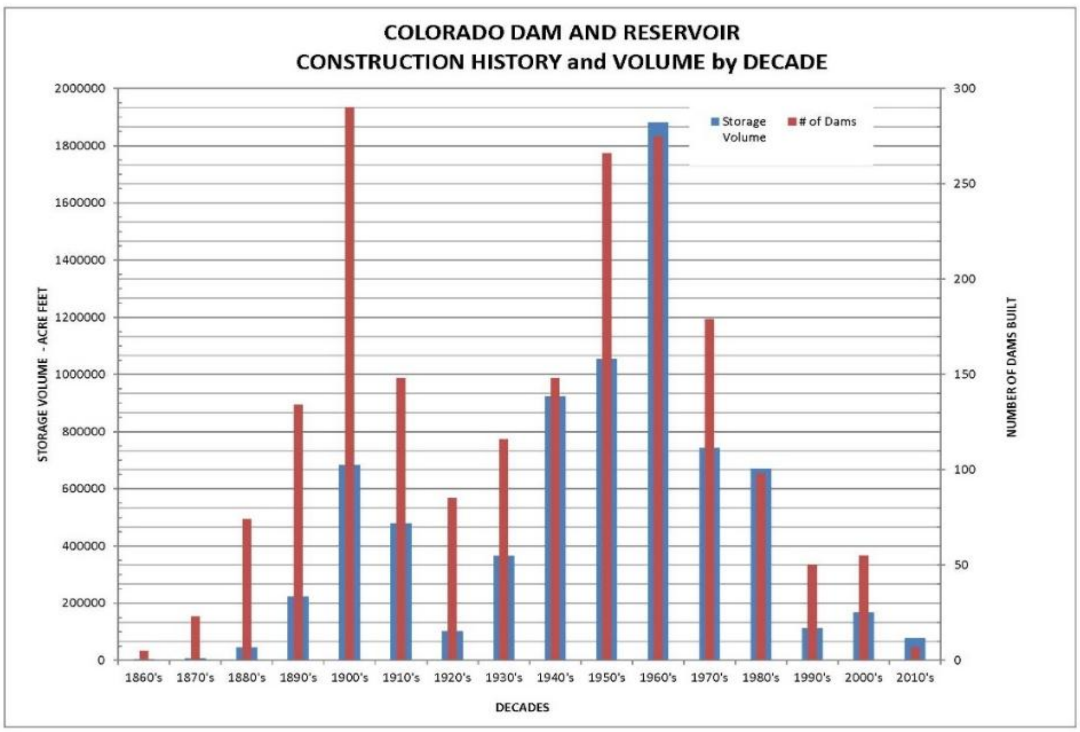


Figure 4.12 does not include storage capacity associated with flood control reservoirs because it can only be used on a limited basis for water supply storage.

While storage is a critical element for managing Colorado's future water supplies, new storage projects may be contentious and face numerous hurdles, including permitting and funding. In many cases, it may be more practical and efficient to reallocate or enlarge an existing dam and reservoir than to build a completely new structure. In determining whether a reservoir is suitable for enlargement, we use the following factors: the ability to capture excess yield, the potential for exchange, the reservoir location relative to more senior water rights, the engineering characteristics of existing facilities, interstate compact considerations, and environmental benefits and threats.

Table 4-3: Largest Potential Reservoir Storage Increase by Storage[28]

Name	Division	Max Storage	Normal Storage	Storage Delta	Surface Area	Managing Organization
JOHN MARTIN	2	805,440	232,942	572,498	8955	U.S. ARMY CORPS OF ENGINEERS
CHERRY CREEK	1	265,770	13,226	252,544	852	U.S. ARMY CORPS OF ENGINEERS
GRANBY	5	752,048	539,800	212,248	7260	U.S. BUREAU OF RECLAMATION
PUEBLO	2	535,507	357,678	177,829	4646	U.S. BUREAU OF RECLAMATION
ANTERO	1	115,000	26,500	88,500	2600	DENVER BOARD OF WATER COMMISSIONERS
BEAR CREEK	1	81,075	2000	79,075	110	U.S. ARMY CORPS OF ENGINEERS
BLUE MESA	4	1,019,748	940,800	78,948	9180	U.S. BUREAU OF RECLAMATION
GREEN MOUNTAIN	5	222,645	154,600	68,045	2130	U.S. BUREAU OF RECLAMATION
MCPHEE RESERVOIR	7	440,000	381,100	58,900	4300	U.S. BUREAU OF RECLAMATION
CUCHARAS #5	2	64,820	7414	57,406	915	TWO RIVERS WATER COMPANY
TWIN LAKES	2	141,000	86,000	55,000	2805	U.S. BUREAU OF RECLAMATION
TRINIDAD	2	169,370	119,877	49,493	2018	U.S. ARMY CORPS OF ENGINEERS

The Colorado Division of Water Resources' dams database contains information that can be used to examine enlargement potential for existing reservoirs and dams. The database of dams in Colorado contains information on the volume of water a reservoir can hold when filled to the normal high-water line, and the volume of water that would be present if the reservoir filled to its capacity. The difference between the volume of normal storage and of maximum storage is called the storage delta. For many reservoirs the storage delta is "flood storage" needed for containing floods flows and, therefore, is not available for enlargement of storage. Nevertheless, advances in meteorology, hydrology, and dam engineering make it possible to reassess reservoirs and potentially use existing flood storage for active storage. The portion of the reservoir associated with the storage delta has the largest surface area; therefore, a relatively small increase in the water surface elevation will result in a large increase in water storage capacity. As an example, at John Martin Reservoir, an increase of one foot in the normal high-water line of the reservoir results in an increased storage capacity of nearly 9000 acre-feet.[b]

Table 4-3 shows maximum storage, normal storage, and surface area for the reservoirs on the potential enlargement list as developed from the dams database. While it is certainly not the only indicator regarding the potential for enlargement, a large storage delta is a threshold criteria. An existing reservoir is understood to have the potential to inundate a known land area that includes the area associated with its maximum capacity. Therefore, a reservoir with a large storage delta can expand its additional storage capacity without increasing the area potentially inundated and minimizing the associated environmental effects. The most efficient way to generate a list of dams and reservoirs that can be considered for enlargement is to use the database to evaluate the storage delta. Table 4-4 shows the results of the query from all 1900 jurisdictional dams in the database. The table shows 323 candidate dams that meet the criteria of a storage delta greater than 500 acre-feet. Figure 4-13 shows the geographical distribution of the dams by the range of potential storage that exists.

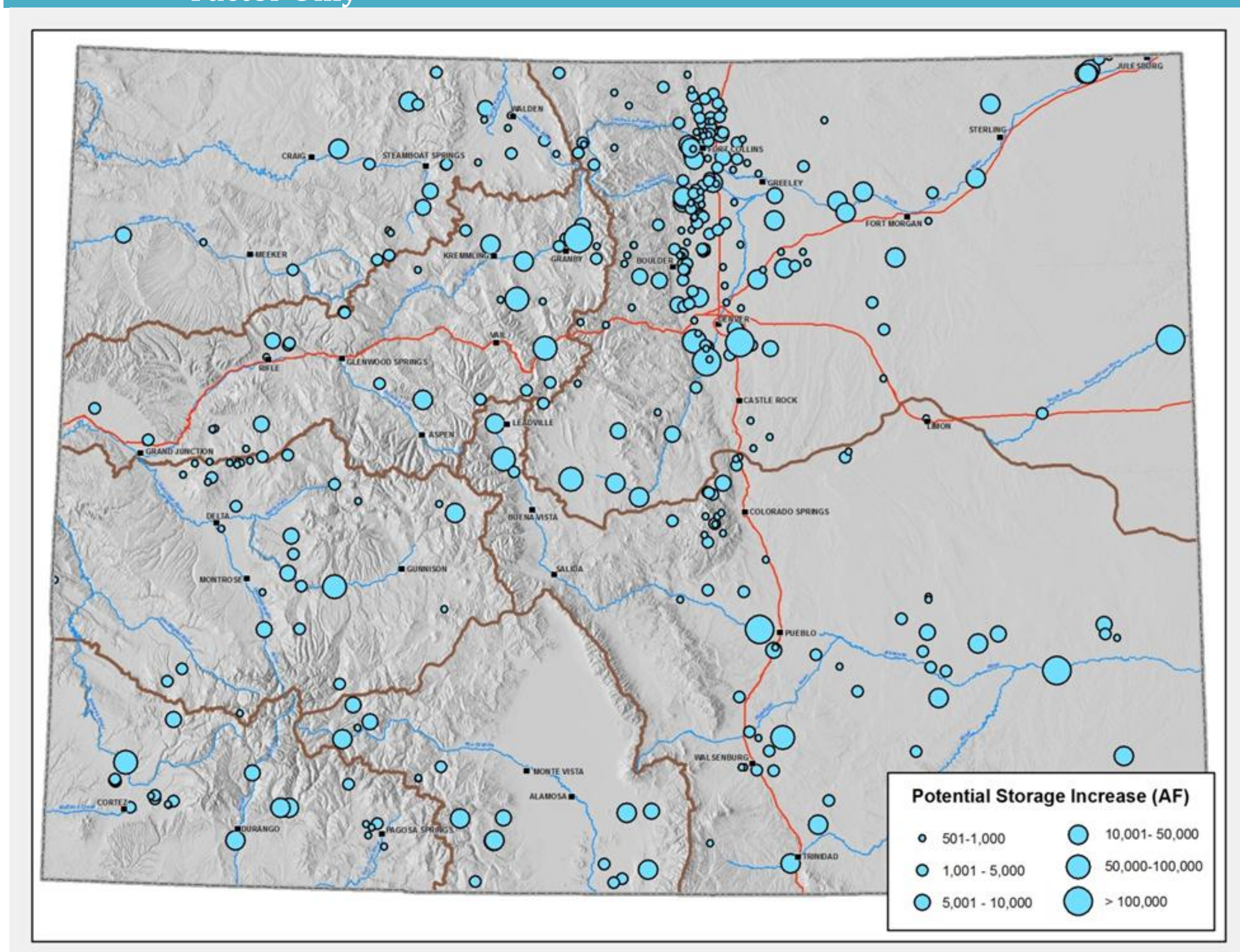
Table 4-4: Number of Dams by Water Division That Fall Into the Various Ranges of Storage Delta

Water Division	STORAGE_DELTA Range (acre-feet)						Division Totals
	501-1000	1001-5000	5001-10,000	10,001-50,000	50,001-100,000	>100,000	
1	53	61	10	16	2	3	145
2	19	23	5	5	2	2	56
3	2	5	4	5	0	0	16
4	16	10	3	1	1	0	31
5	9	15	3	3	2	1	33
6	8	9	4	2	0	0	23
7	6	7	2	3	1	0	19
	113	130	31	35	8	6	323

[b] This table shows *potential* reservoir storage increase. Agreements, interstate compact obligations and other constraints, notably the unavailability of flood storage and the need to retain freeboard for dam safety purposes, may make the potential increase not usable.

In general, the reservoirs with the largest storage delta are those owned by the federal Bureau of Reclamation and the U.S. Army Corps of Engineers. The Bureau of Reclamation reservoirs are primarily for storage of project waters, not for flood storage. Conversely, the U.S. Army Corps of Engineers dams are dual purpose and have the largest storage deltas because they include dedicated flood storage capacity.[29]

Figure 4-13: Potential Statewide Reservoir Storage Increase Based on Storage Delta Factor Only



Weather Modification

Weather modification, also known as cloud seeding, is used to increase available water supplies. The World Meteorological Organization states that weather modification programs that are well designed and well executed have demonstrable results with no documented negative environmental effects from using silver iodide for cloud seeding.[30] Colorado is a leading state for weather modification activities with seven permitted ground-based wintertime cloud seeding programs. The goal of these programs is to increase snowpack and streamflow. In comparison to other sources of new water, cloud seeding is a relatively low-cost means of increasing system supplies. The recreation sector, especially the ski industry, relies heavily on cloud seeding. In 2006, because of prolonged water supply shortages in the Colorado River Basin, the Colorado Water Conservation Board signed agreements with the New Mexico Interstate Stream Commission, California Six Agency Committee, Southern Nevada Water Authority, and Central Arizona Water Conservation District to collaborate and financially support cloud seeding in Colorado. For additional information on weather modification efforts within the state, please refer to the Weather Modification Program pages on the Colorado Water Conservation Board website.[31]

Water Quality

Water quality and quantity are inextricably connected. Understanding water supply and demand alone is an incomplete picture. There must be enough water available for use with suitable quality for irrigation, drinking water, recreational uses, and the protection of aquatic life. This section briefly outlines some of the key connections between quality and quantity while Section 7.3 provides a more detailed discussion.

Based on the 2012 Integrated Report (reporting period 2010-2011):

- 65 percent of river and stream miles and 28 percent of lake and reservoir acreages evaluated statewide attain water quality standards.
- 25 percent of river and stream miles and 49 percent of lake and reservoir acreages statewide do not have enough data to determine if water quality standards are being met.
- 10 percent of river and stream miles and 23 percent of lake and reservoir acreages evaluated statewide are not meeting water quality standards for one or more pollutants (i.e., they are impaired water bodies).[32]

Over the past 40 years Colorado water quality management programs have ensured clean water for uses such as growing crops, providing drinking water, and enjoying water-based recreation. These programs benefit all Coloradans because clean water is essential to the state's healthy environment, diverse economy, and quality of life. This is why both protecting and restoring water quality are fundamental to supporting Colorado's Water Values and implementing Colorado's Water Plan.

Water supply decisions need to include water quality management considerations to sustain and improve existing statewide water quality conditions. A more specific discussion about the relationships between water quality and quantity is provided in Section 7.3.

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