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4. Historical and Projected Water Supply

Introduction

Water supply in Colorado is a complex interplay between weather, geology, and legal constraints; all influencing how much water is available for beneficial use statewide. At 6,800 feet, Colorado has the highest mean elevation of any state [1]. 70% of Colorado's surface water supply originates high in the Rocky Mountains. This is also where our major rivers begin, flowing down the slopes, onto the plains, and across the borders into 18 downstream states. Three of the nation's hardest working rivers begin within Colorado: the Arkansas, the Colorado, and the Rio Grande [2]; and all of Colorado's rivers flow out of the state. West of the Continental Divide, water flows west toward the Pacific Ocean, and east of the divide, waters flow toward the Gulf of Mexico. Colorado's rivers and streams provide surface water and replenish alluvial groundwater supplies, while deeper groundwater aquifers provide a resource that can be extracted and used as well. Groundwater accounts for approximately 17 percent of water diversions in the state. Surface water supplies are highly variable, both seasonally and annually. This high variability in our annual supplies is further complicated by a warming climate [3]. Over the last 30 years average annual temperatures have risen 2.0^{o}F statewide and are projected to increase an additional 2.5^{o}F-5^{o}F by 2050 [3]. While surface water supplies are renewable, two major sources of groundwater in eastern Colorado – the Denver Basin Aquifer and the Ogallala Aquifer – are not. Understanding and managing our water supplies today and in the future is critical to helping ensure a secure water future for all Coloradans.

4.1 Description of State Waters

Colorado has eight primary river basins: South Platte, North Platte, Arkansas, Rio Grande, Gunnison, Colorado, Yampa/White/Green, Republican, and the basin of the Southwest, composed of the Dolores, San Juan, and San Miguel Rivers. All of these basins are dependent upon winter snowpack and spring runoff to replenish and sustain their flow. However, precipitation varies in amount and in distribution across the state. While some portions of the state receive just seven inches of precipitation annually (San Luis Valley), others average over 60 inches of precipitation (some areas of the mountains) (Figure 4.1-1-1). Precipitation amounts are largely influenced by elevation, and the orientation of the mountains and valleys [4]. Statewide Colorado averages 17 inches of precipitation a year [4]. In general, the mountains receive more precipitation than the eastern plains, and winters are typically wetter than summers. Despite most of the precipitation falling during the winter months, demand for water is highest in the summer months and growing season.

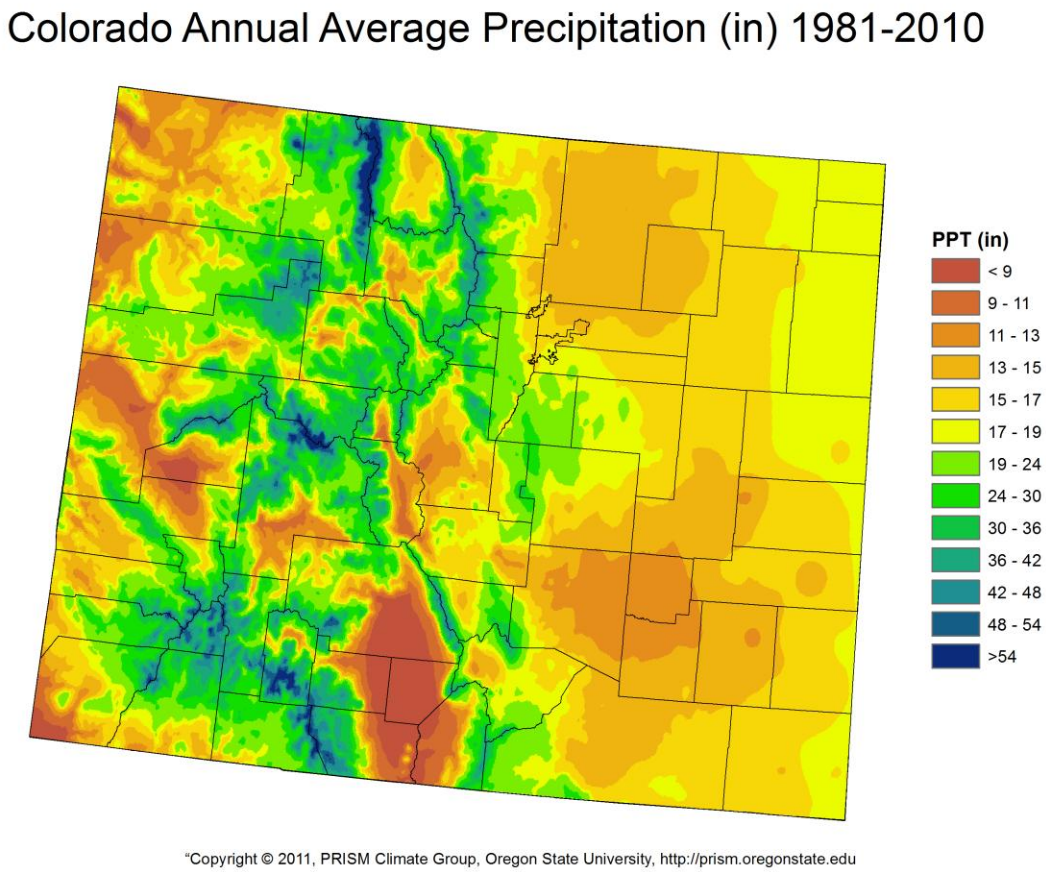

Figure 4.1-1: Average annual precipitation statewide for the 30 year period 1981-2010 in inches.

Annual precipitation varies a great deal from year to year for different parts of the state, with both floods and droughts possible in the same year. In fact, in 2011 and 2013, one portion of the state experienced record flooding while another experienced extreme drought.

In order to utilize water year-round and meet the needs for agriculture, our cities, and the environment, numerous reservoirs have been constructed to hold the water when it is plentiful, and release water when demand is heightened. Because 70% of the surface water is found west of the continental divide [5], and 70% of the state's consumptive use is east of the divide [6], many reservoirs on the Western Slope service water for the Front Range and eastern plains. The state as a whole has the capacity to store approximately 7.5 million acre-feet in 1,953 reservoirs. These numbers and the decades in which those storage reservoirs were constructed are shown below in Figure 4.1-2 It should be noted that approximately 4.2 million acre-feet of the 7.5 million total storage in the state is contained in 113 federally owned reservoirs. Figure 4.1-2 does not include storage capacity associated with flood control reservoirs as that can be used on only a limited basis for water supply storage. Nearly half of the state's storage capacity is located on the west slope in the Colorado River Basin and its tributaries [7]. Colorado employs water storage and infrastructure to utilize its legal entitlements before the rivers flow beyond the borders of the state, assist in flood control, sustain water users of all types (agricultural, environmental, municipal and industrial) in periods of drought, comply with interstate compacts, and augment the system in order to maintain compliance with water administration. The majority of this storage was developed in the middle of last century (Figure 4.1-3) and both construction and storage have remained relatively stable over the last 30 years (**Error! Reference source not found.**).

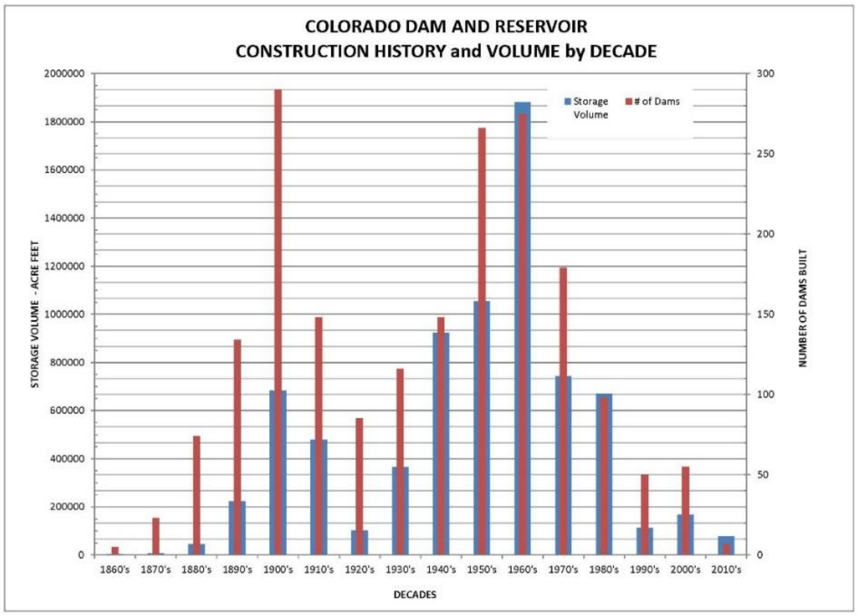

Figure 4.1-2: Colorado Dam and Reservoir Cumulative construction and storage

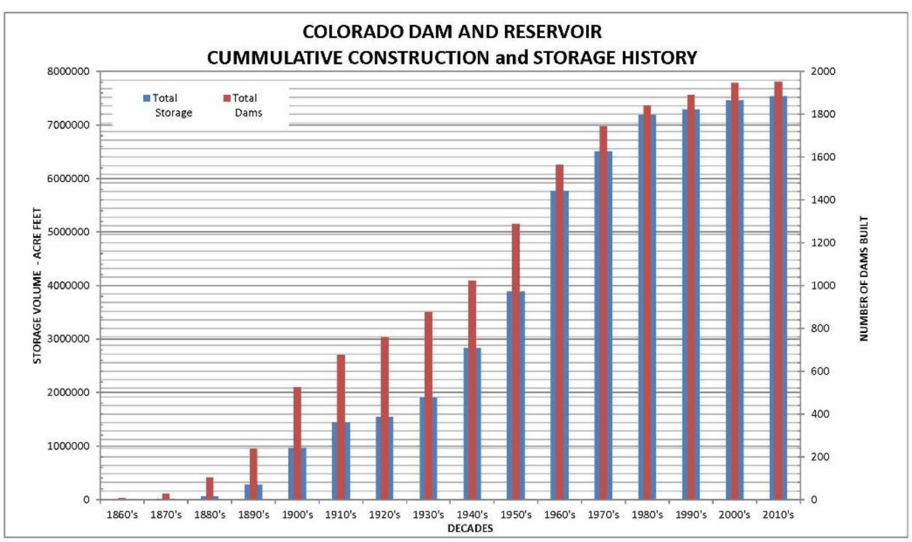

Figure 4.1-3: Colorado Dam and Reservoir Construction and Volume by Decade

Groundwater also plays an important role in statewide water supply, with seven principal aquifers or aquifer systems, both alluvial and bedrock, recognized [8] [9]. Nineteen of Colorado's counties and approximately 20% of the state's population rely heavily on groundwater [8]. Some areas of the state have better access to groundwater (e.g. the San Luis Valley and the various designated groundwater basins on the eastern plains (**Error! Reference source not found.**). Groundwater offers the benefits of natural infrastructure and protection from evaporationevaporation. The drawbacks are uncertain and varied recharge rates – in some cases, the total amount of water is finite or considered a non-renewable resource.

There is significant potential for groundwater storage in Colorado in both alluvial and bedrock aquifers, with total available capacity statewide of approximately 10 million acre-feet (MAF) of alluvial aquifer storage and over 150 MAF of bedrock aquifer storage [10]. However, there are relatively few applications of managed groundwater storage in Colorado, and bedrock storage may be cost prohibitive or have limited applications. Colorado has 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. Although recharge into the shallower unconfined alluvial aquifers is physically easier than in the deeper confined bedrock aquifers, storage in alluvial aquifers can be more difficult due to the transient nature of groundwater flow in tributary alluvial aquifers; this generally makes storage in those aquifers short term and reliant on accounting that is based on sophisticated groundwater modeling. While groundwater storage has its advantages (e.g., lack of evaporation), there can be challenges in limited recharge rates, maintaining control over the recharged water, retrieval of the water, and delivery to the customer.

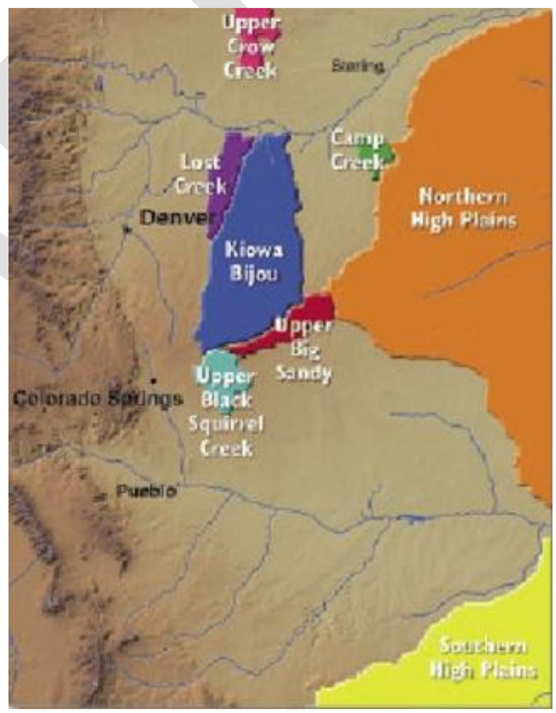

Figure 4.1-4: Designated Ground Water. Image courtesy of Colorado Foundation for Water Education

As the state prepares for the future, water management agencies are examining as many indicators of future climate as possible. Climate change models suggest a decrease in the water available for use, and a decrease in the period during which that water is available. These models indicate that to a reasonable degree of scientific certainty, water systems will likely be more stressed, and risk factors to those systems will likely increase in the future. Those river basins that are already overappropriated are likely to be more impacted than those that are not. Consequently, the challenges to be faced in the coming decades are not likely captured by past experiences. By preparing for this possibility today, Colorado will build resilience and help to ensure a more secure water future.

4.2 Current Supplies

Existing water supplies vary greatly from year to year and basin to basin throughout the state – it is possible to experience both drought and flood conditions in the same year in Colorado. Even in years that are not officially classified as drought or flood, there remains great variability within the basins, with average conditions often spanning volumes in thousands of acre feet (Table 4.2-1) [11]. Streamflow also varies greatly from basin to basin and is not equally distributed across the state. A low flow in one basin (e.g., Colorado) may be greater than a high flow in another (e.g. North Platte, Southwest, and Yampa/White). Table 4.2-1 and **Error! Reference source not found.** illustrate these points. Additional information on flood and drought impacts can be found in section 7.1.

Basin	Gage Name	Gage ID	Drought	Dry	Average	Wet	Flood
Arkansas	Arkansas River at Canon City	07096000	293,800	404,600	611,000	797,700	940,300
Colorado	Colorado River near Dotsero	09070500	852,000	1,060,500	1,788,400	2,333,000	3,029,600
Southwest	Animas River at the state line	09363500	365,400	443,600	886,400	991,000	1,181,500
Southwest	Dolores River near Dolores	09166500	140,600	195,100	396,700	491,700	515,700
Gunnison	Gunnison River near Grand Junction	09152500	824,300	1,114,700	2,243,100	3,153,100	3,765,700
North Platte	North Platte River near Northgate	06620000	121,600	196,700	390,200	565,600	728,700
Rio Grande	Rio Grande near Del Norte	08220000	325,700	462,500	742,200	965,500	1,030,700
South Platte	South Platte River near Kersey	06754000	248,900	412,300	916,200	1,644,900	2,628,600
Yampa/White/ Green	Yampa River near Steamboat Springs	09239500	180,600	244,200	394,800	502,300	599,300
Yampa/White/ Green	White River near Meeker	09304500	276,700	353,700	499,500	666,800	758,300

Table 4.2-1 Annual Flow Values for Varying Conditions at Select Gages (AFY)

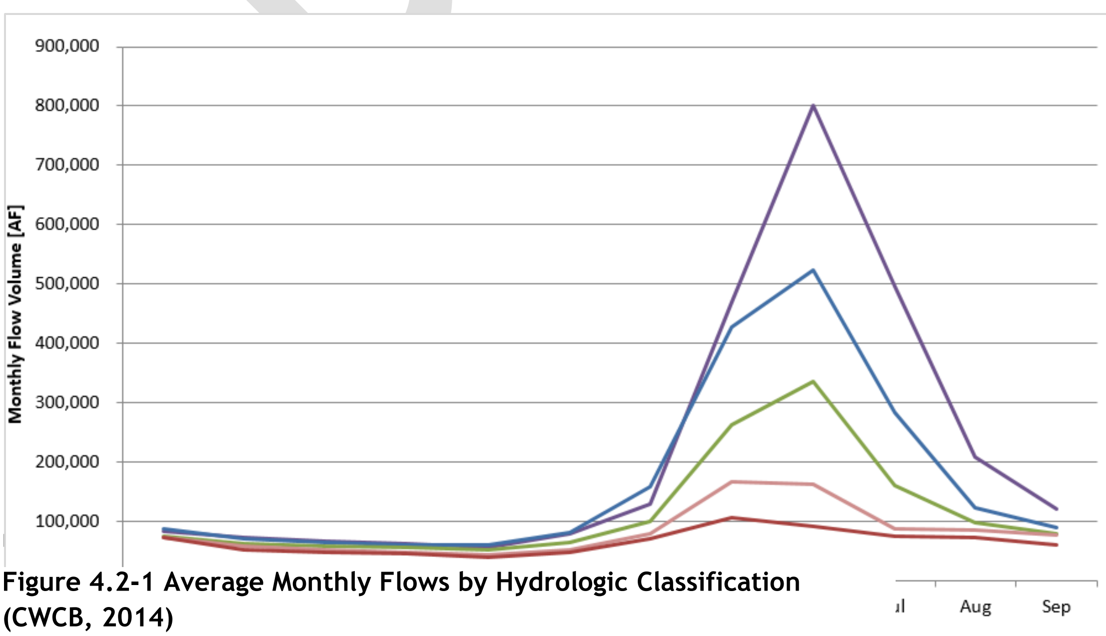

Figure 4.2-1 Average Monthly Flows by Hydrologic Classification (CWCB, 2014)

Dry years can have a significant effect on the water available and impacts can last for years; while wet years offer relief with as much as six times the amount of annual water supplies as a dry year (e.g., lower South Platte) (Figure 4.2-2) , there is no consistency in the intervals when dry and wet years occur Both the Rio Grande and the Arkansas basins have been dry the better part of the last decade, with only three above average precipitation years since 2000 [12]. The larger Colorado River Basin, which has seen its driest 14-year period since 1963, experienced above-average flows in just 3 of those 14 years [13]. Conversely, the September 2013 floods resulted in the Halligan Reservoir rising 30 feet in just over 24 hours, and going from nearly empty to full in a matter of days [14]. This great variability makes management of limited water resources challenging. Water managers rely on networks of reservoirs, pumps, and tunnels to store and move water, so it is available to meet demands when at their peak, while complying with relevant environmental mitigation requirements to maintain ecosystem health. Increasing temperatures may further complicate management by increasing evaporation, and shifting the timing of when water is available.

Dust, when deposited on top of our snowpack, speeds snowmelt and results in earlier spring runoff. This is significant because earlier snowmelt allows plants more time to transpire resulting in a decrease in flows in our rivers and streams. These "dust-on-snow" events occur when winds deposit dust from around the Southwest desert on the surface of the snow, increasing the impact of solar radiation and causing earlier melting. Studies have shown that dust events can advance snow melt timing, enhance snowmelt runoff intensity and decrease snowmelt yields [15] [16] resulting in peak snowpack runoff occurring three weeks earlier [16]. Since 2005, when tracking of dust events began, 91 events have occurred, ten of which were in WY2013, the year in which the heaviest deposition was observed. [17]. While future severity of dust-on-snow events is uncertain, if events continue at recently-observed rates, they will affect Colorado's present and future water supplies by decreasing flows 5% on average. On the Colorado River that amounts to 750,000 acre-feet of water, or twice the amount of water the City of Denver uses annually [16].

Weather modification, also known as cloud seeding, is a tool utilized to influence the availability of water supplies. The World Meteorological Organization states that well designed and executed weather modification programs will have demonstrable results [18] and there are no documented negative effects to the environment from using silver iodide for cloud seeding [19]. The State of Colorado has seven permitted ground based wintertime cloud seeding programs with the goal of snowpack and streamflow augmentation. In 2006, due to prolonged water supply shortages in the Colorado River Basin, the CWCB 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 support locally sponsored programs. For additional information on weather modification efforts within the state please refer to the Weather Modification Program website within the CWCB.

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STATEWIDE

Summary of Observed Wet & Dry Surface Water Hydrology

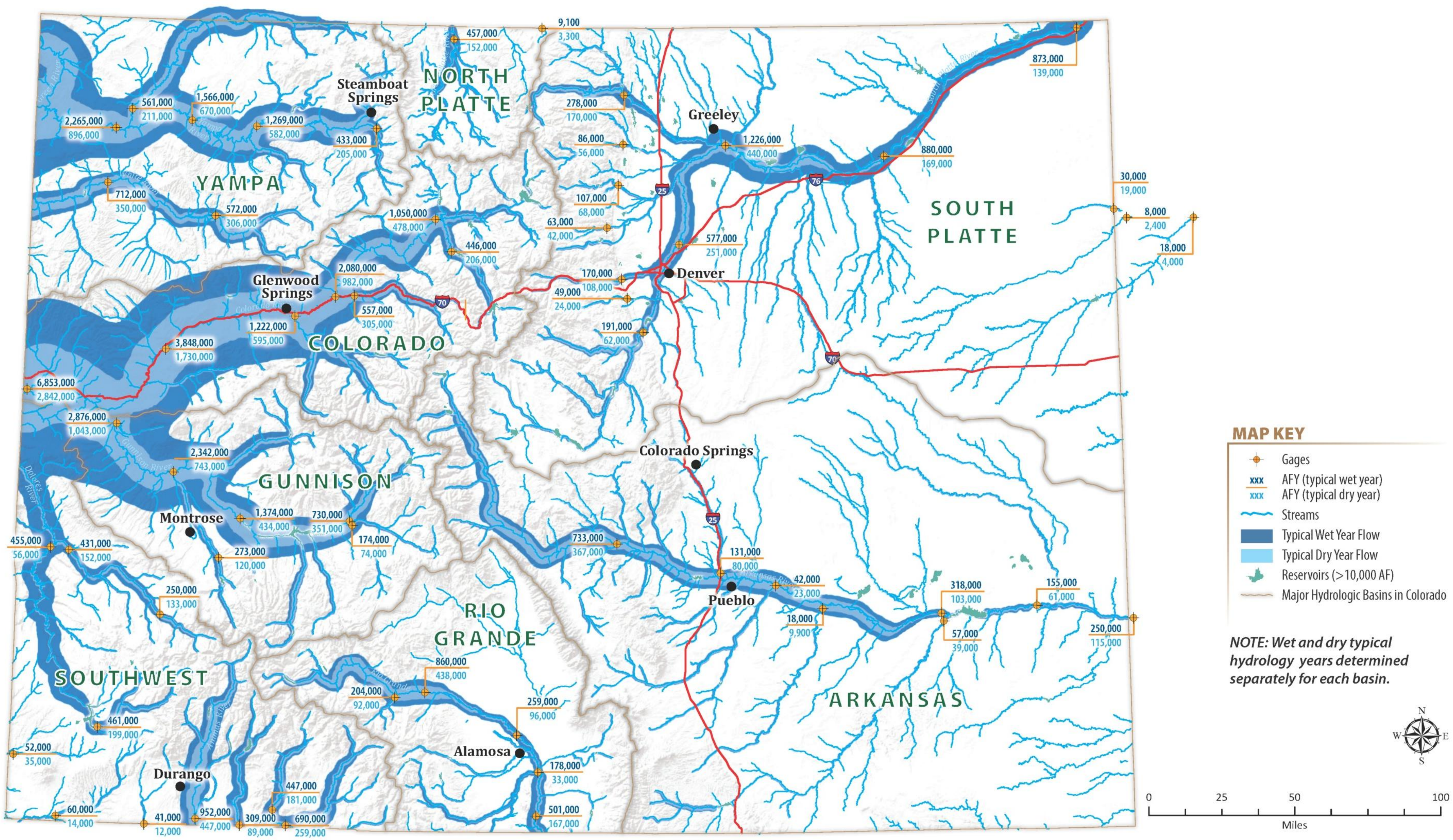

Figure 4.2-2: Wet and Dry Year Flows at Select Gages (CWCB, 2014c)

4.3 Future Supplies

Climate variability and change has the potential to greatly affect the water available for beneficial use in the State of Colorado in the coming decades. Projections consistently show Colorado facing a warmer future [3], and while precipitation projections are less certain, higher temperatures will drive increased demand for water through increased evapotranspiration rates [20]. As the climate of Colorado shifts, past variability in streamflows, even in the more recent past, may not be a sufficient guide to future variability [21]. Continued study and planning are critical to determining not just whether future supplies will fulfill future demands, but whether future supplies will fulfill *current* demands without changes in our status quo.

Storage is also likely to continue to be a critical element for managing Colorado's future water supplies. Yet new storage projects can be contentious and face a number of hurdles, and in many cases it will be easier and timelier to enlarge an existing dam and reservoir than to build a new one from scratch. Enlargement potential for reservoirs and dams is related to a number of factors.

Physical factors affect the suitability of a reservoir for enlargement, as does location. The ability to capture excess yield, provide potential to exchange the reservoir location relative to more senior water rights on the given river system, and the engineering characteristics will all need to be assessed. Environmental factors and impacts are also a primary consideration in evaluating if a reservoir or dam should be enlarged.

The Division of Water Resource has examined enlargement potential for existing reservoirs and dams through the use of information contained in the DAMS database. A preliminary list of reservoirs with potential has been compiled and is based on such factors as the difference between the maximum and normal storage, or storage delta (**Error! Reference source not found.**). A large storage delta is one criteria for evaluating enlargement potential. It should be noted that in general the reservoirs with the largest storage delta are those owned by the US Bureau of Reclamation, and the US Army Corps of Engineers. Additional discussion and analysis will be necessary to more clearly define additional criteria for enlargement potential and the goals of additional storage. All necessary factors will need to be included when developing a prioritized list of existing reservoirs and dams to be considered for enlargement [22].

Additional factors such as the success of demand management and the extent to which agricultural water rights are transferred will also affect the availability of future water supplies. These are further discussed in chapters five and six.

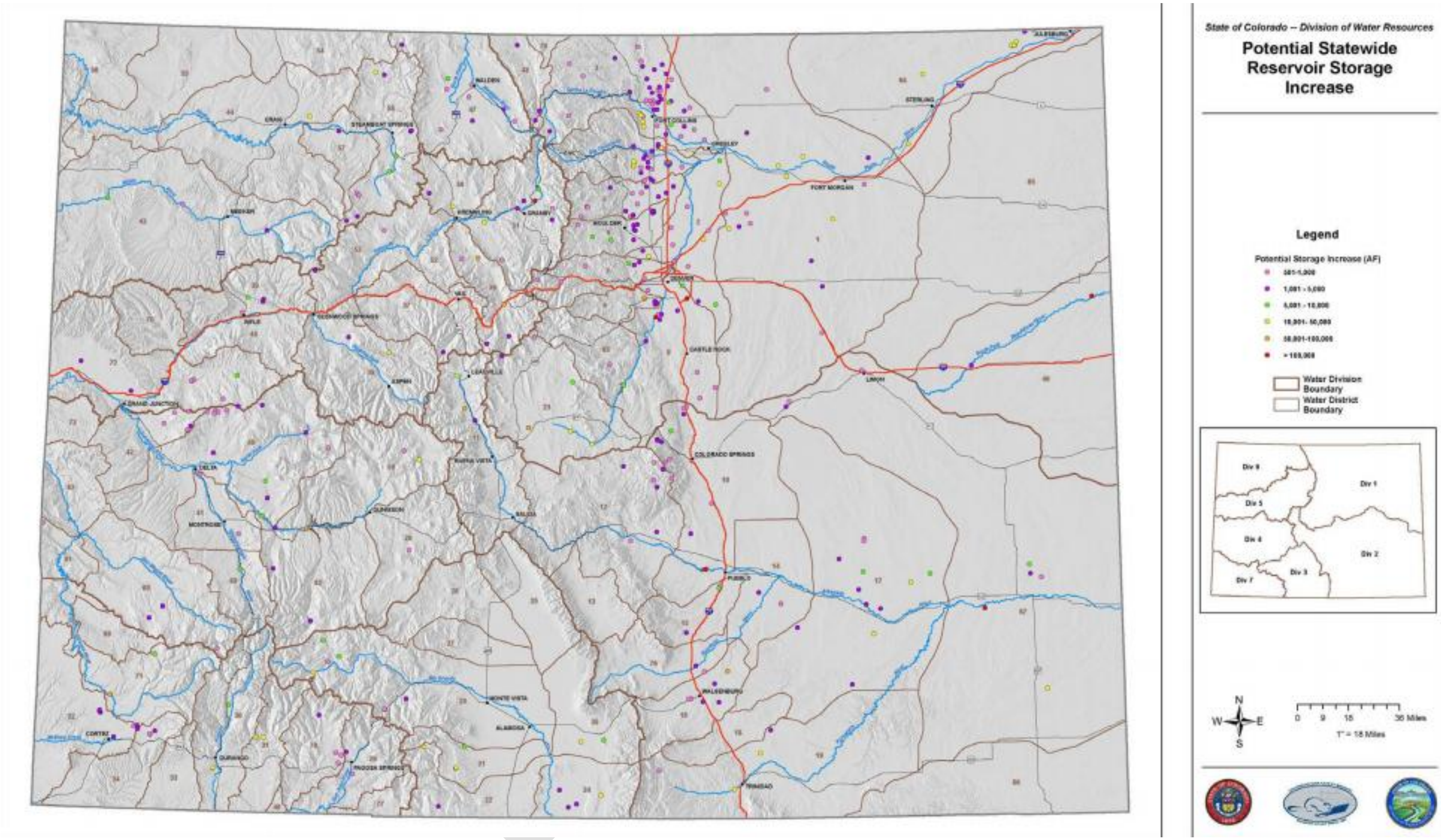

Figure 4.3-1: Potential Statewide Reservoir Storage Increase based on Storage Delta factor only

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Bibliography

[1] US Census Bureau, "Statistical Abstract of the United States; Table 366. Extreme and Mean Elevations by State and Other Areas," 2012. [Online]. Available: https://www.census.gov/compendia/statab/2012/tables/12s0366.pdf.

[2] US Geologic Survey, 1990. [Online]. Available: http://pubs.usgs.gov/of/1987/ofr87-242/pdf/ofr87242.pdf.

[3] J. Lukas, "Climate Change in Colorado," State of Colorado, 2014.

[4] N. J. Doesken, 2003. [Online]. Available: http://climate.colostate.edu/climateofcolorado.php.

[5] U.--.-. C. Citation.

[6] B. Harding, "DRAFT Technical Memo: SWSI Climate Impact Support, Development of Projected Gauged Flows," July 18, 2014.

[7] Natural Resource Conservation Service, "Basin Wide Reservoir Summary," June 2014.

[8] Colorado Geologic Survey, "Groundwater," 2014. [Online]. Available: http://coloradogeologicalsurvey.org/water/groundwater/.

[9] Colorado Water Conservation Board, "Statewide Water Supply Initiative," 2010.

[10] Colorado Geological Society, "Artificial Recharge of Ground Water in Colorado- A Statewide Assessment," 2004.

[11] Colorado Water Conservation Board, "Historical Streamflow Analysis Tool," 2014.

[12] National Climatic Data Center, "Climate at a Glance - Time Series," August 2014. [Online]. Available: http://www.ncdc.noaa.gov/cag/time-series/us.

[13] US Bureau of Reclamation, "US Bureau of Reclamation Upper Colorado Region," 11 July 2014. [Online]. Available: http://www.usbr.gov/uc/water/crsp/cs/gcd.html.

[14] Division of Water Resources, "Halligan Reservoir Diversion Records," 2013.

[15] T. H. e. a. Painter, "Impact of disturbed desert soils on duration of mountain snow cover," *Geophysical Research Letters,* 2007.

[16] T. H. e. a. Painter, "Response of Colorado River Runoff to Dust Radiative Forcing in Snow," *Proceedings of the National Academy of Sciences,* 2010.

[17] Center for Snow and Avalanche Studies, "Colorado Dust-on-Snow Program WY2013 Summary," 2013. [Online]. Available: http://snowstudies.org/dust/SBBSA/summary_2013.html.

[18] World Meterological Orginization, "Refernce to be added".

[19] Weather Modification Association, "Position Statement on the Environmental Impact of Using Silver Iodide as a Cloud Seeding Agent," July 2009.

[20] Colorado Water Conservation Board, "Colorado River Water Availability Study," State of Colorado,

Denver, 2012.

[21] Colorado Water Conservation Board, "Colorado Drought Mitigation and Response Plan," 2013.

[22] Colorado Division of Water Resources, Office of the State Engineer, Dam Safety Branch, "DAMS applications portion of the Colorado Decision Support System (CDSS) water information database," 2014.

[23] Division of Water Resources, "Colorado HIstorical Average Annual Stream Flows," 2011.

[24] Colorado Water Conservation Board, "SB 06-193 Underground Water Storage Study," 2007.