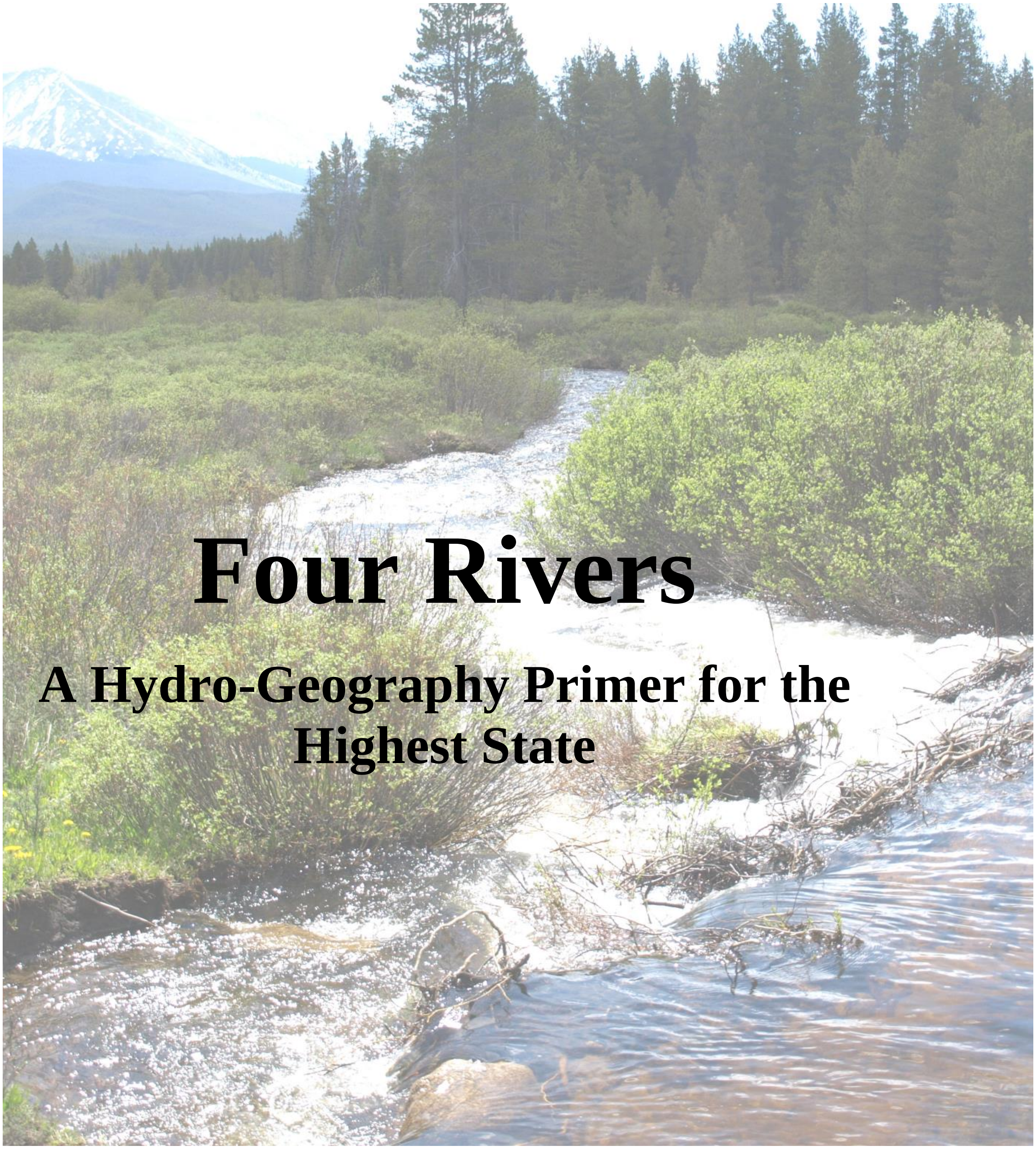

Four Rivers

A Hydro-Geography Primer for the Highest State

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Introduction

Rainwater and snow melt – topography and gravity. These are the simple ingredients needed to create a river. That river can be one of nature's most beautiful and functional elements but can also become dangerous, toxic, garbage strewn, sterile, and ugly. The choice between these two options is often made by the humans who live, manufacture, grow, and move things along the banks or in the watersheds of this (usually) naturally flowing waterway. It is a cliché that water is life – but clichés are repeated so frequently because they are often true. In innumerable Native American tribal cultures, water is even more than life, it is a sacred substance that defines existence. No life that we know of can exist without water, and rivers are nature's way of moving water across the landscape from higher to lower elevations spreading this life-giving substance around.

Colorado has dramatically exaggerated topography and large relief between the high mountains above and the plateaus and plains below. Because of these elevation differences, the mountains of the state became the birthing grounds for many of our streams and rivers – the physical science reasons for this phenomenon are highlighted in the **Water** chapter. Because of the number of important rivers of the West that originate in the state, some actually call Colorado the "Mother of Rivers." This rather hyperbolic name has a large grain of truth in it. Almost all of the West, that land west of the hundredth meridian, is a normally dry landscape only punctuated by the wetter mountains that give a reprieve to the aridity of most of the area. The mountains are known for their steep slopes and rocky crags, but they are also known for their expansive forests – ponderosa and lodgepole pine, Engelmann spruce, subalpine and Colorado blue spruce, and, of course, our beloved aspen groves. The natural vegetation on the usually much drier plains and plateaus consists of short grass prairie, shrubland, and maybe some scattered piñon-juniper woodland. All of our cities at the lower elevations have tree-lined boulevards and lush, green lawns. But these can only exist because we bring enough mountain water into town to irrigate these non-native vegetation types.

Colorado has four celebrated river systems that begin in the highest reaches of our mountains. The first of these was named the 'Grand' by the initial Anglo settlers in the state, but eventually in the 1920s was renamed the Colorado River and is the only river system that drains the land west of the continental divide. It rises in the far northwestern corner of Rocky Mountain National Park and flows south into Middle Park. From Middle Park it runs through Gore Canyon and westward through Glenwood Springs. By this point it has become a relatively large river by western standards. It continues west past places such as Rifle, De Beque, Parachute, and Clifton. Finally, it reaches its confluence with the Gunnison River at Grand Junction. From this point almost to its mouth in the Gulf of California, it is flowing through the canyons and gorges of the Colorado Plateau country. It has a significant cadre of tributaries that are entirely or at least begin in the state including the Gunnison, Dolores, White, Yampa, and San Juan Rivers. In total the Colorado River basin has a flow of almost 9 million acre-feet a year (an acre-foot is the amount of water in an acre covered by water one-foot deep) (Figure 1).

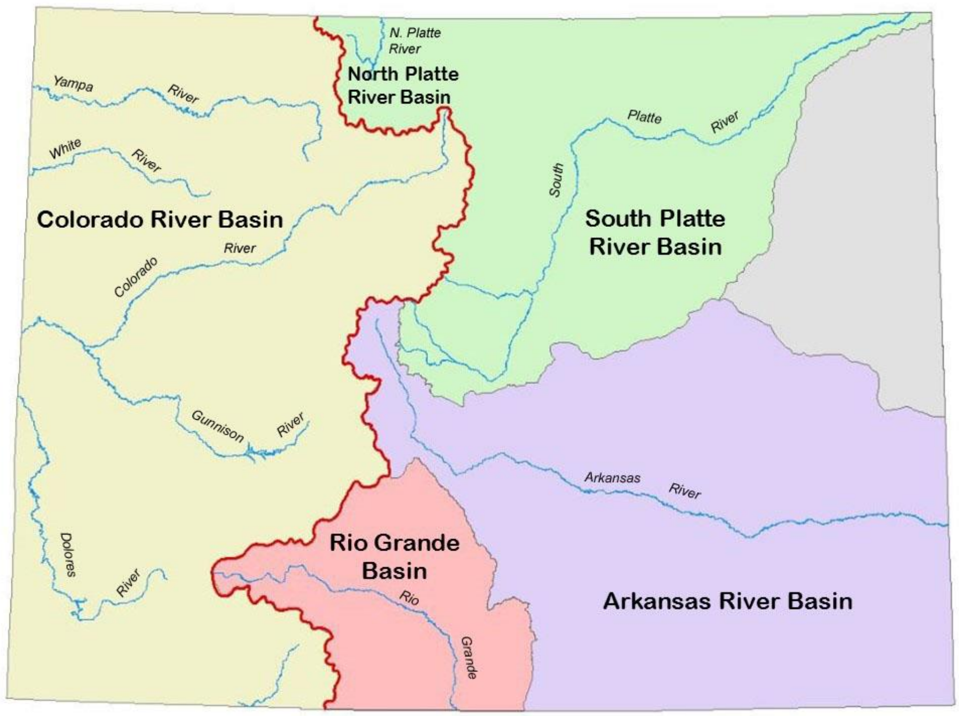


Figure 1 – This map shows the watersheds for the four major river systems of Colorado – the Colorado, Rio Grande, Arkansas, and Platte Rivers.

The Western Slope of Colorado is where most of the state's precipitation falls – this is borne out by the fact the total discharge from our three other rivers, all on the Eastern Slope flowing to the Gulf of Mexico, is barely one-ninth that of the Colorado basin. The Rio Grande, the Platte, and the Arkansas Rivers together discharge just over 1 million acre-feet per year. We will see in later chapters that this is the reason for some understandable discontent on the western slope (see the chapters **Diversions**, **Law**, and **Compacts**). The Rio Grande starts in the high mountains on the eastern side of the San Juans near Stony Pass and Canby Mountain. It flows eastward through volcanic landscapes for many miles past Creede and South Fork where it enters the San Luis Valley and then to Del Norte where it starts to head southeast toward Monte Vista and

Alamosa. The remainder of its course flows through a geologic landscape known as the Rio Grande rift. From there it heads due south and eventually out of the state into New Mexico.

The Arkansas River has two major sources – both a few miles outside of Leadville. The first is just below Tennessee Pass where Tennessee Creek flows through a landscape of widespread willow carrs. The second and slightly larger branch starts on the southern slopes of Mt. Arkansas near Fremont Pass. These two branches come together just on the northern edge of Leadville. From here the river runs almost straight south through the large valley on the eastern side of the Sawatch Mountains until it reaches Salida. This valley is also part of the Rio Grande rift geologic structure. At Salida the river makes a hard-left turn toward the east where it eventually runs through the Royal Gorge and into Cañon City. From here to the Kansas border, the Arkansas drains almost all of the southeastern part of Colorado and flows over short grass prairie and semi-arid landscapes. It exits the state just east of Holly at one of the lowest elevations in all of Colorado – a mere 3,317 feet above sea level.

The entire northeastern part of Colorado is drained by the Platte (both North and South) River. The North Platte drains North Park -- the far northwestern corner of the Platte Basin. This is the smallest of the four 'Parks' in Colorado (the three others are Middle and South Parks and the San Luis Valley). The North Platte flows north into Wyoming and eventually meets with the South Platte at North Platte, Nebraska. The South Platte has three nearly equal sources – prosaically called the North Fork, Middle Fork, and South Fork. The North Fork rises just below Handcart Peak and Webster Pass while the Middle and South Forks begin in the Mosquito Range just below Mt. Lincoln and Weston Pass respectively. The South and Middle Forks converge just east of Hartsel before they reach Spinney Reservoir in South Park. The North Platte joins them just as the river flows into Platte Canyon southwest of Chatfield Reservoir near Denver. The fully formed South Platte then flows northeast through Denver and out into the plains of northeastern Colorado. It eventually leaves the state just beyond Julesburg in the far northeastern corner of Colorado.

Our four rivers are important for the influence that they have on the state of Colorado and most of the western and southwestern lands of the US. They impact what ecosystems exist, where people live and work, what economies are viable, and almost every other aspect of life. But the rivers are also being influenced by physical characteristics of the land, most especially by the geology and topography over which they flow. The comprehensive geology of Colorado is almost infinite in its complexity and is well beyond the scope of this book. But a relatively simple synopsis of it will be useful for understanding water and the rivers that move it. Figure 2 is a cartographers's perspective of Colorado geology. It highlights in vibrant colors the major classes of rocks in the various parts of the state.

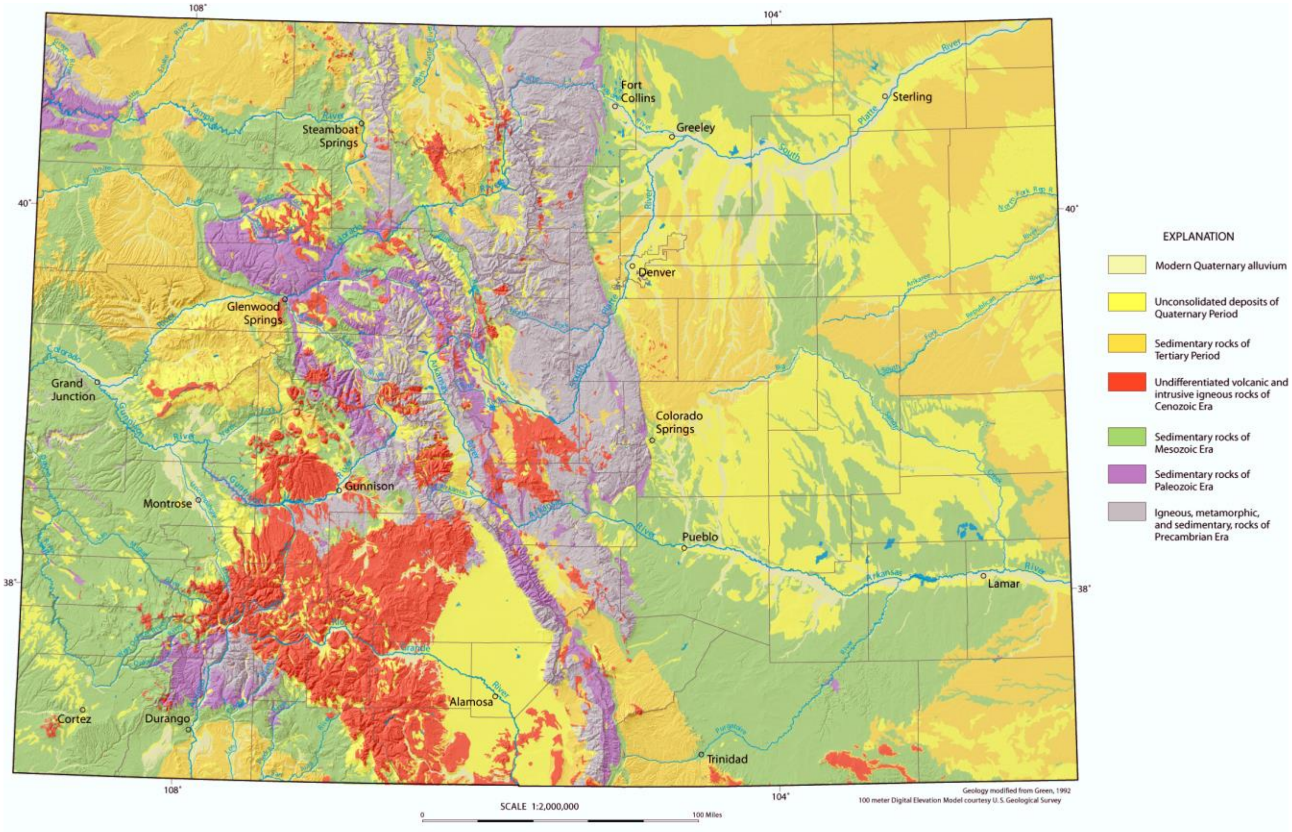


Figure 2 – This is a simplified geologic map for the state of Colorado. (courtesy of the Colorado Geological Survey)

It has been quaintly stated in an old saw that water runs downhill except when it runs uphill toward money. We have plenty of uphill movement of water in Colorado (see the **Diversions** chapter), but without the artificial assistance of pumps and siphons, all water obeys gravity and runs from high to low. And as we will see in the chapter on **Water**, most of our flowing water originates in our high mountains where that downhill run starts. The question here might be, why does Colorado have all those high-altitude landscapes we call mountains? That query is almost totally answered by looking at and understanding the geology of the state -- both its multitude of rock types and the physical movements of the crust of the earth that rearrange those rocks both vertically and horizontally.

The foundation of geology anywhere on earth starts with the scientifically established theory of plate tectonics. To simply state this theory, large, solid plates of the earth's crust are constantly in motion, driven by molten and semi-molten magma circulating at considerable depths below them. These plates vary in size, rock type, density, and chemistry. It is generally accepted by geologists and geophysicists that seven large plates along with seven medium size plates and probably a dozen smaller plates cover the earth. Some plates are more dense (often called oceanic plates) while others are slightly less dense (continental plates) (Figure 3). Some plates only move horizontally, some denser, oceanic ones are subducted (forced down) under the less dense continental ones. Over billions of years all of these movements have made the continents wander, new parts of continents to form, some plates disappear, and vast mountain systems to rise and eventually wane as they are relentlessly eroded. The place we know of as Colorado has, over hundreds of millions of years, experienced its share of horizontal movements ranging from tropical latitudes to more northerly ones. It has also experienced the many ups and downs of repeated mountain building and mountain destruction, all coming from innumerable plate movements and relentless erosion. We know that there have been multiple mountain systems in the area of Colorado – the mountains we see today are only the latest.

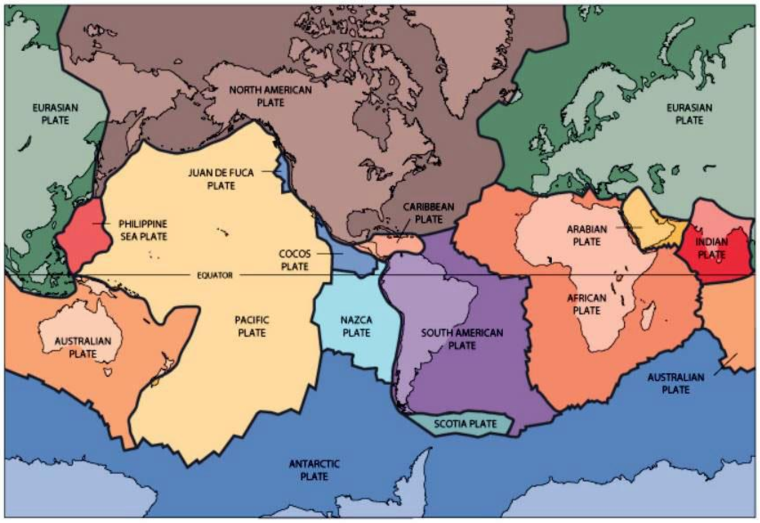


Figure 3 – This is a basic map of the worldwide tectonic plates that cover the earth. (courtesy of the U.S. Geological Survey)

Over the course of earth's 4.5+ billion-year history, the spot on the planet that we call Colorado has had multiple mountain building episodes. Probably there are some we will never know about – their remnants have been obliterated by erosion and tectonic activity. We are certain about the last two of these orogenic periods, however. The first of these occurred during the Pennsylvanian period (Figure 4). At the beginning of that period, Colorado was under the influence of and often covered by shallow seas in a tropical environment near the equator. But rapid tectonic changes thrust up two separate but related highlands – one was called Frontrangia (for the obvious reason that it was basically where our current Front Range is), the other was the Uncompahgre Highlands in the more southwestern part of Colorado. These two highlands were often surrounded by shallow seas as evidenced by the sediments that have been left behind.

COLORADO'S GEOLOGIC TIME SCALE

Era	Period	(Millions of years ago)	Major Geologic Events in Colorado
CENOZOIC	Quaternary	Present–1.8	Development of present topography, ice ages, huge dune fields, widespread mammalian extinction, widespread faulting, basaltic volcanoes, development of caves
	Neogene	1.8–23	Rio Grande rifting and regional uplift by block faulting (to present elevations); widespread basaltic volcanism; major canyon cutting
	Tertiary		
	Paleogene	23–66	Catastrophic volcanoes erupting; erosion and basins developing; Laramide mountain building; igneous plutons intruding and creating rich mineral deposits
	K/T Boundary	66	Asteroid impact causes worldwide extinction of plants and animals; end of the "Age of Dinosaurs;" beginning of "Age of Mammals"
MESOZOIC	Cretaceous	66–146	Subtropical to tropical climate; shifting shorelines of Western Interior Seaway; deep- and shallow-marine and non-marine conditions; onset of Laramide mountain building; final retreat of marine waters; dinosaurs
	Jurassic	146–200	Lakes, swamps, braided and meandering streams; repeated invasion and withdrawal of sea; coastal dune deposits; dinosaurs
	Triassic	200–251	Semi-arid and arid conditions; mudflats, alluvial plains, dune fields adjacent to eroding Ancestral Rockies; deposition of "redbeds;" dinosaurs dominant life forms
PALEOZOIC	Permian	251–299	Dune fields; continued erosion of Ancestral Rockies; deposition of coarse "redbeds;" mass extinction
	Pennsylvanian	299–318	Widespread karst development on Mississippian limestones; shallow seas and evaporite basins; rise of the Ancestral Rockies; erosion of great volumes of rock and deposition into alluvial fans
	Mississippian	318–359	Widespread shallow sea
	Devonian	359–416	Widespread shallow sea; intrusion of kimberlite diamond pipes
	Silurian	416–443	Widespread shallow sea; uplift and erosion
	Ordovician	443–488	Local deepening of seas and cyclic sea level rise and fall; first vertebrates in the world
	Cambrian	488–542	Invasion of sea from west and east; dike intrusion; rapid development of hard-bodied life forms
PRECAMBRIAN PROTEROZOIC EON		542–2,500	Rifting, a major continent/island-arc collision; three periods of regional metamorphism; three periods of folding; formation of major shear zones; three periods of granitic intrusions; a period of major dike intrusion; deposition of a thick sequence of continental sedimentary rocks
PRECAMBRIAN ARCHEAN EON		2,500–4,000?	Granitic intrusion, regional metamorphism, and folding; metamorphism at 2.7 billion years ago

Figure 4 – This is the geologic timescale for Colorado as depicted in ***Messages in Stone****, Colorado Geological Survey. (courtesy of the Colorado Geological Survey)*

The second of these latter uplifts, called the Laramide Orogeny, began about 65 - 70 million years ago and lasted for almost 30 million years. The current explanation by geologists for this uplift is that because of the Ancestral Rockies and the stresses caused by massive earth movements when they were formed, the area's basement rock core was weakened by fractures, fissures, and thinning. It is speculated that a low-angle subduction plate coming in from the west at the end of the Cretaceous period provided the force to push up large masses of old, buried intrusive granitic and metamorphic rock (often classed together as 'crystalline' rock) that moved upward through the overlying sediments. Tremendous upward movement lifted the buried intrusive rocks at least 20,000 vertical feet. Most of our highest mountains – the 13ers and 14ers – have these crystalline rocks as their core. In addition to the Laramide uplift, some of our current mountain regions also have been formed by extensive volcanic activity, coming especially during the Tertiary period (see Figure 4 again). The eastern San Juan Mountains, the Flattops, Grand Mesa, the West Elks, and the southern end of the San Luis Valley are all evidence of this significant volcanic activity of the Tertiary.

These very large-scale earth movements and wide-spread volcanic extrusions have produced an amazingly complex set of rock types in the state. Figure 2 shows broad categories of what the geology at the surface is in Colorado. But there are myriad rock, mineral, and sediment classes that make up these seven major geologic mapping elements. This stunning complexity of rock and the level of uplift in any given region have a profound impact on how rivers flow. Harder rock resists erosion more than softer rock; the more water erodes rock and soil, the more sediment is carried in the river; steeper slopes force water to run faster downhill; shallow slopes force the river to deposit the material carried by moving water; and all of these factors interact with weather and climate to define how much, where, and when the water in rivers and the sediment they carry affect the landscapes along its course.

Most of our four river headwaters start in areas that have some type of granitic and/or metamorphic crystalline rocks of the Precambrian era. The North Fork of the Platte starts in an area of ancient gneiss – a major form of metamorphic rock in Colorado. The Middle and South Forks of the Platte start in areas of approximately 1.4-billion-year-old granites with some remnants of Pennsylvanian age sedimentary rock formed from material coming off of the Ancestral Rockies. The Colorado River begins in an area with a combination of Precambrian granites and gabbro – an igneous rock with different chemistry than granite. The Arkansas River's main stem starts in almost exactly the same rock as the Middle Fork of the Platte – their origins are only about four miles from each other. Tennessee Creek is an outlier as it begins in an area of the Pennsylvanian age Minturn sedimentary rock and some newer (if 65-million-year-old rock can be new) igneous intrusions. The only one of our rivers that begins in a major area of Tertiary volcanic activity is the Rio Grande. It begins in the hardened ash flows from multiple calderas in the San Juans.

The remainder of each of the courses of our rivers is no less complicated. The simplest is the Rio Grande. It runs through the Tertiary volcanic rocks of the eastern San Juans until it reaches the San Luis Valley where it continues for most of its course in Colorado over the unconsolidated deposits of the Quaternary period. The Arkansas flows south on the sediments in its own valley bounded by the Sawatch and the Mosquito Ranges then turns east where, after 20 miles or so, it goes through the metamorphics and granites that make up the Royal Gorge. From here to the Kansas border, it flows over much more recent sedimentary rock of various origins. The Middle and South Forks of the South Platte flow over the sediments filling South Park then through more ancient Precambrian igneous rocks until hitting the plains near Denver. The North Fork is consistent in its continued flows through the Precambrian landscapes. All three forks are merged west of Denver and flow over sedimentary geologic landscapes as the Arkansas does. The Colorado probably has the most varied geology for its entire length. From Granby Reservoir until the Utah border, it runs over granites, volcanics rock, Precambrian metamorphics, and a huge variety of sedimentary rocks.

The geology always matters, but the inexorable and relentless forces of erosion will invariably win out in the end. All four of our rivers carry huge amounts of sediment that comes from the erosional processes of the moving water. Over time all rivers erode their beds and carry sediment from their respective watersheds. Sometimes they erode spectacularly steep canyons, other times nearly flat floodplains that can hardly contain the water. John Wesley Powell gave us a geologic axiom that we should keep in mind – to paraphrase him, the faster mountains rise, the faster they erode. Wonderful and awe-inspiring examples of this axiom can be seen in places like the Royal Gorge. It is such a deep and narrow chasm because the land rose very rapidly and provided the Arkansas River with the potential energy characteristics needed to downcut rapidly. We see this in Glenwood Canyon east of Glenwood Springs along the Colorado; we see it in Waterton Canyon on the South Platte; we see it in the Black Canyon of the Gunnison; and, we see it in many, many places along the Colorado after it leaves the state (Canyonlands and the Grand Canyon to name just two). The combination of topography, climate, geology, tectonics, and time has created one of the most diverse and interesting fluvial landscapes in the country.

The geology and topography of the state set the physical stage for what happens to our four rivers as they traverse from the highest elevations until they leave for the lands beyond the stateline. But the physical character of each river basin is only a precursor to what influences humans have on the watersheds. It is certain that humans have used our rivers for thousands of years. It is inconceivable that any Native American group occupying the state would not make use of the most verdant, diverse, and fecund ecosystems in Colorado, but we have little written evidence of this use. There are some clues to the skill and ingenuity of some of these groups in their manipulation and use of water for survival. In the **Law** chapter, for example, the elaborate and extensive system developed by the Ancestral Puebloans to irrigate crops and manage water is outlined. Only the actual physical remnants of the irrigation systems in far southwestern Colorado tell the story of how these peoples engineered their water world and allow us to discover the elegant and utilitarian history. There was no written record. That is the case for nearly all of the indigenous groups that lived and moved through the land for thousands of years. This is especially the case for the more nomadic tribes who left little corporeal evidence of their use of the water resources of our rivers.

We do have written evidence for the first actions by the Euro-Americans in Colorado in the seventeenth century. The earliest of these excursions we know about are the tentative explorations of the Rio Grande in the San Luis Valley. Santa Fe, in what is now New Mexico, was established by the Spanish in 1610 (that is 10 years before the pilgrims stepped foot on Plymouth Rock). It was only natural for Spanish explorers to travel upstream along the Rio Grande into what is now the San Luis Valley of Colorado. There was considerable resistance to these forays by the Native Americans, mostly the Utes, who already were using the river and the lands around it. Most likely, the first *entrada* or exploration that reached into the San Luis Valley came from members of the Don Juan de Oñate expedition in 1607. The Pueblo Revolt of 1680 drove the Spanish back to El Paso, the Spanish returned with a vengeance by 1690 and a renewed push into the Valley began in earnest. Exploration for gold and silver and the land giveaways by the Spanish and eventually by independent Mexico (even though they did not really own the land) were common with huge swaths of the Valley awarded as 'Land Grants'. These grants included the Sangre de Cristo, Guadalupe, and the Vigil and St. Vrain. Some of these land grants still affect property ownership and resource use in the Valley. The small village of San Luis on the southeastern side of the Valley was the very first permanent human presence when it was established in 1852 – the oldest town in Colorado.

The first official U.S. government expeditions came in the immediate wake of the Louisiana Purchase. Lewis and Clark, of course, are known for their explorations of the northwestern parts of the Purchase. In 1806 Lt. Zebulon Pike was sent into territory that was along the tenuous border between the new U.S. territory and that land considered part of Mexico by the Spanish. Pike was tasked to get to the Arkansas River where a part of his group was sent downstream to the mouth, and the remainder, including Pike himself, went upstream to find the source of the Arkansas and also the Red River that was thought to start near the Arkansas. Many historians feel that Pike was intentionally sent to the area by his commander General James Wilkinson to provoke a confrontation with the Spanish. Pike never got the war started with Mexico that Wilkinson seemingly wanted, but he did get himself and his men arrested and taken to Mexico. They were soon released and sent back to the United States. The Arkansas River became the de facto route of choice for movement between the U.S. and Santa Fe (along what became known as the Santa Fe Trail). The U.S. Army and frontier entrepreneurs such as the Bent brothers established forts and waystations along the route. The heyday of these private/public ventures was the 1840s and 50s.

The first official expedition on the South Platte was fourteen years later. Major Stephen Long was sent to explore the South Platte River to the Rocky Mountain front then south along the foothills of the Front Range and on to the Arkansas. Part of his party descended the Arkansas while the remainder were still looking for the Red River that Pike never found. Long never found it either, mostly because it does not start in Colorado as everyone thought. Long's journey did have two impacts. The first is trivial – Edwin James, the naturalist with Long's party, climbed Pikes Peak even though Pike thought it would never be climbed. The second impact had very profound effects. Long and James were not impressed with the dry lands of the high plains in Colorado. They labelled it "the Great American Desert." This description had significant negative effects on the ability of the nascent Colorado Territory to attract farmers, ranchers, and others for decades. At that time Colorado was a place to get through as fast as possible to get to California, Oregon, and other places farther west.

A little over two decades later in 1842, John Frémont followed Long's route up the South Platte, but with different impressions. Frémont was trying to find a railroad route through the Rockies. Along the way he meticulously catalogued the natural features of the landscape, including the many streams leaving the mountain front, and decided that with a little effort, this part of Colorado could bloom. Frémont made additional excursions into Colorado including his 1848 expedition during which he tried to cross the San Juan Mountains in winter still looking for the railroad route west that he envisioned. Several of his men died in this misadventure and literally ended Frémont's hopes for a stellar political career.

The history of exploration of the Colorado River during this time is less straightforward. With the exception of Frémont and Captain John Gunnison who was also searching for the elusive railroad route with a bit more success, there was very little official U.S. involvement. The majority of the early Anglo-Americans in the Colorado basin were fur trappers and a few prospectors. Most of the exploration of the Colorado was done far southwest of Colorado, especially at the lower end of the river along the California – Arizona borderland. There was also the famous John Wesley Powell and his Colorado River expedition in 1869 that went from Green River Utah through the Grand Canyon. Again, this was downstream from Colorado. Only after precious minerals were found on the western slope of the Colorado territory did the landscape get the study it seemed to deserve. That said, there was an official Spanish foray into the Colorado basin in 1776, although not to explore the river per se. Two Spanish priests, Silvestre Escalante and Francisco Dominguez, and eight companions left Santa Fe in the early summer of that year in an attempt to find an overland route to the California missions. They traveled north through far western Colorado and the Uncompahgre Plateau crossing the Gunnison River and the Colorado upstream from today's Grand Junction. They never made it to California, turning back near what was to become Provo, Utah.

Now, of course, our four rivers have been studied and restudied; engineered and re-engineered; and fought over again and again. Water is one of the most important substances in the world, and most of the people of Colorado realize that our rivers and the water they carry are our lifeblood. This book is an attempt to put the story of these rivers into some kind of perspective and to provide a basis for a better understanding of our riverine heritage and future.

Generally, most people in Colorado are hard-pressed to name the four major river systems of the state. Almost everyone can name the Colorado, but even people living along the eastern mountain front often cannot name the Arkansas or the South Platte. Beyond not knowing what our four major rivers are, there have been several studies about how people in the state feel about water issues in general (BBC, 2016 and Pritchett, et al., 2009 are two of the most scientifically based surveys). Many respondents to these surveys do not know that most of the water used in the state – well over 80% -- goes to agricultural irrigation for farming and ranching. Industrial, residential (both indoors and outdoors), and commercial make up most of the remainder. Many of the respondents responding to either survey know that we have limited water resources in the state and that drought is an ever-present problem. A little more than half of the residents feel that we have enough water for our current needs, but that number goes down precipitously if asked if we have enough water resources for 40 years in the future. Some of the solutions proposed to help solve this future problem include more reservoirs, conservation (although most only want voluntary and not mandatory conservation efforts), education, and limiting state population growth.

Water is one of the most important substances in our lives. It is acutely critical in many parts of the West, including Colorado. Simply put, we need it to live. Whether we believe that is sacred or not, it will have a major impact on the way we live, work, and play in Colorado from now into our lasting future. The multiple stories of our rivers and our water are complex, legalistic at times, and ever-changing. This book is an effort to uncomplicate some of the complexity, and to provide the basic knowledge that all Coloradans should have about the precious resource of water and the state's waterways that provide it.

Water

Water. One of the most important and quirky molecules on Earth. Made up of two hydrogen ions and one oxygen ion, water seems pretty mundane compared to some of the other molecules in nature that are extremely complex such as the humus molecule in soil. Humus is so complicated that no chemist or soil scientist has ever been able to completely describe the components and structure of it. But water with just three ions is simple, right? One little kink of its molecular structure makes the seemingly simple chemical makeup of water into nature's oddball. It all arises from the angle (just under 105^{o}) at which the two hydrogen ions attach to the oxygen ion and the fact the hydrogen ions are positively charged and the oxygen ion is negatively charged (Figure 1). The angle of the ions transforms the water molecule into a miniscule magnet with two oppositely charged poles that attract or repel depending upon how the molecule is positioned in relation to other water molecules.

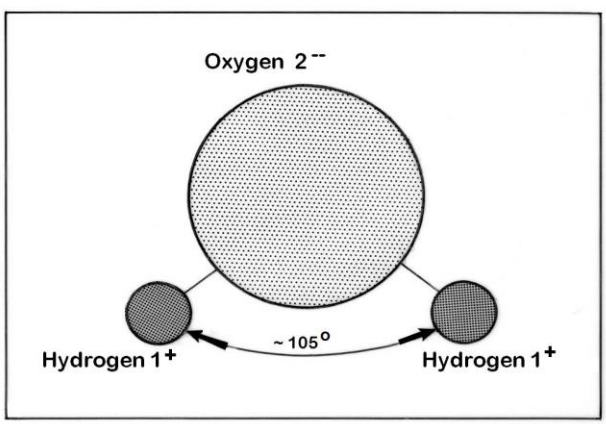


Figure 1 -- The water molecule with 1 negatively charged oxygen ion and 2 positively charged hydrogen ions. The angle of the ions in the molecules makes for a small bipolar magnet and produces many of the odd characteristics of water in nature.

This geometric oddity causes all kinds of strange phenomena to occur in water: it produces the surface tension we see with striding insects on top of calm water; it produces the capillary action that helps water climb to the tops of 300-foot-tall redwood trees; and, it increases water volume by 9% as it goes from liquid water to frozen water; it keeps expanding as its crystalline matrix rearranges itself as temperatures get even lower. Water also has one of the highest specific heat values of any substance in nature causing it to heat very slowly ("a watched pot never boils") but also to give off its heat very slowly as well. And water is known as the universal solvent (although it is not strictly universal as it does not dissolve everything); more substances on earth can be dissolved by water than any other material. This fact has a huge influence on our water quality as the water that runs over and through the soil dissolves salts and other minerals. One result of this process is the dramatic increase in the salinity of our four rivers in the last few decades – especially the Colorado and the Arkansas. Increased salinity, for example, has a significant detrimental effect on crop production.

As stated in the **Introduction**, water is absolutely essential to life as we know it. All life on earth depends on water and its chemical and physical character, and it is perfectly formed chemically to function at the temperatures and pressures that we have in our world. Anyone who lives in Colorado for long has experienced that early spring day immediately following a snowstorm -- you can observe the sun melting the snow at the same time as there is water vapor in the air. You are witnessing a natural, scientific 'miracle' where a single substance can exist, even for a short time, in its three different phases at exactly the same time – we have snow (solid water) lying on the ground, liquid water flowing down the gutters, and gaseous water as vapor in the air all occurring at the same moment together.

One last fact about water needs to be understood. No one is making any more of it. The water we have now is the water we are going to have, basically, forever. Except for miniscule amounts of 'new' water that are being exhaled into the atmosphere by volcanic activity, we have all of the water that we will have into the future. The only way we keep getting new snowfalls in our mountains each year, or rains to water our crops, is because of the hydrologic or water cycle. Basically, water evaporates from the oceans or other water sources or is transpired by plants. This water vapor is moved by global atmospheric patterns over the oceans and continents, condenses into liquid and/or solid water in the form of clouds, and precipitates onto the earth. Some of this water flows into our streams that eventually flow to the oceans, some goes into groundwater to be used later; and, some re-evaporates immediately to start the cycle once again.

It is obvious to anyone living or visiting Colorado that usually more snow falls in our mountains than at the lower elevations of the state. We just take that fact for granted – often without thinking about why that occurs. Without getting into the intricate details of things like vapor pressures or wet and dry adiabatic lapse rates, dew points or specific humidity, the main fact is that warmer air has the ability to hold more water vapor without it condensing to liquid or solid water than colder air. If you cool air and it reaches a temperature where it can no longer hold all of the water vapor in it, the vapor becomes liquid or solid water. A second fact is that as air rises, it becomes less dense – in other words there are fewer molecules in a given volume than at lower elevations. Heat is nothing more than the friction of molecules hitting each other as they move around. If there are fewer molecules, as at higher elevations, there is less friction and therefore less heat – in other words it is colder. As an air mass moves up the slopes of our mountains it is cooled and can hold less water vapor. The vapor must condense into liquid or solid water that, under the right conditions, will become rain or snow. The result of this moving air up the mountains (called orographic lifting) is that the mountains are where most of the water is and the place where our rivers have the things they need to start flowing – water and elevation.

There are many more physical and chemical characteristics of water beyond those just highlighted, but the most important for this book is the fact that our four rivers are made up of this crazy material. Water is the thing that flows in our rivers and streams, and the work water does in them and for them is the story of this chapter.

Water in combination with gravity is the substance most responsible for creating the landscapes we live in. When rain falls or snow melts, most significantly in our high mountains, that liquid water can do several things. The water may evaporate straightaway and begin the water cycle anew. It can soak into the soil to be used immediately by plants for growth and transpiration. It can be stored and slowly moved through the soil to be either used by plants at some later time, evaporated back into the atmosphere, or flow through the soil to enter water courses at a later time. It is estimated that up to half of the water in our streams and rivers comes from this groundwater. Finally, the liquid precipitation or melted snow can also run off as surface flow that enters our small rills and gullies, streams, or rivers directly. The water that flows in our rivers does the work of shaping the land over many, many millennia to create the places we inhabit.

The big picture of how moving water transforms and shapes landscapes is really pretty simple: water erodes soil and rock, it moves this material, and eventually it drops or deposits it in a new place. The details of this scenario are a bit more complex. The start of this entire process is the physical and chemical weathering of rock into particles small enough to be eroded and transported by water. The weathering is what makes the rock and soil available for moving water to pick it up or erode it. Moving water has energy – in particular, it has kinetic energy. Water also has mass or weight and with the help of gravity and sloping land, it too has velocity. The word erode comes from the Greek word for "gnaw out," and as water runs over the land, it erodes the weathered material in all of its forms and sizes.

The movement and work done by water can be extremely complex. But one way to help simplify it is by using diagrams to smooth out much of the variability and chaos in the system. The diagram below is a simplified (but not yet simple) Hjulstrom diagram showing what happens with moving water and the material it erodes, transports, and deposits (Figure 2). The diagram puts into visible context the basic physical equation for how much energy moving water has: one half of the mass (or weight in the vernacular) multiplied times the velocity squared. The more energy, the more ability to erode and transport material.

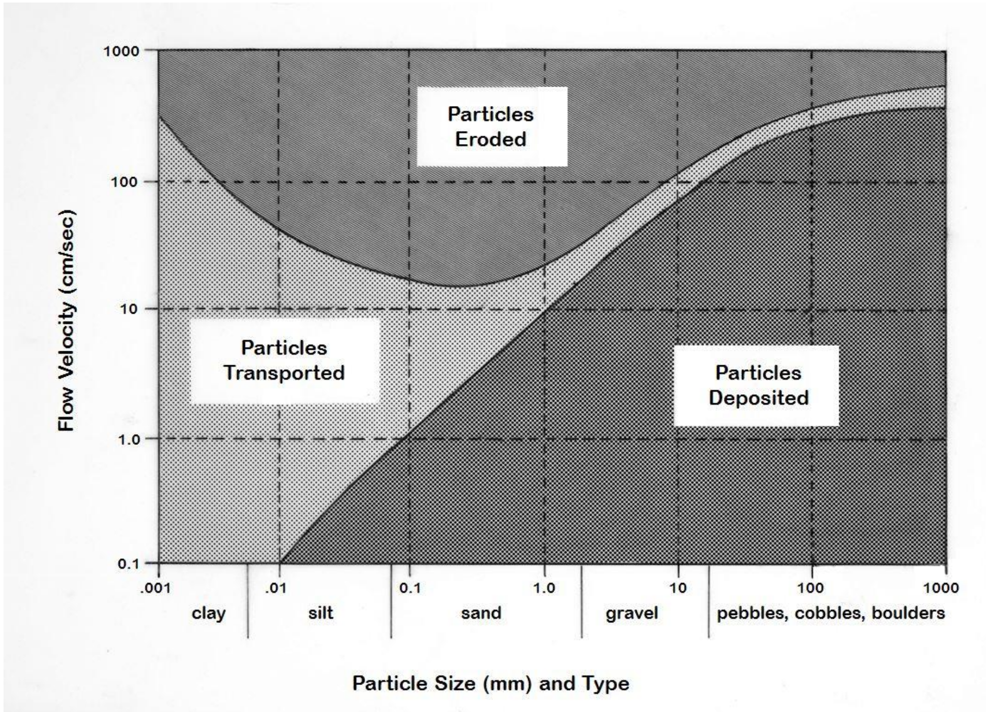


Figure 2 – This is a simplified example of the Hjulstrom diagram used to show the erosion, transport, and deposition of various sediment sizes compared to water velocities.

The horizontal axis of the diagram is the size of the particle being affected by the moving water. This is a logarithmic scale, so the sediment size increases rapidly going to the right. The vertical axis is the speed of the moving water, also at a logarithmic scale. It takes more energy to erode small particles (like clays for instance) because these particles hold tightly to each other because of their crystalline composition. Basically the faster the water moves, the bigger the particles that can be eroded. And the faster the water moves, the bigger the particles that can be transported. Then as the water slows down (as when it hits a flatter area in its channel) the material starts to be deposited – the larger material first and subsequently smaller and smaller material. It takes really slow water, in a lake for example, to allow the smallest clay particles to be deposited. To put this in the most vernacular terms -- in essence fast water can erode a lot and move a lot; slow water does not erode much and cannot carry much. The combination of water speed and sediment size determines when erosion, sediment transport, and deposition will take place. And in turn this combination determines what our river channels and floodplains will look like, how they will change over time, and what impacts they will have on the adjacent ecosystems and human occupation.

Flowing streams and rivers move material in three distinct ways. First, because water is such a good solvent, many minerals actually get dissolved in the moving water. The water in the stream is no longer pure water, but a solution of water and solutes. These dissolved substances may come out of solution downstream after the water starts to evaporate and redeposit the minerals. The second way water transports material is through the process of suspension. Here water actually carries solid material, usually the smaller particles, in the main flow of the stream. The third way water transports material is through the process of moving the bedload – the larger sediment along the bed of the stream that is too large to go into suspension. The moving water produces friction that can drag and bounce the material along the bottom.

There is an almost infinite variety of patterns for river and stream channels. The details of water and sediment interactions seen in the Hjulstrom diagram interact with the larger scale, landscape properties including total amount of sediment available, the discharge or amount of water flowing in the stream or river, the slope angles of the land, and the basic geology of the area over and through which the river runs. All of these factors combine creating innumerable intricate, complex, and functional channel patterns.

With the immensely diverse set of landforms in Colorado from our high mountains to our plains to our plateaus, we get an entire suite of varied river patterns.

The very headwaters of our rivers probably demonstrate the simplest of stream channels. All of our four rivers start in the high elevations of the Rockies. Usually they begin in a relatively small depression below a mountain peak where runoff from rain and snowmelt coalesce into a small, flowing watercourse that soon picks up more water and starts its decent down steep rock steps. The water cascades over boulders and rushes down precipitous slopes (Figure 3). Gravity is in charge and the water is forced to follow a course determined by the local landscape – which is one of large boulders seemingly randomly strewn down the mountain side. Every so often the adolescent river may hit a flat area where the water spreads out to form a wetland of willows, alders, bog birch, and sedges. Beaver, either former or current residents, help create many of these meadows with their system of dams and pools (Figure 4). Soon the stream hits another steep section and continues its boulder-determined trip down the mountain.

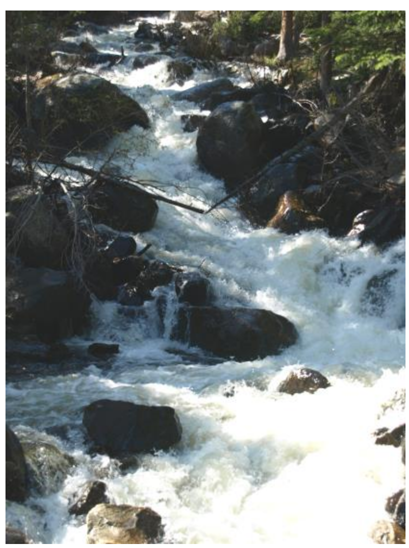


Figure 3 – This is an example of a high energy, cascading steam in the high mountains of Colorado. This is Homestake Creek just below Homestake Dam.

Figure 4 – Italian Creek, a tributary of the Taylor River, has innumerable beaver dams and ponds – typical of mountain streams in the high valleys of Colorado.

By the time our rivers leave the high mountains and either start their flow over the flattened plains or begin cutting their way through the western plateaus, they have gained considerable amounts of water and sediment from countless tributaries. They are real rivers at this point, or at least what we call rivers in Colorado. The form of the channels starts to change dramatically at this point. The slope gradients are much shallower; the boulder strewn landscape of the mountains gives way to flat lying sediments and nearly horizontal geologic strata. As the waters exit the mountains, it is as if they are finally unbound by their hard rock constrictions. The river spreads out and flows at a seemingly slower pace. When the water flow encounters some small impediment, the flow may be slightly diverted in one direction or another; the water moves generally in the new direction until it no longer has the energy to erode its bank and it is turned back to start its flow in the other direction. This process continues and the river channel form takes on a sinuous, meandering route that wanders from one side of the river's floodplain to the other. These meanders will continue until there is some drastic change in the landscape over which the river runs. Sometimes it continues until it reaches the river's end. Of course there are an infinite number of small variations caused by the chaos of the land, but this general form of these meandering river patterns is seen throughout the world (Figures 5 and 6).

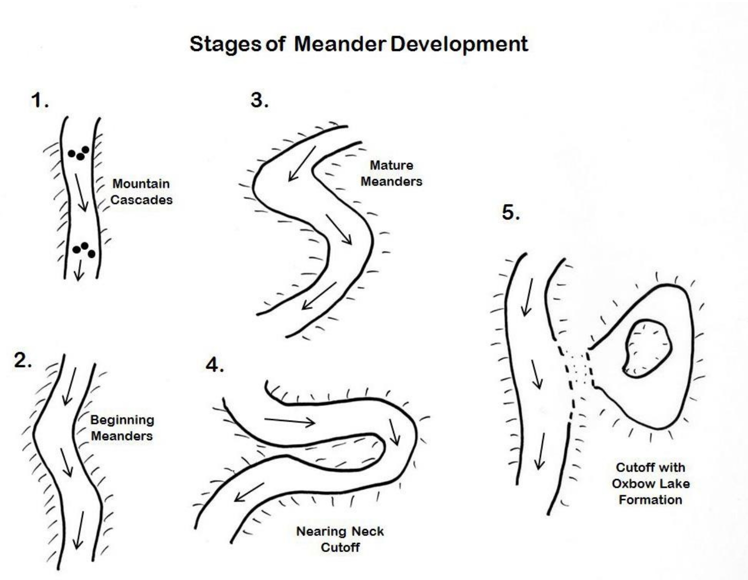


Figure 5 – A schematic of a time-series for the development of meandering rivers and oxbow lake cutoffs.

Figure 6 – A quintessential example of a meandering stream – this river reach is part of the Middle South Platte River in South Park.

Fly fishers everywhere recognize and depend on this configuration of meanders. Where the water is forced to turn, it creates a cut bank. The water is deeper on this side of the channel and there is often an overhang that fish love to occupy during certain parts of the day. Just across the channel from the cut bank is the point bank – this is a shallow, often gravel strewn area. The river reaches between cut banks are often waters that are not as deep as at the cut banks and not as shallow as the point banks – these are called the riffles. The anglers know these different parts of the river because the fish they are after know and use these dissimilar depths and speeds of the river at various times for various reasons.

Over long time spans these meanders can become more and more sinuous until, at some point, the river erodes through the narrowed neck and creates a cutoff – often the cut off part of the river remains for some time as an oxbow lake. Eventually the lake may dry up and become just a part of the floodplain itself. Old cutoff oxbow lakes can often be identified from above more easily than on the ground.

A third basic kind of channel is found downstream of areas that provide large amounts of sediment of various sizes from large gravel to sand, silt, and clay. During high flows that most often occur during spring snow melt in the mountain headwaters, the stream's/river's ability to carry sediment is greatly increased. The large amounts of fast flowing water carrying this debris load eventually exits the mountains and encounters the vastly lower river gradients in the plains. The water slows and starts to deposit the big load of material, clogging the channel of the river with more sediment than it can move. As the river struggles to continue downstream through all of this material, it starts to flow in small, intertwining channels that resemble badly braided hair (Figure 7). In fact this kind of channel pattern is called a braided stream. From above it appears to be a chaotic collection of separate stream channels that merge then split then merge again – this pattern can continue until the river has enough energy to move the sediment provided. In today's environment of controlling river flows by using dams and reservoirs to manage the timing of release for downstream use, there are fewer rivers with the major pulses of large sediment movement and deposition. But, as we will see below, at least one of our four rivers has a historical legacy of this process that we can clearly see today.

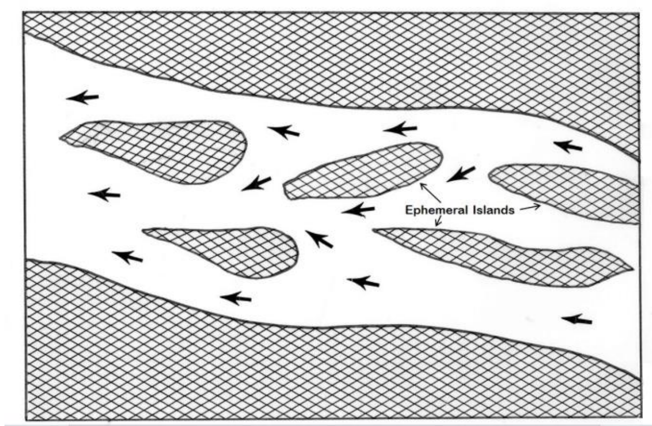


Figure 7 – A schematic of the branching, interlaced channels of a sediment clogged braided stream.

When John C. Frémont explored along the South Platte River in the summer of 1842, he found a river choked in gravel with innumerable shifting, ephemeral islands and multiple, crisscrossing small channels. If he had been here in early May, he would have found a river in full flood stage from the melting mountain snowpack carrying huge amounts of sediment downstream. But those big flows would have only lasted for a few weeks. The lower flows of summer would not have been able move the debris any longer, and vast amounts of mostly sand and gravel were dumped in the middle if the river channel. This sediment created innumerable small, temporary islands in the channel that the moving water had to navigate around and through. The landscape would have to wait until the yearly snow melt flood the next year to get the sediment moving again. Frémont also found a river valley basically devoid of trees – any saplings that got started in the valley during the summer months were flooded and dislodged during the next year's spring floods. The current channel pattern of the South Platte from Platteville to the Nebraska state line is the now a tree stabilized braided pattern not seen in Frémont's day. Water loving cottonwood trees and other vegetation nowadays create a heavily wooded riparian zone important for animal habitat all along the river. An example of the relic braided stream can easily be seen in the satellite image of a small part of the South Platte (Figure 8). The trees lining the water course are in stark contrast to the semi-arid grasslands through which the South Platte runs. The temporary debris islands are now semi-permanent as there is seldom enough water in the river to rework them into new landforms as was an annual event before the middle of the twentieth century.

Figure 8 – The South Platte River east of Greeley is a quintessential example of a relic braided river. (courtesy of http://earthexplorer.usgs.gov/)

The headwaters of the Arkansas River from Tennessee Pass to Cañon City have several channel patterns that ebb and flow. But mostly this upper reach of the river runs fast over and around rocky stretches which create significant rapids. It has a relatively steep gradient that keeps the water moving at high speed, at least for a river. This is what makes the Arkansas so great for rafting. Like all of our rivers, when the Arkansas exits the steep stretches of the mountains and enters the flat lying plains, it slows down. The Arkansas carries sediment as any river does, but historically its load was less than the sediment we see in the South Platte because the Arkansas has lower flows and somewhat more resistant landscapes upstream than the Platte. There is some braiding of the Arkansas as it flows east, but it is more of a typical meandering river complete with cut banks, point banks, riffles between meanders, and old oxbow cutoffs. The scene in Figure 9 comes from a section of a satellite image between Boone and Fowler along the river east of Pueblo. There are no oxbow lakes containing water any longer, but their landform remnants can easily be seen at several points in the floodplain along this reach of water.

Figure 9 – A fine example of mature meanders along the Arkansas River between Boone and Fowler. (courtesy of http://earthexplorer.usgs.gov/)

The Rio Grande probably has the least dramatic departure from the mountains of any of our rivers. The very upper stretches of the river are steep and rocky, but the river enters a relatively broad and level valley from some distance above Creede all the way to South Fork where it enters the San Luis Valley. There are meanders and wetlands in these reaches, but the truly intricate and well-developed meandering system of the Rio Grande comes below Del Norte. This stretch of the river could be used in geomorphology textbooks as the example of the quintessential meander river. Figure 10 is a small reach of the river between Del Norte and Monte Vista in the Valley. It is complete with multiple, very sinuous meanders and oxbow lakes that are still lakes. Both the Arkansas and the Rio Grande are lined by the riparian vegetation so important to wildlife habitat.

Figure 10 – The much more highly developed meanders with oxbow cutoffs along the Rio Grande between Del Norte and Monte Vista. (courtesy of http://earthexplorer.usgs.gov/)

The main stem of the Colorado River exhibits a whole variety of channel forms. Its very top reaches are the same relatively straight, cascading waters we see in the other rivers. But the Colorado enters the relatively flat Middle Park immediately after it leaves the reservoir system for the Colorado-Big Thompson project (Grand Lake, Shadow

Mountain Reservoir, and Granby Reservoir). Because of the volcanic landscapes of Middle Park, this valley is not as flat as the other parks in the state, so there is a variation of channel forms including meanders and some areas of minor braiding. Just downstream from Kremmling and its merging with the Blue River, the Colorado enters Gore Canyon. From this point to the area west of Glenwood Springs, the river runs through multiple canyons and steep stretches. But in some respects the most interesting part of the Colorado is just west of Fruita to the Utah border. Geologically, this is the far northeastern edge of the Colorado Plateau. The Plateau covers about 130,000 square miles of Colorado, Utah, New Mexico, and Arizona. It is generally a geologically high area with flat lying sedimentary rock that has been uplifted en masse. As rivers run through these uplifted sedimentary strata, they tend to cut down into the rock as the plateaus and mesas are uplifted – much as if you moved a layer cake up into a sharp knife that was being held steady. The first such downcutting into the Plateau takes place in this last reach of the Colorado before it exits the state (Figure 11).

Figure 11 – These are entrenched meanders typical of river channels throughout the Colorado Plateau. This is the Colorado River just east of the Utah state line. (courtesy of http://earthexplorer.usgs.gov/)

As the river moves southwest from Fruita it enters a series of canyons including Ruby and Horsethief Canyons. These are the first examples of what the Colorado will be doing for hundreds of miles until it finally exits the Grand Canyon near Callville, Nevada where John Wesley Powell's 1869 expedition down the Colorado River ended. From Rattlesnake Canyon to the border, the river channel pattern is a string of entrenched meanders. These were originally meanders just like the current ones of the Arkansas and Rio Grande. But with the rapid uplift of the land, the river eroded downward quickly (in geologic time scales) and cut the meanders deeply into the plateau. Almost all the rivers throughout the Colorado Plateau have created these entrenched canyons that define the Southwest. The landscapes of Canyonlands and the Grand Canyon are known worldwide for their deeply entrenched meanders. Horsethief Canyon is just the first taste of these spectacular landforms created by the Colorado in our Southwest.

The rivers of Colorado run with the water that inherently has the remarkable qualities that all water has. The landscapes the rivers create and the life that the rivers support all derive from the water. As Coloradans we should be especially mindful of the marvel of what our rivers do and what they should mean to us. At the molecular scale water has the most intriguing qualities of any natural substance. With no trace of hyperbole, the water at the macro scale in our rivers makes the life we have in Colorado possible.

There is little water in the state that is not used, owned, fought over, or enjoyed. And most of that water is concentrated in the streams and rivers that all flow from here to states and countries downstream. As Heraclitus of Ephesus once said circa 500 BC, "No man ever steps in the same river twice, for it's not the same river and he's not the same man." Our river waters continually flow and are renewed each moment as the snows melt and the rains fall in the high mountains and on the parched plains and plateaus. The good news is that the ever-present and inexorable hydraulic cycle with its evaporation, transpiration, condensation, and precipitation keeps the rivers and streams of Colorado flowing.

Watersheds

When precipitation falls, whether as rain or as snow, much of it will soak or infiltrate into the soil. Some of it will evaporate or sublimate back into the atmosphere and move elsewhere as water vapor to become precipitation once more. And the rest will trickle and flow downhill either immediately from the rain or eventually after the snow melts. Usually, the beginning of this flow comes as sheetwash – a term used by geomorphologists that implies the water runs more or less as a continuous sheet or surface runoff. Because of the ubiquitous variations in the land surface and the type and extent of vegetative groundcover, the sheets will soon start to coalesce into small rivulets running downslope. These rivulets, in turn, often merge and become somewhat larger water channels. This sequence continues until these small watercourses come together into what we would consider a permanent stream. This stream is the culmination of all the downhill flowing water that feeds it. The land area that has captured and focused all of this water into the stream is considered its basin or watershed.

This small stream's watershed is but one of a collection of streams and their watersheds that will eventually collect in an ever-bigger stream. This next stream’s watershed, much like the Russian Matryoshka nesting dolls, is made up of all the smaller basins that have contributed to its water volume. Eventually, this cascade of smaller to larger streams becomes one of our rivers. Fluvial geomorphologists have actually created a system for numbering the level or order of each of the streams as we go from the smallest (first order stream basin) to ever larger basins or watersheds. For example, in one such numbering system, the Mississippi River watershed would be a tenth order basin. The Platte and Arkansas Rivers that begin in Colorado are actually eighth and ninth level watersheds respectively that eventually feed the Mississippi. This tessellation of small watersheds would look like a complex mosaic if all of the first level watersheds were outlined on a watershed map. Second order watersheds are made up of two or more first order streams and their watersheds; third order ones are made from multiple second order watersheds and so on until the flows end at the farthest downstream point – sea level (Figure 1).

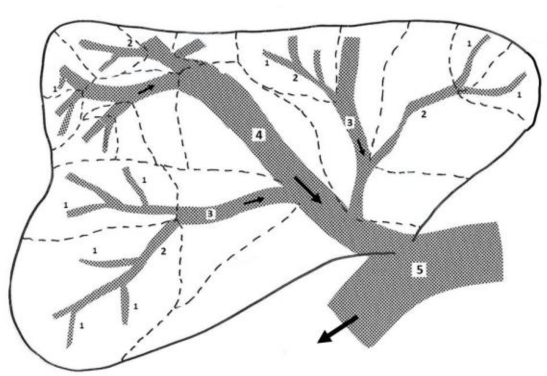


Figure 1 – This diagram shows the hierarchy of watersheds and their ordered streams. Be aware not all watersheds are outlined.

Watersheds are the natural systems that collect and transport water downstream. But they are much more than mere hydrologic conveyer belts. In many ways they are the unifying system for the natural world. With the possible exception of atmospheric processes, watersheds are nature's most important organizing entities for many of the processes and materials in a functioning environment. Water is moved through a watershed, of course, but so are the products of the weathering and erosion of rock and soil. Less of this sediment will be moving in a well-vegetated watershed, increased sediment in more barren landscapes. The ecosystems and habitats of watersheds are not uniform, but the basin does provide an organization to the distribution of naturally occurring vegetation patterns. For example land adjacent to watercourses often support riparian (along the watercourse) ecosystems because there is more moisture available for plant growth and propagation there than in other places within the watershed. Away from the stream ecosystems that can tolerate drier environments will develop. There are, of course, wide variants to this scenario, and if a watershed is large with highly variable elevations (as in Colorado), plant communities will range from those at lower heights in a continuum up to the highest points in the basin. Watershed characteristics will also dramatically affect the water quality at the exit point from the basin to the next larger stream or at sea level. The human habitation intensity, human land uses, ownership patterns, and population numbers within the basin along with the erosional characteristics of the land surfaces of the watershed will all contribute positively or negatively to water quality and quantity.

The patterns of human occupation of the land are often at odds with the land itself. We tend to think we can "engineer" solutions to problems like steep slopes, drainage issues, bad soils, or uncooperative geology. Land ownership and organization often dictate how land is settled and used. The Land Ordinance of 1785 established the U.S. Public Land Survey System (referred to as the Range and Township system). With a few fits and starts, the final model of this system was based on "townships" that were six miles by six miles. They were organized across much of the Midwest and West by regional principal meridians. Most of these lands are prescribed by this survey system to this day. Colorado is part of three separate principal meridians – principal meridians are the organizing basis for large state-sized portions of land. Most of Colorado is organized under the 6th Principal Meridian established in 1855 in Nebraska. Portions of the southwestern part of the state are under the New Mexico Principal Meridian also established in 1855, and a small part of far western Colorado uses the Ute Principal Meridian established in 1880 (Figure 2). This rectangular land organization works reasonably well in the relatively flat and wet East. But as you move west and up into mountainous terrain, the system is very restrictive and often less than useful.

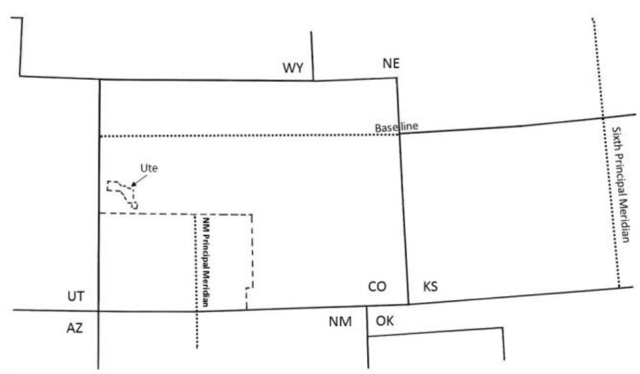


Figure 2 – This is a map of the U.S. Public Land Survey systems for Colorado.

John Wesley Powell realized that the United States Public Land Survey system was not optimal for providing what settlers in the West needed – mostly access to water for irrigation. He suggested in his seminal work, *Report on the Lands of the Arid Region of the United States – with a more detailed account of Utah* (1879), that the entire arid, semi-arid, and mountainous West should be organized more organically, primarily by watersheds not by the straight, topographically blind sets of meridians and parallels that comprise the U.S. Public Land Survey as it exists now and existed in the 1870s. His ideas are discussed at considerable length in the chapter, **Too Little – Too Much**, but the essence is that in order for the optimal use of the land for irrigated agriculture, a system organized by the occupants of the watershed is the only logical method for allocating land

and scarce water and for assembling the communal resources necessary to build the needed irrigation infrastructure.

Each of Colorado's rivers has its own watershed made up of innumerable smaller watersheds that tesselate into the mosaic of landscapes that we encounter on the ground. Each of these landscapes is composed of many natural and human factors including complex geologic relationships, soil types, ecosystem patterns, the hydrologies of drought and plenty, individual and small-scale landuses, and the large overarching management of large land tracts by the federal government. While Powell's proposal would have directly affected how agriculture was conducted in the West, watersheds are much more complex, natural, systematic, and coherent than just a way to manipulate water for human use. When we layer one of the factors that make up a watershed upon the myriad other layers of these factors, a watershed becomes the logical, if complex, structural scheme for the land.

GEOPHYSICAL SETTING

The foundation for every watershed is the bedrock geology beneath the surface. As described in the **Introduction**, ours is a complex of harder and softer rock arranged and incessantly rearranged by global tectonic forces, massive uplifts and cyclic erosional and depositional periods over the last several hundred million years (see Figure 3 in the **Introduction**). This core of our state varies considerably within each of our four watersheds as well as having significant differences between the watersheds. As stated in the **Introduction**, the simplest, although not simple, watershed’s geology is the Rio Grande basin. Virtually the entire western half of the geological foundation are volcanic rocks of the Cenozoic Era that began to form some 34 million years ago. In the San Luis Valley, massive alluvial (river) and glacial deposits thousands of feet thick fill the geologically sunken valley. These deposits are unconsolidated and have a tremendous ability to hold large reservoirs of underground water in multiple aquifers.

These layers or strata of very loose sands and gravels contain vast amounts of water. There are also strata that are made up of small, clay sized particles that underlie and overlie the aquifers and essentially isolate the various aquifer layers. Some of the aquifers are virtually at the surface of the valley and others at various depths going down thousands of feet. Some of the aquifers are connected vertically while others are effectively isolated. These physical characteristics created by the sediments carried from the mountains also helped create the need for the complex of water laws (see the Law Chapter) that at times aid land-owners and ecosystems and at other times hinder the easy use of water by both humans and the natural world.

As with all of our rivers, the Arkansas starts in the high mountains of central Colorado in an area of very old, Precambrian intrusive igneous rock. It quickly descends into the trough of the Arkansas River that runs between the Sawatch Range to the west and the Mosquito and Ten Mile Ranges to the east. This valley is the down-dropped graben formed by tectonic movements of the Rio Grande rift north of Poncha Pass. The valley bottom consists of unconsolidated glacial and fluvial-glacial debris with the mountain sides having the intrusive rock of the Sawatch and the intrusive and Tertiary sedimentary rock of the Mosquitos and Ten Miles.

After the river flows through the dramatic Royal Gorge carved in more intrusive rock with some ancient metamorphic inclusions, it bursts into the plains of eastern

Colorado. It flows eastward toward the Kansas border in a very subdued landscape of flat to gently rolling sedimentary rock of the Mesozoic age and a large quantity of unconsolidated alluvium deposited over the last several thousand years. Today's Arkansas River and its deposits have minimal impact on the vast area of southeastern Colorado. Most of the sediment is confined to the river itself and its narrow floodplain. The sediment train moves slowly, but inexorably downstream, some of it temporarily stored in reservoirs like the John Martin, but eventually it will all leave the state and find its way to the Gulf of Mexico.

By far the largest portion of the Platte River basin in Colorado is drained by the South Platte River. Its geology while winding its way through the mountains is not dissimilar to that of the Arkansas. But once it exits the mountain front and angles northeast after it passes through Denver, it flows over a very different landscape. At the end of each of the multiple glaciations that took place in the high mountains of Colorado, immense deposits of loose mineral debris were left behind. Much of this material was eroded by strong and incessant winds, mostly coming out from the southwest. These winds picked up the eroded finer particles of these deposits – the sand, silt, and clay sized particles. The smallest of these mineral grains were the clays. They were so small that they stayed in aerial suspension for thousands upon thousands of miles. Much of this material actually made it across the Atlantic. The next smaller material was deposited in places such as what we now know of as Illinois, Iowa, and Indiana – what was to become maybe the finest farming soil in the world. The larger sand grains did not make it that far. Most of this material was set down in vast sheets over northeastern Colorado and in places like the Sandhills of Nebraska. These sand deposits are what the South Platte flows amongst as it works its anastomosing way toward the town of Julesburg and the Nebraska border on its way to merge with the North Platte River near the appropriately named town of North Platte, Nebraska.

The Colorado River spends the most time/distance of all our four rivers in the mountains carving canyons such as the Gore and the Glenwood. It has the greatest flow of all four rivers and does the most geomorphic work in reshaping the land. It eroded its own passage through the Grand Hogback and flows under the Roan Cliffs to exit its mountain landscapes at Palisade where, over many millennia, it has deposited massive alluvial sediments into what we call the Grand Valley. Its sediment and its water have helped humans create one of the most fecund farming regions in the state. Orchards of peaches, apples, and cherries mix with vineyards and wineries. This abundance given by the river lasts a mere 25 miles or so until the river again enters the canyons just south of Fruita. At this point the river is in the terrain we call canyonlands that are a product of its flows and erosion all the way to the Grand Wash Cliffs just upstream from Lake Mead.

SOILS

William Bryant Logan calls soil "the ecstatic skin of the Earth." He makes an elegant case for the importance and beauty of soils, because soil, along with the sun, water and the air around us, is what makes it possible for us to live on this planet. And like almost anything else in the natural world, soils are extremely complex and varied. In biology we deal with the complexity of all organisms by using a taxonomic system that goes from the least numerous called domains down an ever-branching tree until we get to *genera* (genus) and species. With soils we have a six-level taxonomic system starting with the 12 orders branching down to some 10,000+ soil series. The entire United States is covered by the 12 orders – all of the ecological and climatic diversity of the country contains only these 12 major classes. Colorado, with its huge variation in elevation, geology, and precipitation patterns contains examples of eight of these 12 classes. Our soils are created in extremely diverse landscapes from the often-scorched shortgrass prairie to the frequently snow-bound foothills; from the tundra-like alpine to the near deserts of our western plateaus and mesas.

Soils develop slowly in conjunction with their past and present environments. The geology or mineral parent material, the climate – especially the amount and distribution of water and temperature, the types and proliferation of vegetation, and the topography on which they develop are all critical to the complicated processes making the soil upon which we, and most life, depend. All of the factors are themselves complex and varied and progress at various rates over long periods of time. Together they produce almost an infinite variety of soil around the world, the U.S., and Colorado. Humans put things into classes so that we can comprehend and, at least partly, understand the natural world. We cannot deal with an infinite variety of anything very well. The 12 orders of soil determined for the United States are the culmination of many decades of work by soils scientists to try to make sense of that complex, valued substance under our feet (NRCS, 1999) (Figure 3).

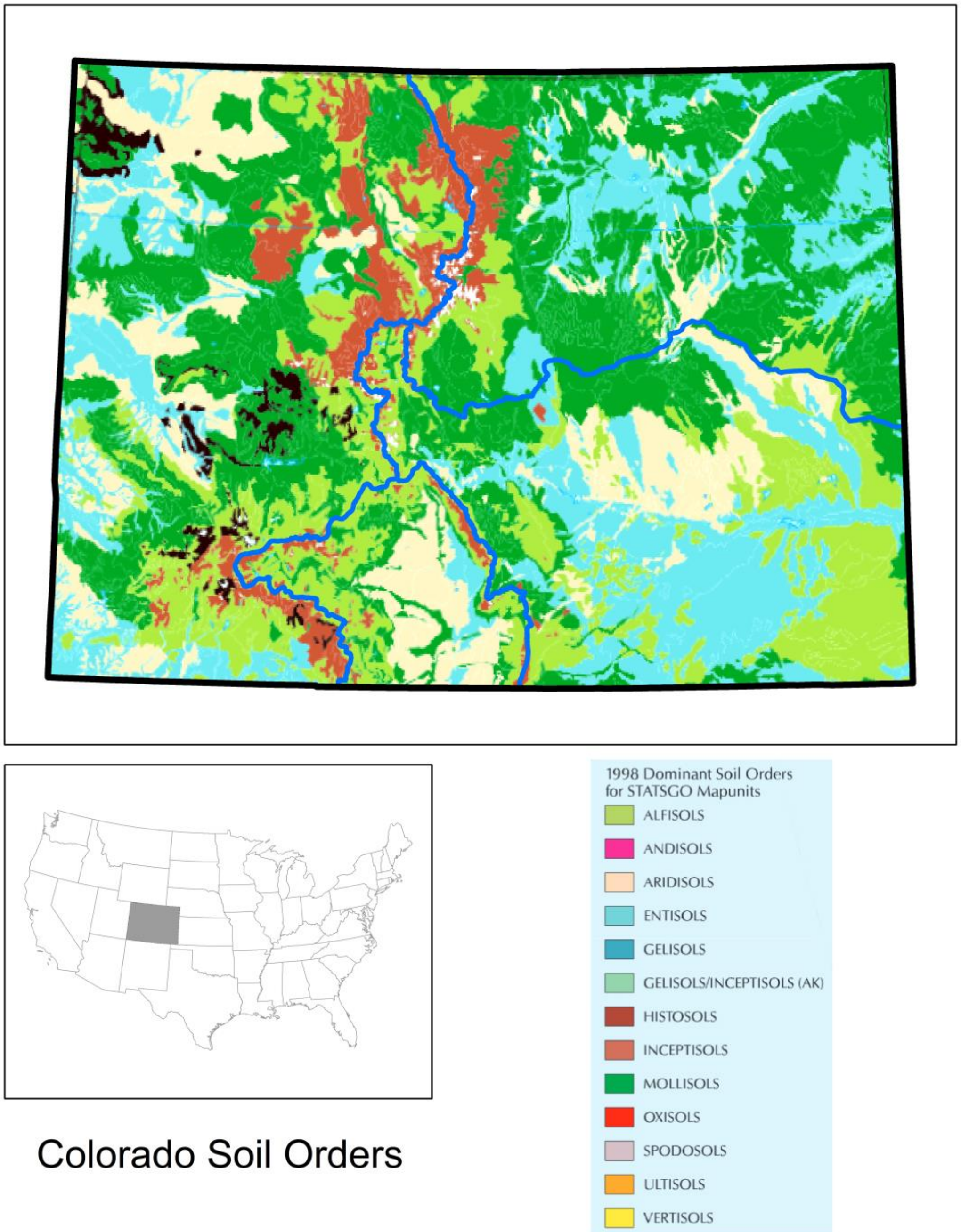


Figure 3 – The map of the soil orders in Colorado. (courtesy of the Natural Resource Conservation Service, 1998).

Each of our four river basins starts in the high mountains of the state. The soil forming conditions in those areas are severe, especially in the winter, and vary almost continuously as elevations change dramatically over short distances. These conditions produce an intricate and seemingly indecipherable mosaic of different soil types as can be seen in Figure 3 along both sides of the continental divide – that topographic line lying between the Colorado Basin and the three other basins. But because we understand many of the processes at play, we can actually see and explain why the soils develop as they have. The most common soil order in that high elevation region is the inceptisols. These are soils that are just barely beginning to develop as soil even though they have been at it for 10,000 years or more. They are just starting to exhibit the common "horizon" structure that soil scientists use to describe soil. These soils are so "new" because the environment that they are in does not allow for much chemical weathering to take place with too cold a winter and too short a summer. There is a soil order that is even less developed than the inceptisols – the entisols. These soils have no horizon development and are the least weathered of any soil order we have. These soils are in their infancy of development and may never reach any kind of maturity at these high elevations.

At altitudes just below the treeless alpine tundra where upright trees start to be the dominant vegetation and down into the montane zone, we get a soil order that is found throughout many forested areas of the country. These are the alfisol soils that are the second most common soil order in the entire U.S. They are not particularly fertile, but the large amount of organic matter contributed by the forest helps to keep them fertile enough for forest growth around the country.

The most surprising soil order that exists at high elevations in our mountains are the mollisols. Mollisols are most often connected with the fertile tall-grass prairie soils in the corn fields of places like Illinois, Iowa, eastern Nebraska and Kansas. These prairie soils developed under the lavish vegetation of the grasslands. Root systems of these grasses go down many feet and when decomposed add huge amounts of fertile organic matter to the soil – year after year, century after century. There is a small but important area in the high mountains that is analogous to the deep grass roots in the plains. Where small lakes form, especially in post-glacial landscapes, lavish stands of willows and alpine forbs grow in proliferation. The mollisol soils developed under these vegetation stands are organic rich, deep black soils.

Once we reach the lower elevations of our watersheds, the soils mostly change in response to lower precipitation rates. Figure 3 shows large expanses of a soil order called aridisols. These are mostly in the Rio Grande watershed in the San Luis Valley, in the northern half of the Arkansas basin in eastern Colorado, and in the far northwestern corner of the state in the Colorado River watershed. The name "aridisol" tells most of the tale on the development of these soils. They are created in very dry, arid conditions where there is not enough precipitation for much chemical weathering to take place. An aridisol paradox of sorts is that if you add water, say through irrigation, the soils can be quite good for many crops. The issue, of course, is getting enough water to these soils in this dry environment (see the chapters on Diversions and Law).

South of the Arkansas River flowing to the east in the plains, we get a very large expanse of entisols. These are the same order as the entisols in the high mountains, but instead of development being stymied by the long, cold winters, it is slowed here because of the lack of moisture – much like the aridisols. There are large stretches of entisols in along the South Platte in northeastern Colorado where the soil is developing on those sand dune formations laid down by the post-glaciation winds coming out of the mountains.

The South Platte watershed in the eastern plains also has a large area of mollisols – those beautiful, dark, organic rich soils found in the Midwest. The mollisols here could probably be called mollisol-light. They are technically mollisols, but they lack the intense fertility of their siblings to the east. Nonetheless, they can be very fecund when water is added through various irrigation schemes. In mid-summer you would be hard pressed to see the difference between the corn fields of Morgan County and those in central Iowa.

The lower elevations of the Colorado River basin show more complex mix of soils than do the other three watersheds. This intricacy of soils types arises from the complexity of the land. The three most common soil orders in the basin are inceptisols (relatively undeveloped soil), alfisols (forest soils), and mollisols (moderately fertile grassland soil). At this point it is well to remember that we have only been talking about the 12 soil orders – there are, in reality, hundreds if not thousands of different soil series in the state. The soil order map (Figure 3) is complex already. It would be unreadable at this scale if we were to attempt to map the very real variation in the soils of our watersheds.

VEGETATION/ECOSYSTEMS

Unless you work with it or are incredibly curious about what is under your feet, soil, and all of the natural processes that produce it, is difficult to understand. But everyone can relate to the vegetation cover on the landscapes that surround us. Most people recognize the basic types of vegetation we see -- whether just trees or shrubs or flowers or vegetables. But, as in the case of soils, there is an overwhelming complexity to the plant world that keeps most of us from really knowing and understanding what plants do and how they interact in the natural world. And, as also in the case of soils, we have created a human designed plant classification system. The Swede Carl Linnaeus established the basics of our plant (and animal) taxonomy in the mid-eighteenth century. We all learned in high school about the way we divide plants into genus and species. This of course is an artificial human concept, but it is useful for helping us make sense of the hundreds of thousands of different plants in the world. But even a few hundred thousand plants are mind boggling for most of us. Ecologists and biogeographers have lumped plants and their environments in something called ecosystems. An ecosystem is a particular collection of plants that associate with each other in a given environment with certain soils, climates, and topography.

An example of this in Colorado would be the ponderosa pine ecosystem of our foothills and lower elevation mountains. There are, of course, ponderosa pines in this ecosystem but also kinnikinnik, mountain mahogany, common juniper, shrubby cinquefoil, dwarf mistletoe and a myriad of other plants that find this patch of ground and the surrounding plants amenable. This ecosystem is also defined by the coarse soils, the warm summers, and a narrow range of precipitation amounts. An ecosystem can be as small as a few square meters or as large as hundreds or even thousands of acres. A map of the entire state of Colorado reveals many ecosystems combine into a larger classification called ecoregions (Figure 4).

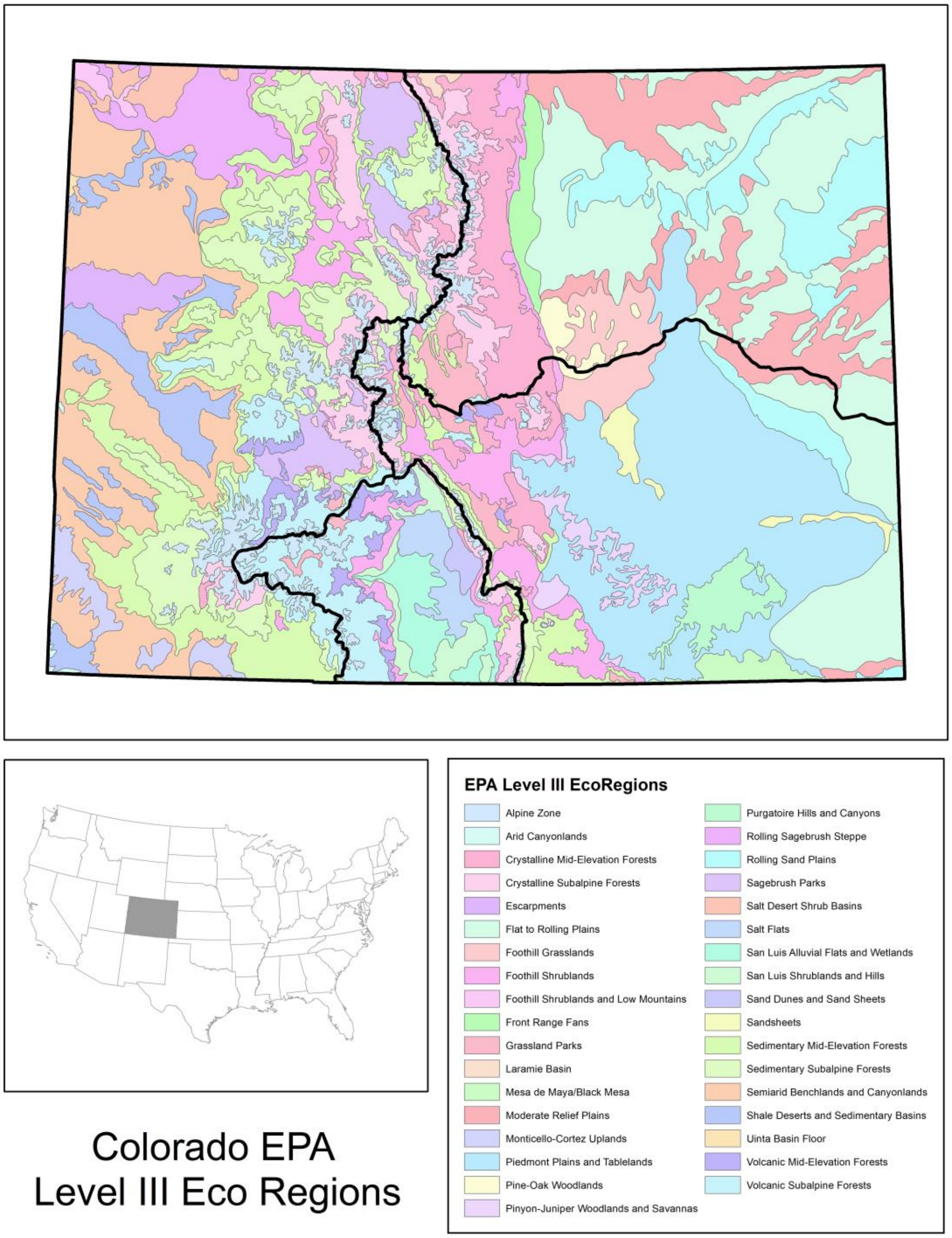


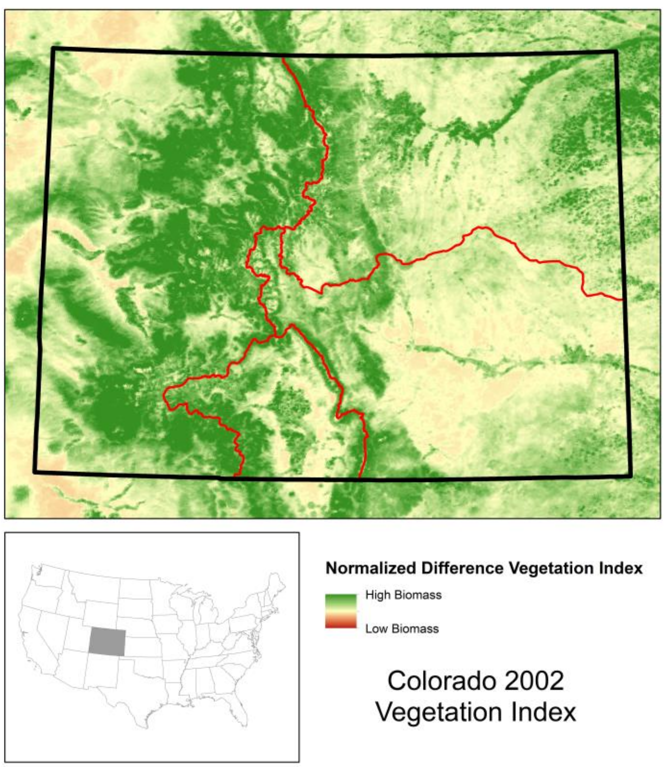
Figure 4 – The map of the Colorado Ecoregions (courtesy of the U.S. Geological Survey, 2006).

As is usual for the upper elevations in all four of our basins, the high mountains are the most complex region, clearly evident in Figure 4. All of the greens on the map are mountain ecoregions that include the alpine zone above treeline, the crystalline (referring to rock type) subalpine forest, the crystalline mid-elevation forests, and others. The South Platte watershed and the far eastern Arkansas watershed are in the high plains. Examples of the ecoregions there include rolling sand plains, moderate relief plains, and Front Range fans. The western two thirds of the Arkansas basin is covered by what is called the southwestern tablelands with ecoregions such as piedmont plains and tablelands, pinyon-juniper woodlands and savannas, foothill grasslands, and sand sheets. The Rio Grande basin in the San Luis Valley has its own unique ecoregions for Colorado, strangely called the Arizona/New Mexico plateau. The four ecoregions included here are the San Luis shrublands and hills, the San Luis alluvial flats and wetlands, salt flats, and sand dunes and sand sheets (of course referring to the Great Sand Dunes National Park and Preserve). The areas of the Colorado basin outside of the mountains are made up of the Colorado Plateau. Some of the ecoregions here include shale deserts and sedimentary basins, semiarid benchlands and canyonlands, and arid canyonlands. Even with this lumping of ecosystems into a larger scale system, it is still complex and somewhat overwhelming.

Another simpler way to view our vegetation largesse is to look at the total amount of vegetation in a place. Ecologists and biogeographers often call this the total biomass of an area, usually in grams of biomass per square meter of land. As you might expect doing this kind of measurement could be beyond onerous – measuring every single square meter and its vegetation amount in the entire state! The simple or easy, and realistically probably the only, way to do this is by using the technology of earth sensing satellites. A short tutorial on how energy from the sun interacts with the earth is in order.

The energy coming from our sun and every other object in the universe can be described using the term "electro-magnetic spectrum (EMS)." Everything from cosmic, gamma, and x-rays to visible light, thermal energy, all the way to radio waves are generated and emitted from our sun. We on earth depend on this energy for nearly 100% of our needs. But not all EMS energy acts the same way. To make it simple let us just look at the visible part of the energy coming from the sun and how that band of energy interacts with vegetation. The chlorophyll that green plants contain is what makes life on earth possible. It produces carbohydrates using water and visible energy, to be more specific, the blue and the red ends of the visible EMS. In other words most of the sun's energy that is used to build plant material comes from the blue and red bands being absorbed by chlorophyll, the green part of the light reflects off of the chlorophyll and bounces into our eyes; therefore, we see green. Just beyond the red part of the EMS is another band of energy called the near-infra red. This part of the sun's energy is almost totally reflected by the same chlorophyll that absorbs the red and blue.

When we compare how much red a sensor can see with the amount of near-infra red, we can tell pretty precisely how much chlorophyll, or plant matter, we have. There are many, many ways that scientists manipulate the red versus infra-red to give us biomass amounts. One of the earliest and simplest is a method called the "normalized difference vegetation index (NDVI)." This algorithm uses a very simple ratio method to compare the two and gives us a good estimate of how much biomass is in an area at any given moment. The scale of the NDVI is from +1 (very high chlorophyll concentrations) to 0 (no vegetation) to -1 (rock and other mineral soil only). We can take any satellite image that has the two bands of red and infra-red and do an NDVI. To illustrate the power of this technique, compare a time of severe drought in Colorado (a summer day in 2002) and a period of moderately high precipitation in the state (a summer day in 2014). Figure 5 (a and b) shows very dramatic differences between the two days. Almost the entire eastern plains in 2002, both the Arkansas and South Platte watersheds, have very low chlorophyll (i.e. biomass) concentrations. The far western edge of the state also has low vegetation. You can see that even in the normally wetter mountains, chlorophyll levels have been reduced significantly. In contrast the 2014 map shows a very healthy vegetation cover in most of the state. The South Platte basin has some low levels of chlorophyll, but that is a normal condition for that region. The San Luis Valley also shows some chlorophyll deficits which is also normal. The far western side of the state is low but not nearly as low as in 2002.



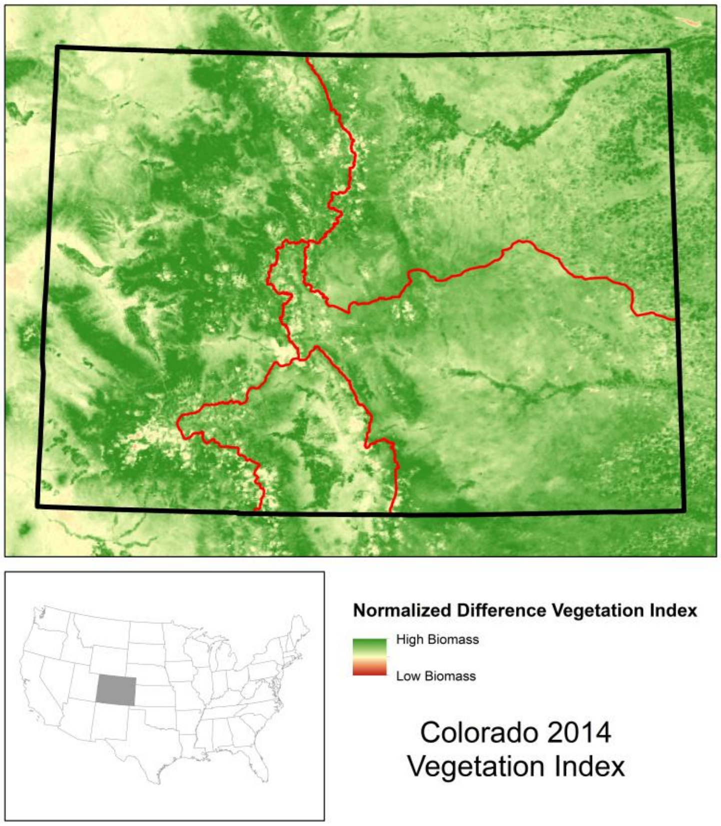


Figure 5 – The NDVI for summer 2002 (a) and 2014 (b) determined by the red and near-infra red bands of the AVHRR NOAA satellite (courtesy of NASA GIMMS).

Figures 4 and 5 illustrate the complex nature of vegetation in our naturally complicated state. We have wide variations in our ecosystems mostly dependent upon elevation. We also get wide variations in the amount and health of our natural environments based on climatic and meteorological deviations, particularly precipitation amounts over weeks, months, and years. The health and vibrancy of our four rivers depend on what is upstream in the rivers' watersheds with vegetation being one of the most important components of this. To understand our rivers, we must understand the natural systems of geology, soils, and ecosystems that contribute to those rivers.

FEDERAL LAND

But the health and vigor of the rivers depends on more than what nature gives us. The uses of the land in each watershed is a significant factor in how those watersheds and their rivers react. Much of our land is privately owned. This is particularly true of the eastern plains – the areas drained mostly by the South Platte and Arkansas Rivers. There are always some restrictions put on private ownership – you cannot rent out your land for a toxic waste dump without strict permitting and building requirements for example. Most of the land outside of our urban areas is used for farming and ranching, and this land also is restricted legally, socially, and naturally (see the chapters on Diversions, Compacts, and Law). But the largest single landowner in the state is the federal government, and what happens on these lands in our watersheds has a huge impact on the health and prosperity of the land itself and the people and other organisms that depend on it.

In Colorado the federal lands make up 35.9% of the state's 66,485,760 acres. Figure 6 shows that most of this land is in the western half of the state. Of all the federal land, the most is managed by the U.S. Forest Service (60.67%) in eleven separate National Forests and Grasslands (Table 1). The Bureau of Land Management (BLM) manages most of the remaining federal land (34.92%). The remainder of the federal land is owned by the National Park Service (2.77%), the Department of Defense (.91%), and the U.S. Fish and Wildlife Service (.73%). The Forest Service and the BLM seemingly serve different purposes, but when you look at their mission statements, they are almost identical. The Forest Service mission "is to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations;" the BLM statement merely substitutes the words "America's public lands" for "Nation's forests and grasslands."

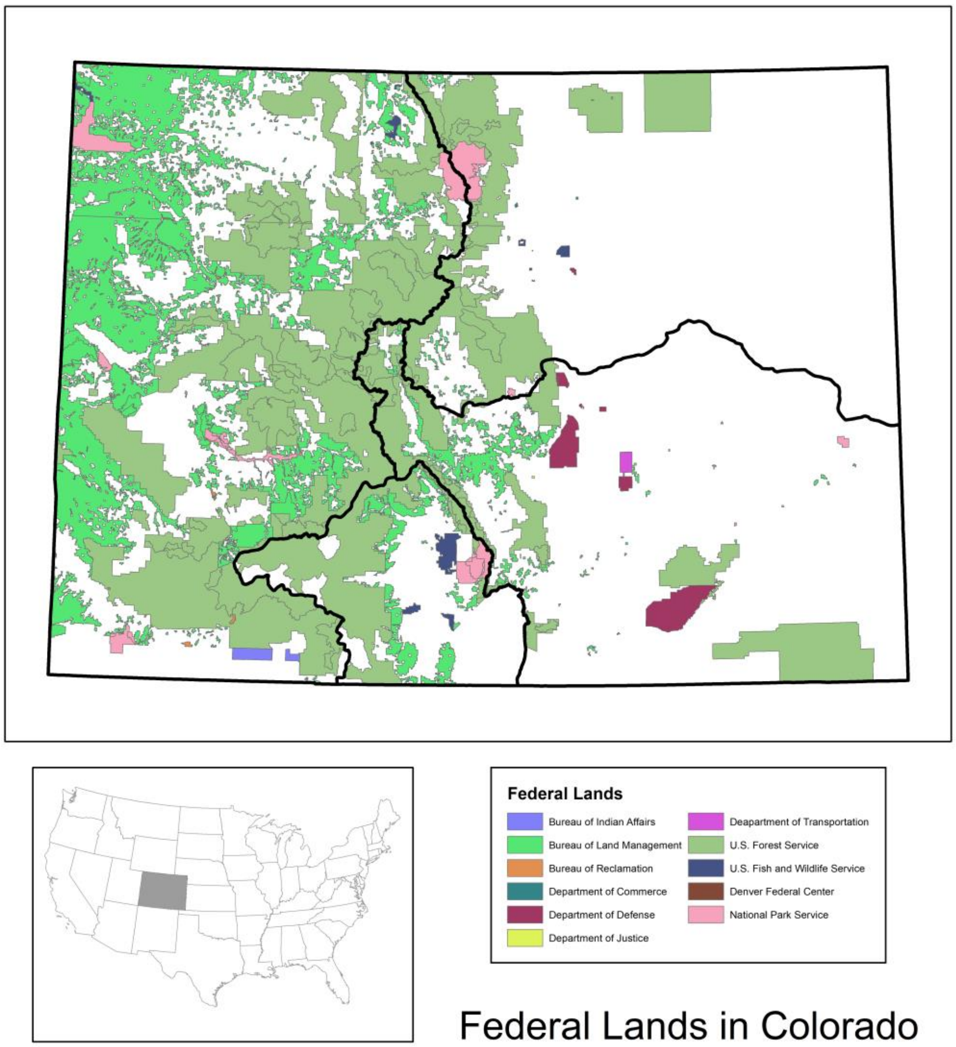


Figure 6 – The National Atlas version of the Colorado Federal lands (courtesy of the U.S. Department of the Interior and the U.S. Geological Survey).

Table 1 U.S. Forest Service Units in Colorado

Arapaho National Forest	Grand Mesa National Forest
Gunnison National Forest	Pike National Forest
Rio Grande National Forest	Roosevelt National Forest
Routt National Forest	San Isabel National Forest
San Juan National Forest	Uncompahgre National Forest
White River National Forest	Comanche National Grassland
Pawnee Buttes National Grassland	

But the reality on the ground between these two agencies is obvious. While they both have multiple-use mandates, the BLM is much more aggressive in promoting and permitting mineral extraction along with oil and gas development for example. As shown on Figure 6 most of the BLM property is along the far western border in the canyonlands and mesas where vast stretches of sagebrush cover the land and large oil and gas reserves underlie it. There are some scattered and patchwork segments of BLM land throughout the mountains and geologic parks also. The overwhelming mountain landowner and manager is the Forest Service. Most of our cherished ski resorts are carved out of leased National Forest land; huge tracts of Forest Service land are leased to ranchers for summer grazing; and, the various National Forests straddle the highest mountains along the continental divide where all four of our rivers begin.

For the Platte and Arkansas Rivers, their initial run through National Forests is short and the impacts on them by that land is minimized. The Rio Grande's upper half is in Forest Service land, and these acres surely affect the quality and quantity of the water in the river. The largest influence on river water by National Forests is certainly that on the Colorado River and its many tributaries. The Colorado has the most water, the most demands on that water, and the largest impacts outside of the state. The National Forests of our state are the birth places of the rivers that come of age as they traverse public land. It matters a great deal how and where these upper reaches of our water courses flow.

Origins

In about 1,600 B.C. the Chinese Emperor Yu made the prescient comment, "To protect your rivers, protect your mountains" (Wilshire, Nielson, and Hazlett, 2008). He knew then what we should keep in mind now, especially in a state with the elevated terrains of Colorado, that the mountains mean most everything to the rivers they spawn. In at least three ways mountains immeasurably affect our rivers: first, in arid and semi-arid environments especially, almost all precipitation occurs from the uplift of air masses being pushed up the slopes of our mountains and the subsequent lowering of temperatures of the atmosphere toward the dew point. This has the effect of forcing the water vapor in the air masses to condense and, through a complex physical process, cause precipitation. Second, gravity is our friend as it moves the water from high places where few of us live to lower elevations where we humans usually reside. We often take this wet beneficence and manipulate this largesse for a myriad of uses. Finally, the water moving incessantly downslope weathers and erodes those same mountains that give us the water to start. If too much erosion takes place, sedimentation from that act muddies the water, fills reservoirs, and damages the distribution systems we need to move the water to where we need it most (see the **Water** chapter).

This last point should be emphasized even though it may seem rather trivial. In reality more than one civilization has been destroyed because of excessive sedimentation of their irrigation systems. One example is from ancient Mesopotamia (today's Iraq). It is generally agreed that agriculture began there about 7,000 years ago. It was able to thrive in the arid climate because of the available water in both the Tigris and Euphrates Rivers. But 2,500 years later the people living in the region decided they needed more arable land watered by irrigation. An elaborate and massive canal system was developed that helped irrigate almost 35,000 square miles (the entire size of the state of Maine) of cropland. The canals were protected by a series of levees, and they were periodically cleaned of sediment by the communal efforts of the populace. But an insidious activity was developing in the high mountains of the Taurus, the headwaters of both rivers in today's Turkey. Sheep and goat grazing were the main subsistence economy of the mountain people who lived there. Vegetation has many positive characteristics including the fact that it almost always helps to protect sloping lands from erosion. Both goats and sheep can easily devastate grazing grounds because they eat so close to the soil surface and allow massive erosion to scar the steep, mountainous terrain. John Muir, the iconic Sierra Nevada conservationist, once said that sheep should be called 'hooved locusts' because of their propensity to denude landscapes. The sediment carried down to Mesopotamia during this era slowly filled the canals and eventually the system could not be maintained. In fact the Persian Gulf's shoreline was moved an amazing 180 miles down stream because of the sediment that choked it.

Today we can see the same thing happening at an even faster rate to reservoirs on the Colorado and other rivers in the Southwest. As an example the depth of sediment deposits at the upper end of Lake Powell created by the Glen Canyon Dam are now at least 150 feet deep. Almost ten percent of Lake Mead created by Hoover Dam is now filled with sediment with more added every day. Smaller reservoirs and lakes in Colorado and the West are also losing considerable capacity through sedimentation. Many water managers see reservoirs as the defense against the droughts that are becoming more frequent as a result of climate change – save the water when we get it and use that saved water in times of scarcity. But the sedimentation problem is one major hurdle to using the current reservoirs to maximum efficiency and to building new ones to increase capacity.

Exploration of Earth, especially in the nineteenth century, consisted in large part of looking for the origins of the world's great rivers. Although most of these river sources were already known by the indigenous groups living in the area, history often goes to those who write it down. John Hanning Speke and his "discovering" the source of the Nile (the Blue Nile at Lake Tana and the White Nile at Lake No) is one such venture. Henry Schoolcraft discovered the source of the Mississippi River in the 1830s. Zebulon Pike was sent west in 1806 ostensibly to find the sources of the Arkansas and Red Rivers – he never found either and was captured by Mexican soldiers as his expedition was in what would become Colorado but was Mexican territory at the time. We seem to still be discovering/looking for river origins. The source of the Amazon River for more than a century had been thought to be the Apurímac River on Nevado Mismi, but in 2012 it was discovered that a completely different tributary (the Mantaro River in Peru) was really the source. The origins of the world's rivers have always intrigued us. But what does it really mean to be the "source" or the origin of a river?

If one really thinks about it, there is never just a single source (a lake of some kind in most cases) for a river. The lake may be the most obvious place the river comes from, where the river starts to flow. But there are innumerable small contributors to that lake or there would not be a lake at all. Rain and/or snowmelt on the slopes above the 'source lake' flow into the collection depression in which the lake sits. These small rivulets of water from every slope surface are the real sources of any river or stream.

Because we humans like order and decisiveness, we say with utter certainty that this river or that stream start at this particular spot, but there are always smaller and smaller trickles of water that flow into the purported source. With these thoughts in mind, what are the origins or sources of our four Colorado rivers?

The major hydrologic fence that we have in Colorado that separates the watersheds of our various rivers is the continental divide. The water west of that sinuous line flows toward the Pacific Ocean (really the Gulf of California officially but also called the Sea of Cortez by many). The water on the east side of the divide flows toward the Atlantic Ocean basin – in the case of our eastern rivers, the Rio Grande, the Arkansas, and the Platte, to the Gulf of Mexico. There are two other divides. The one between the Rio Grande and the Arkansas and the one separating the Arkansas from the Platte. These two do not get the privilege of being called 'continental divides' but are important nonetheless.

The Colorado River is by far the largest of our four rivers. With its tributaries it drains the entire western slope of the state. One would think that the source or origin of such a magnificent river would itself be magnificent – one would be mistaken. The officially designated source of the Colorado lies in the far northwestern corner of Rocky Mountain National Park. It is La Poudre Pass Lake. The main issue with La Poudre Pass Lake is that it is no longer a lake – today it is merely a nice bucolic wet meadow just on the western side of the almost imperceptible continental divide (Figure 1). The lake had always been shallow, and over the centuries water loving vegetation has been slowly encroaching into the lake and filling the lake bed with vegetative detritus and sediments.

This process of 'bogging' in is natural and normal in many lakes. Figure 1 was photographed on a mid-September afternoon so the grasses are dried and brown. In late spring this meadow would be a lush, vibrantly green expanse.

Figure 1 – La Poudre Pass "Lake" wet meadow with just a small trickle of water starting the Colorado River.

The actual continental divide is less than 1000 feet east from what would be the upper end of the lake if there were a lake. It is a very gently sloping landscape where the gradient is nearly imperceptible. In fact it is almost surreal that you can stand next to the erstwhile La Poudre Lake western shoreline and look to the north a few hundred feet and see the Grand Ditch (see the **Diversions** Chapter) flowing from west to east in the opposite direction across the divide. The Grand Ditch gathers its water from along the upper slopes of the Colorado River valley on the west side of the divide and takes that water to the eastern slope to be used for irrigation. It is one of the oldest diversions of western slope water for eastern slope use in the state.

The headwaters landscape of the Colorado is full of unexpected sites. Less than a mile below where the Colorado leaves La Poudre Pass Lake, it enters a very deep and strikingly colored canyon the river has carved over many millennia. Between La Poudre Pass Lake and this canyon, there are several small but vigorously flowing tributary streams, such as Lady and Specimen Creeks, that add substantial water to the Colorado, especially during the wet snow melt season of late spring and early summer. This canyon has been cut into a volcanic landscape that was created 28 and 24 million years ago -- a time of vigorous volcanic activity in many areas of Colorado (Hopkins and Hopkins, 2000). The canyon is colorful, deep, and impressive. It looks somewhat like a similar canyon in Yellowstone National Park that was made famous by the Hayden Survey of the Yellowstone area in 1871. A member of that survey, Thomas Moran, painted a very large canvas of the Yellowstone canyon that now is exhibited at the Smithsonian American Art Museum. The Colorado version is not as majestic or well-known nor does it have a large waterfall, but it is a rugged and beautiful canyon nonetheless (Figure 2).

Figure 2 – Looking southwest down Little Yellowstone Canyon in Rocky Mountain National Park.

The upper Arkansas River has two significant branches that form the main stem of the river. The first of these starts just below Tennessee Pass about eight miles north of Leadville. The pass itself is famous for the small ski area that sits at its apex – Ski Cooper. Ski Cooper will always be associated with the Tenth Mountain Division of the U.S. Army during World War II. Ski Cooper was a part of the division's training ground that included large parcels of land north of the pass that are known as Pando. The branch of the Arkansas that starts on the south slope of the pass is named after the pass – Tennessee Creek. Although it is named a creek, it is considered the 'west' fork of the Arkansas headwaters.

The Tennessee Creek origin is nearly imperceptible. The creek slowly coalesces from several small rivulets adjacent to the Ewing Ditch that is described in the **Diversions** Chapter. Like the start of the Colorado River, this is an almost bucolic setting that is not in any way spectacular. But it manages to gather a significant amount of water as it flows south at a leisurely rate into a large open area known as Tennessee Park (Figure 3). This parkland is easily visible west of U.S. Highway 24 between Leadville and the pass. It has a very large willow carr along its western edge. A willow carr is an area of wetland that is dominated by the water loving willow and other wetland shrubs (there are several different species of willow in the state). Wetland carrs are of great importance to the ecological health of our mountain parks. Not only do they help to moderate flooding, but they are also one of the most prolific and fecund ecosystem types we have. Not only are there large masses of organic mass produced by the rich vegetation, but they also provide some of the best wildlife habitat we have in the entire state.

The valley bottom that underlies the extensive wetlands consists of loose and unconsolidated sediment. Much of this sediment is derived from the alpine glaciers that covered a large part of the mountainous terrain in the surrounding uplands. Very substantial valley glaciers from the Pleistocene epoch filled what we see today as the stream valleys dissecting the mountain landscape. These glaciers eroded, transported, and deposited huge amounts of detritus that ended up in the larger valleys such as Tennessee Park. Finer sediments of silt and clay have been laid down by more recent stream deposition on top of the glacial debris. This relatively fine-grained soil is excellent for the verdant growth of the wetland flora.

Figure 3 – Looking South from just below Tennessee Pass. Tennessee Park is in the distance.

The other headwaters branch of the Arkansas might be considered the "main" origin of the river because it is larger in these upper reaches. On official maps it is called the East Fork of the Arkansas. It begins its flow to the Gulf of Mexico in a much more typical alpine environment. Just two miles south of Fremont Pass on Colorado State Highway 91 sits the 13,795 foot Mount Arkansas. The headwaters start on the very southeastern flanks of Mount Arkansas at just under 12,600 feet (Figure 4). The bedrock in this area consists of Precambrian granites and massive metamorphic gneisses and schists. These rocks are very old (> 1 billion years) and very resistant to erosion. The river flows in a semi-circle around the southeastern and eastern margins of the mountain and emerges to parallel Highway 91 near Storke Portal, part of the Climax Mine holdings on the southern side of Fremont Pass. The start of the East Fork is definitely an alpine environment, but it is far from isolated. A rugged two-track path that intrepid four-wheelers can take travels from near Storke Portal around the base of the mountain with the river in the valley below. Hiking along this dual track is a great introduction to the ecosystems of the alpine lifezone.

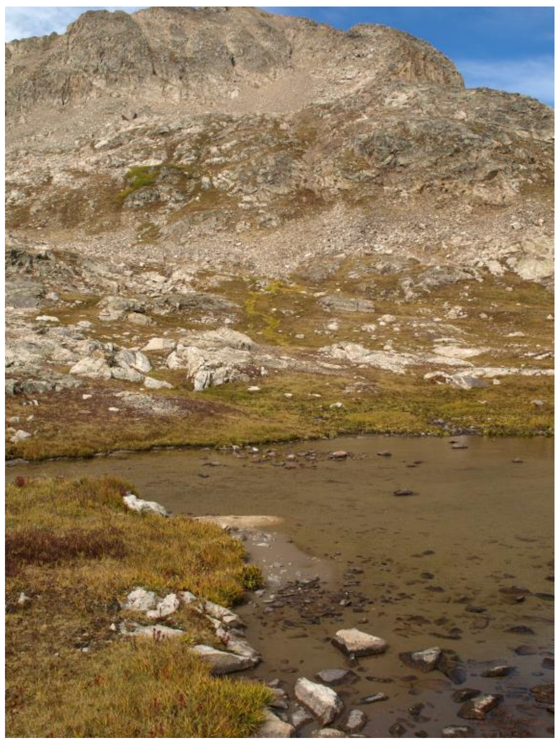


Figure 4 – A small pond that is part of the origins of the East Fork of the Arkansas River. This glacial cirque is the start of the East Fork and sits on the southern flank of Mount Arkansas.

The two branches of the Arkansas merge just west of Leadville Junction which is about two miles west of downtown Leadville. The river is relatively small at this point, but it is definitely a river – at least by Colorado standards. From here it begins its long

1,460-mile travels to its confluence with the Mississippi in far southeastern Arkansas and then on to the Gulf of Mexico.

There is another watercourse that some consider part of the Arkansas River Headwaters. It is called the South Arkansas River and flows down from near Monarch Pass to its confluence with the Arkansas near Salida. This stream is nearly 60 miles south of the confluence of Tennessee Creek and the East Fork of the Arkansas. Because of this distance, it has not been included as part of the origin of the river.

The South Platte River has three officially acknowledged origins – with the unpoetic names of the North Fork, Middle Fork, and South Fork of the South Platte River. The South Fork of the South Platte River continues our string of unspectacular and willow clogged origins (Figure 5). It sits just below and to the east of Weston Pass (11,921 feet) that connects Highway 285 coming south out of Fairplay to Highway 24 just to the south of Leadville. The Weston Pass road is a mild four-wheel drive road with a few steep and rocky sections but no precipitous drop-offs to the side. It passes through some glacially and alluvially deposited sediments at its lower end and is marked by a complex set of lithologies as you go higher, including some relatively young intrusives and some very old granitic and metamorphic intrusive rock types.

Figure 5 – View looking west to the top of Weston Pass. The South Fork of the South Platte River is flowing gently through the willows to the upper left of the photo.

The river at this point is nothing more than a vibrant small stream that flows rather lazily through willow carrs and pasture lands in its lower reaches. It eventually deviates from Weston Pass road and meanders southeasterly across South Park until it reaches the Middle Fork just upstream of two water storage reservoirs and state parks – Spinney Mountain (City of Aurora) and Eleven Mile (Denver Water Board). After Eleven Mile, it turns sharply north and northwest through Lake George and on to its confluence with the North Fork of the river.

The Middle Fork of the South Platte River starts in a much more spectacular setting. It begins in a small tarn just southwest of Mt. Lincoln near Hoosier Pass. Almost immediately it flows into the somewhat larger Wheeler Lake and continues down an impressive glacially scoured U-shaped valley before it drains into Montgomery Reservoir – a water system reservoir for the City of Colorado Springs (Figure 6). Mt. Lincoln

(14,286 feet) is part of the northern section of the Mosquito Range that also includes Mt. Bross (14,172 feet), Mt. Democrat (14,148 feet), and Mt. Cameron (14,238 feet). The bedrock here consists of Precambrian granites and very old (Paleozoic) sedimentary rock. This collection of high peaks sits just south of the continental divide. The divide between the South Platte drainage and the Arkansas River drainage runs directly over Mt. Democrat. The exact sources of the Middle Fork of the South Platte River and the West Fork of the Arkansas River are a mere four miles apart.

Figure 6 – View from across the valley where Colorado Highway 9 ascends to Hoosier Pass. The large glacial valley above the reservoir is the headwaters catchment for the Middle Fork of the South Platte River.

This branch of the South Platte flows south paralleling Highway 9 through Alma until it gets to Fairplay. Much of this stretch of the river has been placer mined for gold from the late nineteenth century up until the 1960s. This was industrial placer mining where large dredges overturned massive amounts of glacially transported gravel looking for minute amounts of the yellow metal. As you drive along the road you can see evidence of large gravel mounds, some of which are now being used as gravel quarries (see Figure 3 in the **Eco-matters** chapter). As mentioned above the Middle Fork has its confluence with the South Fork just east of the small hamlet of Hartsel. This confluence is upstream of Spinney Reservoir, and on maps it is simply called the South Platte River from this point on although it has not yet connected with the North Fork.

South and Middle Forks of the South Platte are rivers people associate with South Park. They both flow into the large, structural basin that sits surrounded by the high mountains of the Mosquito, Tenmile, Front, and the Tarryall ranges. It is a high, relatively flat region where these two branches of the South Platte wonder and meander. Both branches are beloved by fly fishers because of the easy access and fecund riverine environment that supports healthy fish populations, particularly rainbow, brook, and brown trout.

The North Fork of the South Platte is separated from the South Platte by the Tarryall Mountains and the Lost Creek Wilderness area – it never enters South Park. The North Fork starts high in an area where the Mosquito, Gore, and Front ranges come together although it is "officially" in the Front Range. Its origin is in a small cirque basin under Handcart Peak (12,518 feet). The bedrock is very old (≈ 1.7 billion years) metamorphic gneisses. These rocks are riddled with fractures that allowed superheated fluids from thousands of feet below the surface to invade and deposit highly concentrated minerals. Of course this means the area has historically been a mining region with innumerable mining claims in the higher elevations of the North Fork valley (Figure 7). Note in Figure 7 the disturbed slopes directly above the valley of the nascent North Fork.

In fact a current mining operation has blocked the small gravel road leading to the very upper reaches of the watershed (Figure 8).

Figure 7 – This is the upper valley where the North Fork of the South Platte originates. Note the many mining claims and remains on the upper slopes.

Figure 8 – Mining is still somewhat active in the North Fork headwaters as evidenced by this gate that blocks the road to the very source of the river.

Mining has been an economic activity in Colorado since long before it was a state. It is still a significant part of the Colorado economy, at least in certain areas. But mining does cause some very damaging environmental impacts. The impact that is most obvious in these upper reaches of the North Fork is something called acid mine drainage (AMD). This is a very complex process, but the crux of AMD is that after mines are closed, the water level in mines often goes up and interacts with newly exposed minerals in the remaining rocks of the abandoned mine. One important mineral involved is iron pyrite (an iron sulfide mineral) that is often found in conjunction with the minerals that have been mined – gold is one of these. Chemical and organic processes breakdown the iron pyrite and iron oxides are formed. The iron oxides often go into solution in the waters inside the mines. When these iron oxide solutions flow out of the mine and come in contact with fresh water, they precipitate out and form a reddish to yellowish, acidic compound carried in the water – in this case in the upper North Fork. It is easy to see the coloration in the waters of the river as a very deep, almost blood, red. Beneficial water microbes and many fish species are negatively affected by this acid drainage. Luckily, as more fresh water from small tributaries is added to the river as it flows east, the acid solution becomes more and more diluted. The upper parts of the river are affected a great deal, but by the time the North Fork reaches the South Platte, the acid concentrations are at a significantly lower level.

The North Fork flows east out of the high mountains past the small town of Grant. It continues in that direction until it merges with the South Platte near a very small hamlet called, appropriately, South Platte. This confluence is just west of Waterton Canyon and a few miles upstream from Chatfield Reservoir. The reservoir was built in the late 1960s by the U.S. Army Corps of Engineers as a result of the devastating 1965 flood. The reservoir is now also part of the Denver Water Board water supply for the city, and it is a state park.

Unlike all the other four rivers, the North Platte does not arise in the high mountains of the state. It begins in Middle Park, just a few miles southwest of the small town of Waldon. And it does not start as a single trickle of water coming from an old glacial cirque; instead it begins at the less than spectacular merging of Grizzly and Little Grizzly Creeks at an elevation of about 8050 feet. It begins and flows north through a flat, wide open valley that is choked with willow carrs and intensively meandering streams. In spite of the fact that it is in the farthest northern reaches of the state, it is a fecund and verdant land that includes habitat for many species. In fact it is so well endowed with excellent habitat that the then Colorado Division of Wildlife (now known as Colorado Parks and Wildlife) reintroduced 24 moose to North Park in 1978 (see the **Too Many – Too Few** chapter). This reintroduction has been wildly successful, and with other introductions around the state, have established a healthy and vibrant moose population in the mountain valleys throughout Colorado.

The origin of the Rio Grande is probably the most remote of any of the four rivers. It begins in the high elevations of the San Juan Mountains. The small mining town of Creede is the closest community on the eastern side of the Continental Divide to the headwaters. As the crow flies Silverton is the closest town to the source, but it is on the western side of Stony Pass to the west of the divide. To get to the source, one must go past Rio Grande Reservoir; the road becomes a very narrow and rocky passage for many miles as you travel almost due west toward Stony Pass which is the access over the continental divide at this point. Just east of the pass is Canby Mountain (13,478 feet) where the river begins its flow to the Gulf of Mexico. The river flows from a small valley on the northern flanks of the mountain. It curves around the base of Canby to the south and southeast for about two miles until it turns and heads almost due east.

The bedrock of Canby Mountain is decidedly volcanic. Almost all the rock in this area was emplaced during several million years of intense volcanic activity during the Tertiary age. The volcanic activity here is marked most dramatically by several large calderas -- remnants of violently explosive and massive eruptions of volcanic material. Rich zones of precious metals, especially gold and silver, are found in the innumerable fractures produced by these very large events. Silverton is one of the most famous mining towns in Colorado. There are few places in this landscape that have not been affected by mining over the last century and a half.

The Rio Grande is a typical mountain stream near its source, but soon it is flowing through a series of ever widening valley bottoms (Figure 9). Even above Rio Grande Reservoir, it is a relatively slow moving and meandering river. It remains so as it flows past Creede, South Fork and into the San Luis Valley.

Figure 9. The far upper valley of the Rio Grande just a few miles from the Continental Divide.

Our mountains are absolutely critical to Colorado for our water. Without them we would be a much different and drier place. Our mountains are also important beyond our borders. In fact 17 downstream states get some of their water from the largesse of our mountains. Without the particular geography of our Colorado landscapes, much of the west and southwest of our country would be very different places. The climate and hydrology of Colorado's mountains, plains, plateaus, and rivers matter to millions of people. They are not only important for the physical reality of our need for water, but economically, socially, and politically our mountains and their rivers are crucial.

Where and how the water of rivers finally finds its way to the oceans is of critical importance. But where these rivers start might be more personally fascinating. The small beginnings of a river's flow are much more intimate and accessible than most river mouths – these may be huge and almost undefinable (such as the complex and shifting mouth of the Mississippi River in the Gulf of Mexico). In the case of Colorado's rivers, the beginnings are usually in the high elevation alpine regions where vistas are long and landscapes are approachable with a little effort.

Law

According to the *Oxford English Dictionary,* **law** is "the body of rules, whether proceeding from formal enactment or from custom, which a particular state or community recognizes as binding on its members or subjects." This definition of law provides for very broad application of the concept. It can be a set of written rules agreed upon, or mandated from some authority, or some combination of both that a community uses to keep order, make things run, and help to satisfy societies needs however they are determined. When it comes to water law in the formational years of the territory/state of Colorado, there was little that was binding or accepted as custom. It was often stated in Colorado and the West that "whiskey is for drinking, and water is for fighting." That quip is usually attributed to Mark Twain, although there is no evidence he ever uttered those words. Only when users of large amounts of water affected other users or potential users did the idea of establishing laws to govern water evolve. It was mostly because of large amounts of water being diverted for use in mining and because Colorado was just becoming a state with a newly written constitution, that Colorado water law began to be codified.

On the other hand, according to the definition of "law" above, we have actually had water law in Colorado (or what would become the state of Colorado) for well over 1,000 years. The southwestern mesas and plateaus of Colorado have been the home of many groups of people for a considerable time. It is a place of remarkable archaeological treasures often collectively associated with the Anasazi. 'Anasazi' is actually a Navajo word – many people say it means 'the ancient ones' but most agree it means 'enemy ancestors' – a mildly pejorative term that is offensive to a large number of Native

American groups. A more acceptable term is ' ancestral Puebloans' which acknowledges the links between them and the Pueblo cultures existent today in the Southwest.

Five hundred years before the Magna Carta, a thousand years before the Continental Congress approved the Declaration of Independence, and eleven hundred years before Colorado had a constitution or Custer had his last stand, the ancestral Puebloans had the equivalent of water laws and customs that allowed them to develop a hydrologic system that lasted for well over 300 years. Archaeologists, historians, and water engineers have uncovered an elaborate system of canals, conduits, berms, and reservoirs that fed an irrigated farming culture large enough to supply thousands of people with food in an otherwise arid landscape. Accomplishing this feat required considerable organization, and cooperation -- the equivalent of laws as defined above. The well-known and respected water engineer Kenneth Wright wrote about this system in his *Water for the Anasazi* -- "… people had to be available … to excavate, dredge, operate and maintain the reservoirs, and a community social organization was necessary for the selection and direction of a work force, year after year and generation after generation, to keep the reservoirs operable."

These ancient hydrologic engineers clearly used communal effort to keep the system running. For example the reservoirs that collected and stored water for future use would, over time, start to fill with sediment that was brought down by erosion from the higher elevations that supplied the water. Either the reservoirs would need to be dredged or expanded above the sediment layer. Dredging with small baskets or ceramic tools would have been a nearly impossible task, so the community helped to raise the reservoirs time and again so they had renewed capacity to hold water. The 'law' used to get this cooperation was less a punitive mechanism and more a call for communal action to help all in their struggle to survive and thrive in this dry, and often, inhospitable region. The climate of southwestern Colorado throughout the entire ancestral Puebloan era was mostly dry with intermittent wet periods. There is a considerable amount of speculation as to why the ancestral Puebloans disappeared from the region around 1300 AD. Some say it was climate change, but the climate had been variable all the way through their time in southwestern Colorado. Some say it was an especially severe time of violent attacks by some invader or internal strife, and others talk about a cultural pull toward other Puebloan groups to the south and east. There is no consensus – but it is very likely a combination of all three of these factors that finally and permanently pushed and/or pulled the ancestral Puebloans away from their mesa homes. Whatever the cause, the ancestral Puebloans were gone from the Mesa Verde region, and their exquisitely engineered structures, including their water system, were left for others to find and study.

Modern water law is a very, very complex topic. But it can be simplified (overly simplified?) into two major categories in the United States in which we can class the general water law in a given region. The first type is Riparian Rights and addresses surface water use. In the more humid eastern part of the country, there is usually much more precipitation on a regular basis and, therefore, many more creeks and rivers. The odds that someone is living on a stream are pretty high. In Ohio, as a typical example, anyone who has water in a stream or lake on or adjacent to their land can take a reasonable amount of water from that water source for their needs. The legal catch here is, what is a reasonable amount of water – that is usually the cause of litigation in riparian rights states. But there is the implicit right to that water by anyone without having to pay someone for it. Groundwater extractions are more complex, and the laws are usually involved and often arcane.

The other category of water law is the Prior Appropriation Doctrine, often called the Colorado Doctrine or more colloquially, "first in time, first in right." The system really started in the California gold fields where it was determined that the first miner to use the water for mining (a beneficial use by definition), was the one who had the first call on that water. The very basic concept is that upstream or downstream users who came later may not get as much as they want or need, and if you came too late, you might get none at all. But it was not just about mining. Farmers and ranchers were also realizing that there was little water to go around, so the first user of a water source got prior or earlier or senior rights than the next one to put the water to beneficial use and on down the line.

In the Colorado Constitution [Article XVI] approved in 1876, all-natural water sources in the state were designated a public resource – in essence, the people of the state owned the water. Users could have rights that allowed them to use the water if it were for a beneficial use. These rights were just like any commodity and could be bought or sold. They could even be lost if your water rights were not being used over an extended period of time – this is called abandonment. The doctrine became known as the Colorado Doctrine because Colorado had the most articulate and robust law concerning water law in the West. The definitive Colorado Supreme Court case (Coffin vs. Left Hand Ditch Co.) was in 1882. This, along with much previous case law and Article XVI of the

Colorado Constitution, confirmed that riparian law was "inapplicable to Colorado" and much of the West has used that unambiguous idea ever since.

Justice Gregory Hobbs, Jr. has outlined the four basic principles of Colorado water law in the Colorado Foundation for Water Education's *Citizen's Guide to Colorado Water Law* (2015). First, all surface and groundwater in the state is a public resource that is meant for beneficial use by individuals or by public or private organizations. Second, you do not own the water but if you have water rights, you have the right to use it for beneficial purposes – remember, the water belongs to all of us. Third, you can use water courses and aquifers to move or store water for later use. Fourth, if you own water rights that are not near where you will put them to beneficial use, you have the right to build facilities across the private property of others to the place where the water will be used if the private land owners consent or if there is just compensation for the disturbance. This is a very significant move away from riparian rights where it is explicit that your rights are determined by your juxtaposition to the water source.

The details of Colorado water law can be very complex, but the basic understanding is fairly straightforward. The first person (Joe) to get an adjudicated water right from a water source (maybe the Cache la Poudre River near Ft. Collins) and puts that water to a beneficial use gets the first priority to that water. The next person (say Susan) who gets a right for water from the Cache has the second priority, which is junior to Joe's. The next person (Immanuel) gets his right to use some of the water but is junior to both Joe and Susan – and so on until all the water is allocated. But there are wet years and dry years in Colorado (see Too Little – Too Much). When the droughts come, and they will, there is often not enough water to go around. If there is just enough for both Joe and Susan, Immanuel must close his head gate and dry up his fields. If the drought continues, and there is only enough for Joe and maybe half of Susan's appropriation, Joe gets all of his and Susan gets her half and poor Immanuel starts to look for places to buy some water with more senior rights. The oldest adjudicated water rights in the entire state belong to the People's Ditch Company in the community of San Luis in the southeastern part of the San Luis Valley (Figure 1). That ditch company has an 1852 water right that is proudly declared on a brass marker at the south end of town. Obviously, this right's date is long before we had the official Prior Appropriation legislation for the state -- in fact it is 24 years before Colorado was a state. But it was recognized that they were using this water for beneficial uses and the right was declared or adjudicated retroactively.

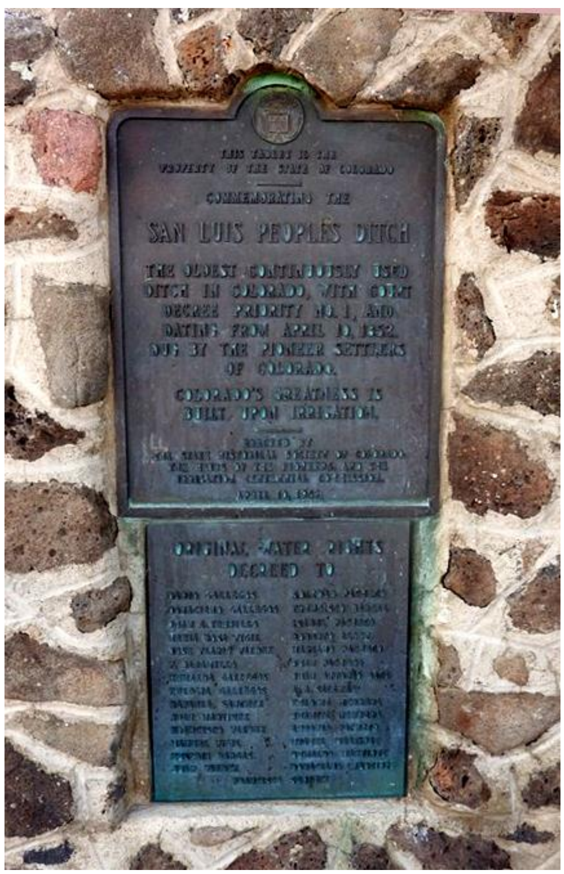


Figure 1 – The People's Ditch and commemorative plaque in San Luis. This is the oldest priority water right in Colorado.

The state of Colorado has created an intricate, yet rigorous, system for enforcing and adjudicating what really happens on the ground. The legislatively created Colorado Division of Water Resources has established a system of seven water divisions defined by river basin boundaries – the South Platte River, the Arkansas, the Rio Grande, the Gunnison, the Colorado, the Yampa/White River that happens to include the North Platte (only because of proximity to the White River even though it is strictly part of the Platte River basin), and the San Juan/Dolores River Basins (Figure 2). The Division of Water Resources houses the State Engineer who has authority over all water in the state. There is also a Division Engineer for each of the Divisions who is responsible for making sure the system is working in their Division. Each Division also has a Water Court which is responsible for adjudicating the water rights within the Division. The Court does not create a "water right" but merely confirms it by decree. The right actually comes when unallocated water is put to beneficial use. The Divisions are very large with many, many water users, so the state has divided the Divisions into multiple districts with a Water Commissioner for each district. These commissioners are the water arbiters for all of the adjudicated water rights of their individual district. They are the hands-on people who make the determinations of who gets what water when and what priority rights are fulfilled and which ones may not be because of the lack of water. There are also "ditch officials" or "ditch riders" who actually go into the fields and along the ditches to assure the waters being used are in accord with the priorities.

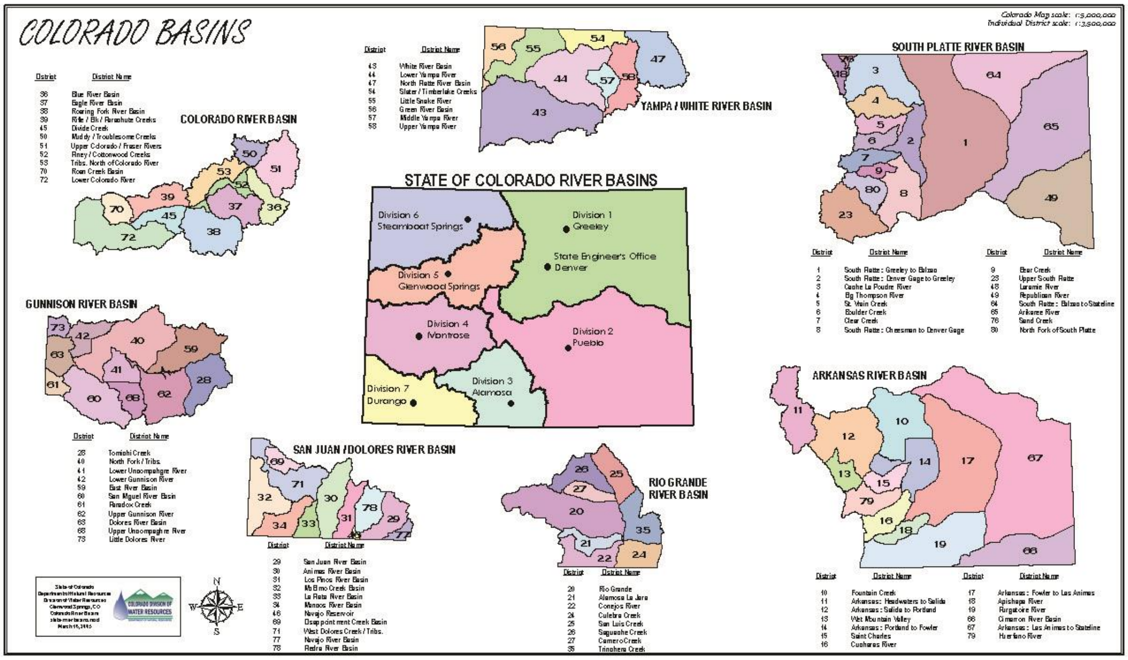


Figure 2 – Colorado Division of Water Resources legal Divisions and Districts. (courtesy of Colorado Division of Water Resources)

If there is not enough water, a "call" is issued by the water user to his or her ditch rider. In 2002 District 7 Engineer Ken Beegles wrote a scenario for just what a 'call' entails. This is an adaptation of his synopsis –

> *A farmer, maybe Sam from above, is trying to irrigate his grape vines on a hot July day. Soon he realizes that there is not enough water in the ditch to get his appropriated shares. He contacts his ditch rider who checks the ditch and water available and affirms Sam's need. The ditch rider contacts the district water commissioner who starts the process of finding Sam enough water. There might be some non-decreed users who are taking water because there may have been an excess, but they are the first to be told*

they must shut their water gates. If there is still not enough water for Sam, the commissioner looks for the most junior water right holder and informs them to close their water gate. This goes on until Sam has all of the water that he can use now – he cannot get more than he can put to beneficial use. For example the ditch rider will make sure that Sam does not over water his vineyard.

The summer gets hotter and drier, and in August an apple grower (Alice) on the same ditch with an earlier appropriation than Sam does not have all the water she needs from her appropriation. She calls the ditch rider and the process starts again – this time Sam happens to be a junior rights owner and may need to close his water gates to give Alice all the water she can use beneficially and is within her adjudicated rights.

This is the stark reality of what "first in time, first in right" really means to real people on the ground. If you have junior waters rights in a basin of a creek with many others also using the water during drought conditions, you may lose out in a big way. One way around this dilemma is to buy more senior rights. Water rights are just like any other commodity in that they can be bought and sold. So if you have no water rights or only very junior rights, you can, with the appropriate amount of money, purchase older water rights. But as demands increase for more water, these older rights are increasingly valuable and will cost more and more in the future.

There are people who view Colorado water law as a bit extreme at times – and they might be right. The example of the ability to use rain barrels is a case in point. With the minor exception of people who are not connected to a municipal water source, for over a century it has been illegal for someone to put a rain barrel under a waterspout coming off of their roof. Rainwater cascading down from the top of your house to your property below does not belong to you. Remember, every drop of water in Colorado is a public resource and the rights to use that water are already adjudicated to someone who owns those rights. In recent years the legislature has taken up this situation, but the powerful eastern plains law makers who are in the most agriculturally intense part of the state have, until recently, blocked every effort to change the law. These same legislators go so far as to state that using a rain barrel on your own land for rainfall on your land is "stealing." But finally in August of 2016, the legislature granted home-owners the right to collect rain water from the roofs of their home in rain barrels. There are still some restrictions to this practice, but a seemingly small and rational part has changed in Colorado water law.

Surface water is what we are most concerned with in discussing our four rivers, but groundwater does have big impacts in certain cases. Water law is applied to groundwater as it is to surface water but with significant variations in most cases. Ground water in the state is regulated by the legislatively created Colorado Ground Water Commission appointed by the governor. There are four classes of groundwater withdrawal in Colorado determined by what groundwater basins are involved and how much water is being removed. The first class of groundwater use is from exempt wells. Exempt wells are mostly for very small withdrawals for individual or a small group of individual households. The second type is non-exempt wells that have virtually the same rules as for surface water use. Non-exempt wells pump more than 15 gallons per minute.

The water in these wells is usually considered “tributary,” meaning that the aquifer from which the water comes is hydrologically connected to a surface water stream so has the same legal status as that surface water. The third type is called designated groundwater basins. There are seven of these spread throughout the eastern plains of Colorado and are controlled by a special group called the Colorado Ground Water Commission. These are basins essentially disconnected from the surface waters that leave the state. The last type is the non-tributary and Denver Basin wells. These have special permits and amounts that may be extracted during a given year.

Groundwater is treated differently than surface water because it is much slower in reacting to daily, monthly, or even yearly precipitation. It may take centuries to millennia to get water into a groundwater aquifer. It must enter at some point on the surface and move slowly under hydrostatic pressures and gravity through the sediments of the basin. These movements take time. For example the Northern High Plains designated groundwater basin is part of the much more massive Ogallala formation that runs from South Dakota all the way south into western Texas and is one of the largest aquifers in the world (see Figure 5 in **Compacts** chapter). The water in that basin is being drawn down at a rapid rate, especially in its southern end. It is estimated that the aquifer will be used up within a couple decades and will not have reachable water in it for the foreseeable future because it cannot refill in a human scale time frame.

The "mining" of groundwater is rapidly becoming a very serious issue. There are places in Colorado that have only a few decades worth of groundwater left. Since these aquifers cannot fill rapidly enough to recharge the water to sustainable levels and most of these communities have no access to surface water, a major water crisis is looming. Most of these areas are on the eastern plains of Colorado where there is little running water and a big need from agriculture. Little farming and ranching on the high plains can take place without irrigation. The dilemma, of course, is that water rights from agriculture are being bought by municipalities (often outside of the river basin) which reduces the economic base for why those rural communities and residences are there in the first place. Reductions are already happening in the dry plains – cities like Colorado Springs and Aurora are buying up water rights in the Lower Arkansas Valley. This gives the farmer or rancher who sells the water a onetime big infusion of cash, but it affects the entire community by reducing the economic foundations on which it survives. Because water rights are a commodity just like corn or cattle, they can be sold, usually to the highest bidder. The City of Colorado Springs established this concept legally in the 1890s when the Colorado Supreme Court confirmed that water rights the city bought from farmers were a commodity that could be bought and sold and that the uses of the water could change in accord with needs (Doyle, 2018). The cities along the Front Range have considerably deeper pockets than the farmers or communities where much of the water has been historically used. This trend will probably continue into the future with potentially dire consequences for these small communities.

There always has been a water conflict between farmers and ranchers whose livelihoods depend on water for irrigation and cities and towns whose residents also need water. As of 2013 agriculture had 86% of all water rights in the state. Domestic use was 7% with recreation and fisheries, industrial, augmentation and/or aquifer recharge making up the remaining 7%. But in times of extreme shortage, there is a "domestic Preference" article in the Colorado Constitution. Basically this states that municipal (domestic) use of water takes precedence over any other use and that agricultural use takes preference over industrial or commercial use. This clause in the Constitution has only been used once. It is a very rare occurrence, but with climate change looming over the region, we could easily see these preferences enforced.

One might also ask, don't the ecosystems in and along the natural waters of the state get anything? When Colorado's water laws were being created in the 19th century, there was little concern for the environment. The idea that we could ever use up resources in the largely untamed West seemed absurd. But as we have seen, the resources of the region are limited and certainly are not overly abundant. From timber, to industrial minerals, to oil, and certainly to water, we have already or soon will reach the limits of extraction. But we have also developed a new concern and vision for the natural environment, and an understanding that a healthy earth is actually good for business. A very large part of Colorado's economy comes from tourism, and free flowing streams are a big part of that industry. Fishing, rafting, hunting, hiking, and other activities depend on functioning and healthy aquatic and riparian ecosystems. The Federal government has created a myriad of laws that focus directly on environmental stewardship including, but not limited to, the Wilderness Act, the Clean Water Act, the Endangered Species Act, the National Environmental Protection Act, and many others. Colorado also has recognized the importance of water for the environment. In 1973 the legislature passed Senate Bill 97 that created the state's Instream Flow Program. This program did not 'allocate' water from the state's streams and rivers, but allowed, even encouraged, the Colorado Water Conservation Board to obtain water rights for flows that would remain in the stream versus water rights for water diverted from a water course. Over the years the Board has been allocated some funding from the state to buy water rights. Since 1973 about 30% of the stream miles in the state have gotten some protection under this bill.

Two crucial issues for everyone in Colorado, in spite of the determination that water in Colorado is a public resource, arise because declaring water a public resource for Coloradans does not mean that all the water gets to be used by Colorado. The Federal Government has Reserved Water Rights established in a 1908 Supreme Court ruling (*Winters v. United States*) that deal with water rights that were implied when Native American reservations were established. Basically, the U.S. government retroactively gave water rights to the various reservations dependent upon the dates those reservations were established. This was an obvious ruling by the U.S. government (how could we 'give' the land away with no water rights that make the land usable), but it has caused considerable argument over the years. In another Supreme Court ruling in 1907 (*Kansas v. Colorado*), the Federal Government also determined that the natural water courses of our rivers in Colorado have always gone through the lands of other states and, in the case of the Colorado River and the Rio Grande, to Mexico also. That means that these downstream political entities should legally get their equitable share of the water in those rivers. The definitive statement in that case is "… that the upper state on such a stream [that crosses state lines] does not have such ownership or control of the waters flowing therein as entitles her to divert and use them regardless of any injury or prejudice to the rights of the lower state in the stream." This means that even though almost all of the water in our four rivers falls as rain or snow in Colorado, the water in those rivers partially belongs to states (and countries) downstream – meaning we have to share. In another Supreme Court case (*Wyoming v Colorado*) in 1922, the Court ruled that the law of prior appropriation actually was in place between states not just within states. If there were a senior water right in Wyoming (maybe on the North Platte), no one in Colorado with a junior right could usurp the Wyoming water user rights. Every one of the states that border Colorado and into which our rivers flow, have some form of prior appropriation water law. So this court case applies to all of the surrounding states just as it does to Wyoming. All four of our rivers, and several of the smaller rivers and streams that leave Colorado, also have compacts, equitable apportionment decrees, and/or treaties with the states and/or Mexico downstream (see **Compacts** chapter). Colorado water law only deals with the water that Colorado gets to keep from our precipitation – our equitable share according to the U.S. government. All the other water must be allowed to flow downstream to users in other states and/or Mexico.

Sometimes we literally run out of water in certain places in the state. Often the reason is an environmental one: there is not enough precipitation to fill the creeks and streams; aquifers are drying up; temperatures are above normal where evaporation and transpiration are higher than normal; or, some other occurrence. Sometimes it is because we have created too many water rights in a location – this happens when rights are adjudicated during wetter periods, and during normal or dry periods there is just not enough water to go around. In either of these cases we say that the water resource has been over-appropriated. In strict terms it means that we cannot have new appropriations without affecting more senior water rights. Sometimes it happens when we use too much and do not have enough to fill water compacts with other states (see **Compacts** chapter). For nearly the last 50 years the Rio Grande, South Platte, and Arkansas Rivers have been close to or at over-appropriation levels. This situation has caused a series of actions to help alleviate the critical need for water. In all of these basins, there has been a dramatic increase in groundwater use, often drawing down the water levels in the states aquifers at alarming rates. There are legal ways to help address the over-appropriation including water exchanges and augmentation plans. But the reality is that there is only so much water to go around, so one of the most useful measures to alleviate the situation is through greatly increased water conservation efforts. Many cities and towns have introduced strict measures for water conservation, and these actions have been made more restrictive during recent severe drought conditions. In the foreseeable future greater conservation measures will need to be undertaken, especially by the agricultural industry. Agriculture uses the largest portion of the state's water by far. We need to keep this industrial sector as an important part of the economy of the state, but really important decisions need to be made soon so we can face the reality of less water for more people in Colorado.

Colorado water law is complex in the extreme – and this chapter has just hit the highlights. Topics that are important to Colorado law that have not been covered include consumptive use, non-consumptive use, surface and groundwater return flows, water exchanges, water banks, storage rights, conditional water rights, and many others. Water law in the state is an organic concept -- it grows and changes much faster than a well-watered Ponderosa pine in the mountains. Dozens of court cases and an equal number of laws have been added to the original parts of the Colorado constitution. Keeping up with the 'fine print' of the law as it stands today is a Herculean task only undertaken by water lawyers and the judiciary. But there are two accessible resources available to the non-lawyer to get a deeper understanding and appreciation for our water law: The *Citizen's Guide to Colorado Water Law* by Hobbs and *Synopsis of Colorado Water Law* by Grantham.

Water law as it is practiced in Colorado has a tremendous impact on our four rivers. The past has seen innumerable diversions of water from the stream channels of the rivers, increased impoundments of their waters in reservoirs, some protection of flowing waters in the river beds, and diversions of western slope waters to the dry Front Range and eastern plains. But the future of water law in the state is going to have to become more flexible and creative to deal with what is coming. Even if we preclude the effects of climate change, Colorado's population is growing rapidly without any sign of a slowdown. And it is growing in some of the driest areas. Can we keep growing crops that require large inputs of water, can we keep fracking for oil and gas that permanently removes large amounts of water from natural water supplies, is it possible for us to develop the oil shale of the western slope; or, can we increase the urban populations along the Front Range with their blue grass lawns? These and other questions will take some collective wisdom to answer. But we will have to deal with climate change on top of these other serious issues. In all likelihood the state will have significantly less water overall to use in the next several decades. Planning for these eventualities needs to be done. There is some movement in this direction – for example the just released *Colorado's Water Plan* (2015) asked for by the governor is a good start. It looks at where we are, where we need to go, and enlists cooperation, not conflict, in basin specific plans. Water is critical to all life, and the importance of it cannot be overstated.

Diversions

Diversions, or more precisely, transmountain (or transbasin) diversions is a very sterile and technical term for the often messy, contentious, expensive, controversial, and highly political process of taking large amounts of water from where it originated and moving it to another place that has a real or perceived need for the water. In Colorado these massive water transfers have been happening for well over one hundred years, mostly taking water from the western side of the mountains to the eastern side. At the beginning they were small (the Ewing Ditch and the Grand River Ditch as examples), but as the population and economic power of the Front Range increased many-fold, the diversion projects and the amount of water they moved grew exponentially. As we have seen in other chapters and as we often experience when living in Colorado, there is most often not enough water to do all we would like. The part of the state west of the continental divide has most of the precipitation and therefore, most of the river flows. In fact about 84% of all water in Colorado that falls as rain, or more likely as snow, falls on the Western Slope. This is good for those who live west of the divide, unfortunately nearly 80% of the state's population lives, works, and farms east of the divide.

There are seemingly an infinite number of demands on the waters of the Western Slope. Downstream states demand and are legally accorded large portions of the streams and rivers that leave Colorado by federal law and numerous Supreme Court decisions. The Colorado River Compact of 1922, the 1948 Upper Colorado River Basin Compact, and the 1944 Mexican Treaty are only the most major of these legal mandates and agreements for the water of the Colorado River basin. There are also the water rights that cities, farmers, mining companies, ski areas, mandated instream flows, and many others own. As discussed in the **Law** chapter, if a person or organization owns water rights in Colorado, they have the legal right to move that water away from its origin to a place where it can be put to "beneficial use" even if that means going under or over mountain ranges to do so. The current population of Colorado is just over 5 million with that number expected to increase by at least 2 million in the next twenty years. By 2050 the population is projected to reach 10 million, with the vast majority of those additional people living along the already thirsty Front Range. As long as more water exists west of the Divide and entities east of the Divide have the rights to a portion of that water, transmountain diversions that move massive amounts of water for 'beneficial use' will be a part of the Colorado landscape. There currently are already 27 transmountain diversions in Colorado (Figure 1).

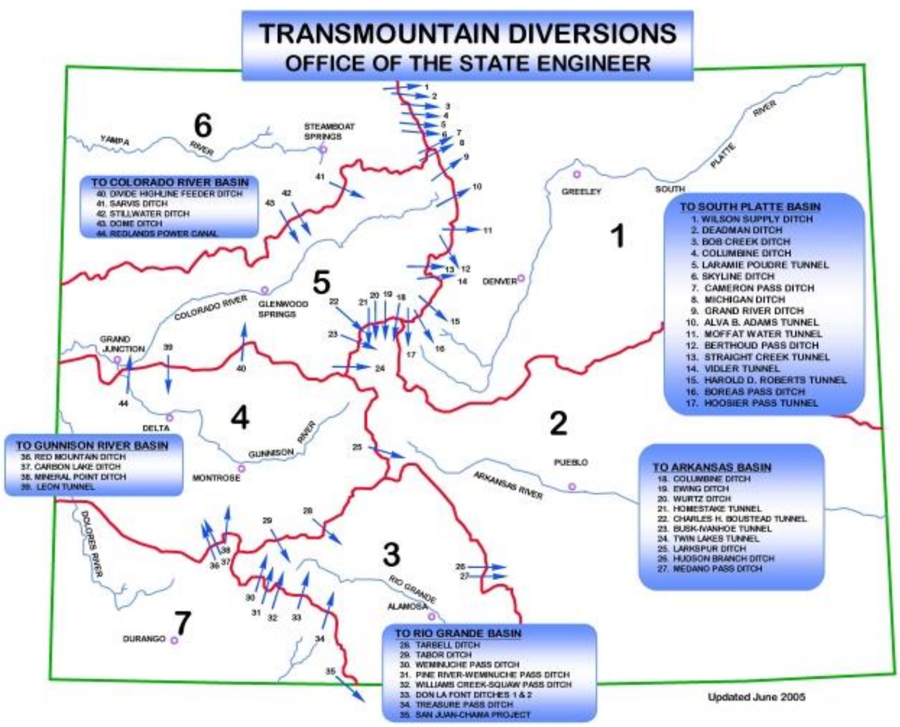


Figure 1 – Map of Colorado's transmountain water diversions. (courtesy of Office of the Colorado State Engineer)

The first transmountain diversion in Colorado was the Ewing Ditch that takes water from Piney Gulch, a tributary to the Eagle River on the western side of the Continental Divide, over Tennessee Pass to the headwaters of Tennessee Creek (Figure 2). Tennessee Creek is also known as the West Fork of the Arkansas River. The West and East Forks of the Arkansas River come together just to the west of Leadville at Leadville Junction. This early ditch was also called Ewing Placer Ditch, probably because the water moved was originally used for placer mining in the upper Arkansas Basin when the diversion was built in 1880. The ditch is still used and transfers an average of just over 1,000 acre-feet of water per year from the west to the east side of the Divide.

Figure 2 – The Ewing Ditch – the oldest transmountain diversion from the western slope over Tennessee Pass to the eastern slope.

The second oldest diversion taking water from the Western Slope to the Eastern is considerably larger and more controversial than the Ewing Ditch. The Grand River Ditch, more commonly known as the Grand Ditch, first built in 1890 and lengthened several times until its final completion in 1936 carries more than 17,000 acre-feet of water directly from the headwaters of the North Fork of the Colorado River over La Poudre Pass to Long Draw Reservoir on the east side of the Divide (Figure 3). Most of its current 14.3 mile length lies inside Rocky Mountain National Park. The National Park was established in 1915, and every extension of the ditch after that date needed Congressional approval. A very large part of the runoff of water from the Never Summer Mountains in the Park goes into the Grand Ditch. This loss of water for the ecosystems of that part of the park has impacted the environment for over a hundred years and the park has fought many court battles to try to reduce the amount of water taken from the headwaters of the Colorado in this area. There have also been several overflows and breaches of the ditch that have caused considerable damage to drainages and creeks in the Park. In 2003 a very large breach caused over 45,000 cubic yards of debris to be deposited in Lily Creek, one of the highest tributaries to the Colorado River. The owners of the ditch paid a substantial settlement to the park for the damage done.

Figure 3 – The Grand River Ditch (also known as the Grand Ditch) at the Continental Divide in the far northwestern corner of Rocky Mountain National Park.

Of the total of 27 diversions that take water from the west side of the Continental Divide to the east side in Colorado including the Ewing and Grand Ditches, fifteen carry less than 2,000 acre-feet of water a year – seven of these small diversions take water from the Dolores/San Juan Rivers (part of the upper Colorado Basin) to the Rio Grande River Basin. Seven large diversion projects carry more than 25,000 acre-feet per year from the West Slope to the East Slope – six of these large diversions move water from the Colorado basin over/through the Continental Divide to the South Platte or the Arkansas River Basins (Coleman, 2014, p. 9) (Table 1).

Table 1 – Major (> 25,000 acre-feet/year) Transbasin Diversions in Colorado

Name	Contributing Basin	Receiving Basin	≈Average Annual Flow (acre-feet)
Alva B. Adams	Colorado River	S. Platte River	215,000
Moffat Tunnel	Upper Colorado	S. Platte River	50,000
Harold D. Roberts	Blue River	S. Platte River	58,000
Homestake Tunnel	Upper Eagle R.	Arkansas River	25,000
Charles H. Boustead	Fryingpan River	Arkansas River	50,000
Twin Lakes Tunnel	Roaring Fork	Arkansas River	40,000
San Juan-Chama	Rio Blanco	Rio Grande	90,000

The largest of all diversions within the state is the Alva B. Adams Tunnel and its extensive infrastructure collectively known by its more formal name of the Colorado-Big Thompson Project with the Windy Gap Project being a smaller part of the overall system. This project is arguably also the most complex politically, economically, and physically of all the transbasin diversions in Colorado. Initial discussion and surveys began for the Colorado-Big Thompson Project (CBT) in 1933 and the final project was not completed until 1956.

The CBT was born from the realization that John Charles Frémont was right in 1842 when he said that the plains just east of the Rocky Mountain front could be fertile cropland if given some water. When Horace Greeley urged young Americans to go west to find their future and the Union Colony was created near the future site of Greeley, the vision of Frémont and of irrigation ditches watering productive fields became a reality. But soon after the Colony began its irrigation of what eventually would become about 12,000 acres using water from the Cache la Poudre River, others flocked to join what they hoped would be an agricultural bonanza in the potentially verdant South Platte River Basin. That hope, if not dashed was at least somewhat dimmed by the lack of additional sources of water for the ditches. The complex and audacious idea for bringing some of the relatively abundant water from the West Slope to the South Platte River Basin in the east emerged. The Grand River Ditch over La Poudre Pass at the Continental Divide was a first, small start, but the farmers of the eastern plains had much bigger irrigation dreams.

Early plans for a much more massive diversion project to move water from the west to the east side of the mountains came to little. An 1889 planning effort funded by the Colorado legislature to get water from Monarch Lake on the west side to St. Vrain Creek on the east ended with minimal effect. The newly formed U.S. Reclamation Service in 1904 proposed a twelve-mile tunnel from Grand Lake to the Big Thompson River that met the same fate – it languished in bureaucracy and resistance. In 1915 Rocky Mountain National Park was established in a location that one might think was deliberately meant to block any project moving water from the Grand Lake area to the east. National parks have very strenuous environmental rules, even back in 1915, which would preclude many of the schemes for a major diversion through the Park. But the bill that authorized the park also included language that specifically would allow the Reclamation Service to use whatever resources within the park that would promote the development and maintenance of a federally sponsored government reclamation project. This set the stage for the events that took place in the decades that followed.

The dry years of the Dust Bowl began in Colorado in the mid-to-late 1920s. As the weather got drier and the crops began to wither and fail, U.S. Senator Alva B. Adams of Colorado started to push for federally sponsored resources to move water from the upper Colorado River to the eastern slope and the South Platte River basin. Once the Roosevelt administration took office and began the ‘New Deal’, the proposed project took on new life and rapidly gained momentum. An informal group of promoters of the project centered their efforts around a core of strong supporters in Greeley and surrounding places. This group eventually took on a more formal status as the Northern Colorado Water Conservancy District. This local group, Colorado state government, and the federal government all backed the idea of a massive transbasin diversion. But, as might be expected, there was some very stiff opposition from nearly everyone who lived, worked, or represented the part of Colorado west of the divide.

Colorado Congressman Edward Taylor was the leader of opposition to this, and most, transmountain diversions taking water from west to east. He wanted to preserve the Western Slope’s future for their own water development and initially insisted that to do a diversion, the western slope would need “an acre-foot per acre-foot” compensation. Needless to say, the west side of the divide had much less economic and political power so Taylor and his allies settled for a compromise that included the building of the Green Mountain Reservoir on the Blue River just upstream from its confluence with the Colorado River near Kremmling. This reservoir would supply water to western slope users only. With more machinations and convolutions that are too numerous to outline here, the Bureau of Reclamation (renamed from the older U.S. Reclamation Service) and the Park Service ironed out differences and in 1937 Congress began funding for the rechristened “Colorado-Big Thompson project” (CBT) (Autobee, 1996).

Funding for the project was split between the federal government and the users of the water east of the divide, especially the Northern Colorado Water Conservancy District. The local costs were mostly offset by the sale of electricity generated from several dams throughout the CBT. Construction began in 1938, but many delays occurred, not the least of which was the advent of World War II. The project was considered, or at least argued to be, so important that in 1943 the varying organizations at the federal level decided the work on CBT was critical to the war effort, so work recommenced. It was not until 1957 that the full water volume (about 215,000 acre-feet per year) planned for the project started to be delivered to the dry fields of the east.

What infrastructure does it take to help irrigate 720,000 acres of farmland up to a hundred miles and one giant mountain range east of where the water exists naturally? The answer is a very complex, highly integrated, and very well-engineered one. The first major piece of the construction puzzle was the Green Mountain Reservoir (Figure 4). There were probably some engineering reasons that this storage facility came first, but it was also to assuage the West Slope interests and ensure them that their concerns would not be laid aside over time. On the west side of the divide, several other reservoirs and linkages between reservoirs were needed. Landowners on and near Grand Lake, the largest natural lake in the state, insisted all along that the lake levels could not vary as they do in almost any reservoir. So a system of other reservoirs, pumping plants, canals, and gravity feeds was created to keep the natural Grand Lake natural. Granby Reservoir was the largest of the reservoirs and the pumping station built there took water from it uphill 125 feet to Shadow Mountain Reservoir (both of these un-natural water bodies are now called lakes). Shadow Mountain connects to Grand Lake and keeps it at the required level. The actual diversion of the water to the Alva B. Adams tunnel is from Grand Lake and the water flows through the tunnel by gravity alone until it reaches the eastern side of the mountains above Estes Park.

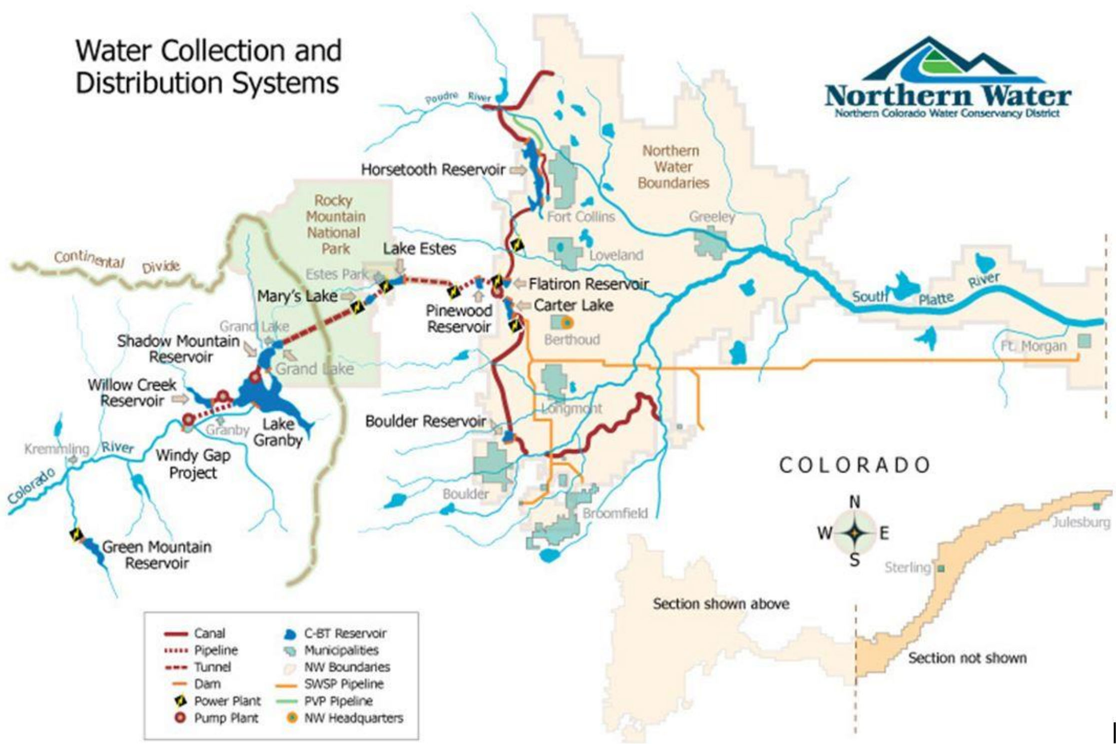


Figure 4 – Schematic map of the Colorado-Big Thompson project (courtesy of the Northern Colorado Water Conservancy District)

On the east side there are siphons and a power plant at Mary's Lake from which the water continues downhill to the Estes Power Plant and then on to Lake Estes held back by the Olympus Dam. More diversions, canals, power plants, tunnels, and reservoirs are located downstream from Lake Estes – some of which use the Big Thompson River but most of the water goes through more tunnels and pipelines (Figure 5). The design of the distribution system and its components on the east side are much more complex and extensive than the collection system on the west side. They include Pinewood, Horsetooth, Flatiron, and Boulder reservoirs. They also include Carter Lake, the St. Vrain, Hansen, North Poudre, Boulder, and South Platte supply canals. A large amount of the CBT water actually ends up in the South Platte River that takes the water to farm fields and irrigation districts far out into the plains east of the mountains. The entire system raises water more than 1,000 feet on the west and drops it more than 3,000 feet on the east (Figure 6). All in all, it is a massive system costing very large amounts of money, effort, planning, and time. It is the largest mover of water in Colorado, but it is hardly the only one.

Figure 5 – Mary's Lake powerplant – a part of the eastern slope infrastructure for the CBT project.

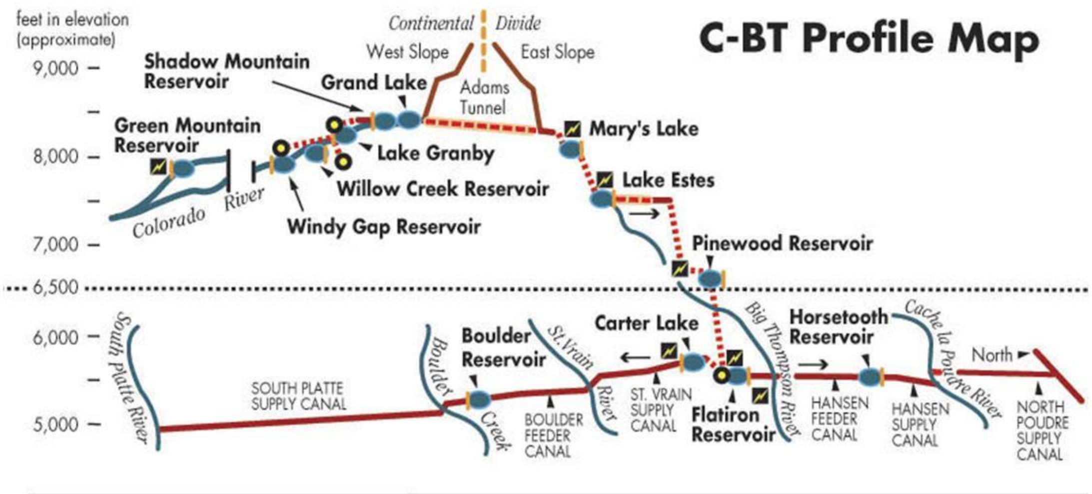


Figure 6 – A profile view of the CBT project showing the elevation changes in the system (courtesy of the Northern Colorado Water Conservancy District)

The CBT project was designed as a single system that served a large number of users – farmers, industry, and several municipalities. The second largest city water system in the state is the Colorado Springs Utilities water system that uses several different transmountain diversion projects that focus water delivery to a single user – William Jackson Palmer established the Fountain Colony in 1871. It was renamed Colorado Springs the next year. As a community on the eastern side of the mountains, it sat squarely in a semi-arid environment, and like any city, needed ready access to clean water. The earliest water supplies for the city came from the south slope of Pikes Peak. Several small reservoirs and tunnels were built that supplied enough water to Colorado Springs to take it into the 1930s. More local water development occurred when the city started putting together the North Slope system of water collection on the Peak including

Crystal and South Catamount reservoirs. The privately held Northfield System that used water from the West Monument Creek watershed was purchased by the city in 1949. But as the city grew, adding population and large government water users such as the U.S. Air Force Academy, it was soon evident that there would not be enough water for the city from these eastern slope sources.

The first transmountain project Colorado Springs developed was the Blue River system in the early 1950s. This project took water from the headwaters of the Blue River and moved it through the Hoosier Pass Tunnel into Montgomery Reservoir on the east side of Hoosier Pass. It then put the water into the Blue River Pipeline that brought the water to storage facilities at Rampart and the newly built North Catamount Reservoirs. As transmountain diversion projects go, this was a relatively small effort that collected and moved only about 8,400 acre-feet of water a year. But it was the harbinger of more massive and complex systems soon to come.

Even as the Blue River system was being built, a much more expansive scheme was being planned in cooperation with the City of Aurora. Both cities owned the water rights to large amounts of water in the upper watershed of the Eagle River – in particular Homestake Creek. The physical needs of a water system bringing Homestake Creek water all the way to Colorado Springs were daunting, but the economic and political aspects may have been even more so. The Homestake Creek watershed is a major supplier of water to the Holy Cross Wilderness area. The initial project was deemed Phase I and captured and delivered over 25,000 acre-feet of water that was split between the two cities. Phase II of the plan was to greatly expand the amount of water from the Homestake watershed, but in 1986 the Eagle County Commissioners denied the land use permit that would have allowed the project to move forward. The two cities sued but the Eagle County decision stood. Colorado Springs and Aurora still owned substantial water rights in the Homestake watershed but had no way of moving that water into their distribution systems. After lengthy legal wrangling and a Supreme Court decision in favor of Eagle County, the Eagle River Memorandum was signed by the numerous interested parties in 1998. This stated that *sometime* in the future, some or all of those existing water rights *might* be able to be used under *certain conditions* (italics added by author). Local agreement about collection points, environmental restrictions, and other issues still need to be negotiated, but someday, more Homestake water will probably make the long journeys to Colorado Springs and Aurora.

In 1972 Colorado Springs purchased majority shares from the private Twin Lakes Company to get much of the Roaring Fork River water the company brought under the continental divide and delivered to the Twin Lakes between Buena Vista and Leadville. Colorado Springs brought this water down the Arkansas River to the Otero Pump station and added it to the Blue River water going to the Springs. This was only the beginning of the complex mix of water rights/sources and conveyance facilities that the city has developed over the last 50 years to supply its water needs.

Since the late 1970s Colorado Springs has been a partner in the Bureau of Reclamation's Fryingpan/Arkansas project that brings water through the Charles H. Boustead Tunnel from the Fryingpan River, a tributary to the Roaring Fork, into the Arkansas River and the Pueblo Reservoir. Colorado Springs built the Fountain Valley Conduit to carry a portion of this water north and uphill to the city, but this relatively small conduit could not carry all of the varied water rights water owned by the city that ended up in the Pueblo Reservoir. After decades of controversy, lawsuits, litigation, and negotiation, the large Southern Delivery System project from Pueblo Reservoir north to the Springs was finally completed in 2016 to carry most of the remainder of the water Colorado Springs had the rights to into the treatment and distribution systems serving the community.

The city also added some complex water exchanges to this mix that they agreed to with the Colorado Canal Company and others who owned water rights in the eastern reaches of the Arkansas River. This last piece of the multifaceted system is euphemistically called “buy and dry” for its buying up of water rights of farmers, in this case in the Arkansas Valley, and transferring the water from farm to city. Many organizations and agencies are trying to work on ways that the resultant abandonment of irrigated farms in some of the communities along the Arkansas and other rivers and streams can be mitigated. There is a long list of ways that water rights can be exercised and water moved from one point to another, and Colorado Springs has used most of them. Figure 7 is a synopsis of the Colorado Springs water system which is duplicated in extent if not in exact details by other cities in Colorado, especially Denver and its famous (or infamous) Denver Water – the city’s organization responsible for procuring water for the City of Denver.

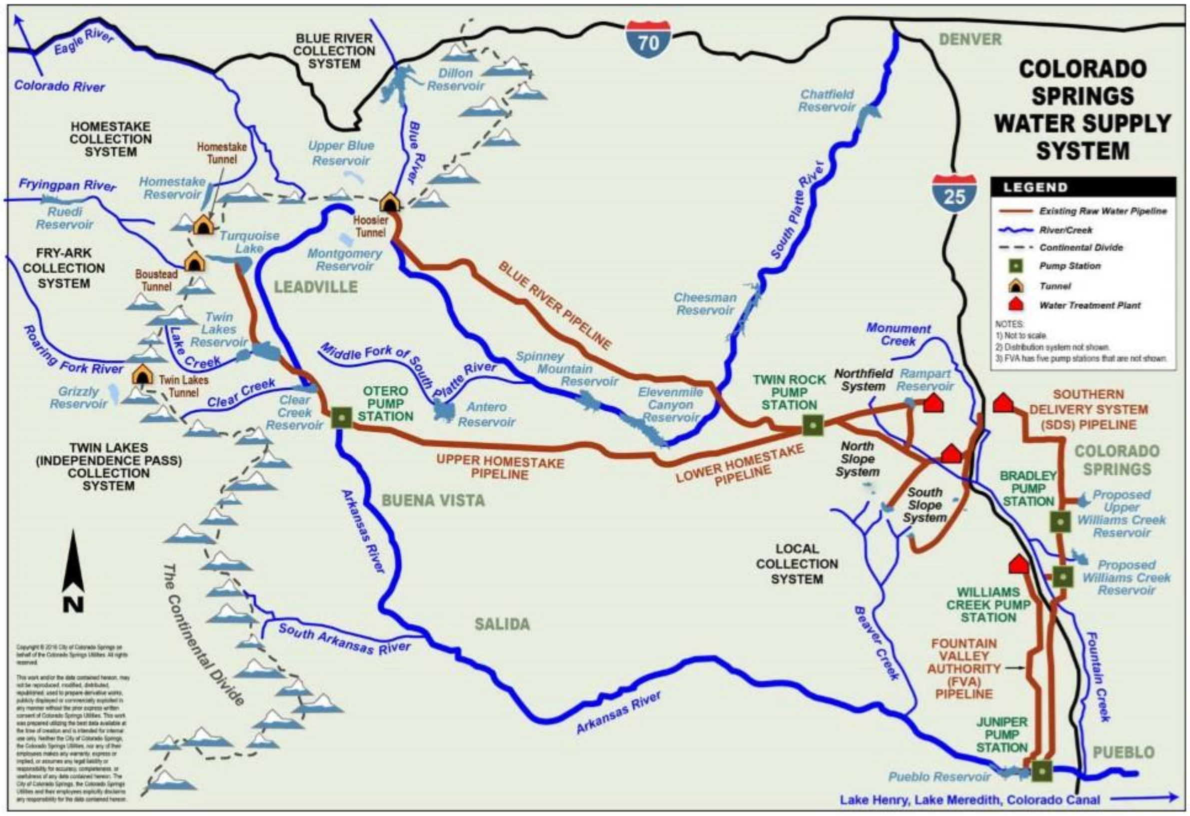


Figure 7 – Map showing the extensive water system for the City of Colorado Springs (under License from Colorado Springs Utilities).

Of all of the Eastern Slope owners of Western Slope water rights, Denver Water might be the most notorious for its aggressive tactics in getting the diversions necessary to move their water over/under the divide. Over the decades Denver Water has used what many would consider intimidation by legal means at best and bullying at worst to get their water from western slope sources. A decision by the U.S. Environmental Protection Agency in the 1980s might have been the first successful chink in the armor of Denver Water. Denver Water proposed the Two Forks Dam on the South Platte River downstream from the little mountain town of Deckers. The dam would have flooded a very large part of the South Platte Valley in the mountains and foothills west of Denver that included big sections of Gold Medal trout fishing habitat. For a variety of reasons, the EPA concluded that the dam would be an “environmental catastrophe” and disapproved the permit. This rejection by EPA was a turning point for Denver Water. They have moved more toward negotiation and compromise in recent years.

One clear and important example of this new, more cooperative strategy is what occurred in 2014 among Denver Water, Grand County, and others in connection to the Fraser River – a major tributary to the upper Colorado River. Denver Water owned substantial rights to water in the Fraser. Before this time Denver had been taking some of its water from the river, but there were many thousands of acre-feet it still had rights to that it could not yet move. Over a number of years, an agreement was reached that provided Denver Water with some flows, mostly during the spring melt season. There were significant restrictions during other seasons and in times of reduced flow from drought. In a statement made by Jim Lochhead, CEO of Denver Water, “We’re not going to be diverting water all the time. We won’t divert water in critically dry years, and we’ll only divert water during the spring runoff. At other times of year, we’ll put water back into the [Fraser] river and improve conditions” (Berwyn, 2014).

Two other issues involving water rights and diversions are less understood, but no less important than those discussed above. The first issue deals with the arcane concept of “return flows” in Colorado water law. Return flows are flows that return to a stream after being put onto irrigated fields. The crop being irrigated certainly uses a large part of the water, but some of the water added to the field runs off on the surface and ends up back in the stream/canal from which it came. Another small but important part of that initial irrigation water soaks into the ground and ends up in the ground water table – it eventually resurfaces and enters the original canal or stream or some other watercourse downslope. Either way these return waters have owners of the rights to them allowing them to use the same water from the original source over (and maybe over) again. With transmountain water transfers, the return water has no one who owns the rights to them, and therefore, the water can be used "to extinction" since there is no one downstream who owns those water rights. This means that the people who own rights on the western side of the divide from where the original water came do not get the benefits of return flows. Legal opinions have made it clear that the owners of water rights taken from the source in the west and used in the east do not have to account for the return flows that would have occurred if the water had stayed in its original basin. The potential water users in the west not only lose their original flows but also their return flows which are substantial. Predictably, this double jeopardy is viewed as legal and proper by those who have moved and are using the water on the Eastern Slope and as unfair and unjust by those on the Western Slope.

The second issue is the question of who suffers the impacts the most from transmountain diversions. For the most part the impacts of diversions affect those areas of the contributing watersheds that are closest to the divide more than the more major streams downslope. Most water is not taken from the main stem of the Colorado River, for example, but from the smaller tributaries upstream. In our examples that means the water is removed from streams such as Homestake Creek, the upper reaches of the Fryingpan and Roaring Fork Rivers, the Fraser River, Lily Creek, and other lesser watercourses (Figure 8). The taking of relatively large amounts of water from relatively small streams impacts aquatic and riparian ecosystems near the headwaters disproportionally to their ability to withstand the removal of the water. In addition to an overall reduction in flows for these small streams, it can have the very negative effect of permanently changing the water temperatures of the streams. This may sound trivial but is seriously important for native species of plants and animals that have evolved to adapt to certain temperature levels of the water. Other water quality issues are also important as there is less water in these upper reaches to dilute pollutants that enter the streams. And there are changes in aquatic and riparian habitats including impacts on endangered species in these ecosystems that line the small watercourses near the divide. There are also major issues for local economies of the communities that make much of their living from tourism and recreation that depend on these headwaters for fishing, hunting, and other activities.

Figure 8 – Homestake Dam and Homestake Creek – part of the Colorado Springs water system.

Water transmountain diversions are not a thing of the past, but the way they have been accomplished may be changing. With more interest in environmental issues, more development on the western slope, more rapid population growth in Colorado and especially along the Front Range, brute force litigation over water issues probably is going to diminish and be replaced by more diplomacy, conciliation, and cooperation. Add to this mix the very real influence that climate change is going to be making on the Southwest in general and Colorado in particular. There are going to be more and more demands put on a system that is going to have less and less water. And most precipitation in Colorado will still be to the west of the Divide while most of the people will be to the east. Considering the needs of all of Colorado's people and natural resources will be the only way to assure that we can maintain Colorado as the place that it is. The Colorado Water Plan initiated by Governor Hickenlooper and finalized in 2015 is an important start in dealing with these issues (see the chapter on the **Water Plan**). This plan hopes to take all the issues that all stakeholders (that means every resident of the state) have and work to solve them where possible and mitigate where it is not**.** The plan specifically outlines seven principles for future transmountain diversion proposals. These principles include the need to consider the environmental needs; the role of conservation and reuse of water; and the idea that western slope needs will be accommodated for any future projects. It is an interesting and hopeful document and should be required reading for all of Colorado (*Colorado's Water Plan*, 2015).

Compacts

The U.S. Supreme Court Decision in *Kansas v Colorado* in 1907 put the 'almost' final and 'sort of definitive' nail in the coffin of Colorado thinking it could keep all of the water that falls on its land for use in Colorado. The decision stated that all the major rivers (especially our four) have always flowed through the states downstream and that these states are accorded their rights to some of the water. The opinion is "almost" and "sort of" because in the next century, there were innumerable local, state, and federal court cases, equitable decrees, memoranda of understanding, treaties and compacts that added to and altered the ways we share and divide up water in the West. By law and logic, the federal government is the legal entity responsible for deciding water issues between and amongst states and with foreign governments since together all of our rivers flow through 18 other states and Mexico. In fact there are three very specific ways the feds can solve controversies between states. First, there is direct legislation by Congress; in essence Congress has the ultimate power to decide issues between states. The second method is through lawsuits between and among states that get to the U.S. Supreme Court as stipulated in Article III of the U.S. Constitution. The results in court cases are often not totally satisfying to either party, and in some cases the court may not even make a definitive decision. The third method, and the one that is most used and understood, are compacts resolved and written by the states involved with federal approval. The idea of compacts is specified in Article I of the U.S. Constitution, and with Congress' approval states can negotiate these compacts that are binding and help preclude and reduce (but not necessarily stop) other litigation. Because Mexico is a sovereign country, water issues with it are negotiated through treaties.

The "godfather" of Colorado water compacts with other states was Delph Carpenter. Many consider him the innovator who came up with the idea of water compacts between states to solve issues before they turned into litigation – the equivalent of legal war over water. Carpenter was a Colorado State Senator from 1909 to 1911 and a descendant of some of the initial irrigators in the state at Union Colony near Greeley. When he left the Senate, he became Colorado's go-to person for water issues with other states. He represented Colorado in the U.S. Supreme Court case of *Wyoming v Colorado* in 1922. He then took his ideas of water compacts between states to the table in the negotiations amongst Colorado, Utah, Wyoming, New Mexico, Arizona, Nevada, and California over the water in the Colorado River and its basin. A quote from the 1922 Colorado River Compact states succinctly the reasons Carpenter and the other states' negotiators came to this historic agreement:

> The major purposes of this compact are to provide for the equitable division and apportionment of the use of the waters of the Colorado River System; to establish the relative importance of different beneficial uses of water; to promote interstate comity; to remove causes of present and future controversies; and to secure the expeditious agricultural and industrial development of the Colorado River Basin, the storage of its waters and the protection of life and property from floods.

Most of the compacts discussed below could use almost identical wording as to why the compact was established in spite of the fact that each compact for each of our rivers is a unique document with a multitude of ways to satisfy these "purposes." The history and wording for each of the compacts for our four rivers is different and unique in their own ways. Looking at them in some detail helps us to put into perspective what we know about Colorado water and how we are part of the larger community of the West.

Although the Rio Grande drains the smallest area (~ 8,000 square miles) of Colorado by far of our four rivers, it is the longest river (1,896 miles) beginning in Colorado. Its small size does not diminish the battles over the water that is used by farmers and ranchers in Colorado's San Luis Valley and allocated downstream to New Mexico, Texas, and Mexico. Much of the area that the Rio Grande drains in Colorado is in the San Luis Valley (~3,200 square miles), the only true desert region in the state with an average precipitation rate between seven and eight inches per year. In spite of the arid climate of the Rio Grande basin in the San Luis Valley, up to 600,000 acres of farm land is irrigated every year and 200,000 acres of the valley floor are in wildlife sanctuary wetlands such as the Baca, Alamosa and Monte Vista National Wildlife Refuges.

The 1938 Rio Grande Compact was finalized only after years of conflict and acrimony (Figure 1). By 1937 a comprehensive federal study of the water in the river system found that even at that early date, the river was already over-appropriated – it was difficult if not impossible to start new water uses without diminishing the water of users already in the system. In the years leading up to the study, Congress had, for a variety of reasons, repeatedly set embargoes in place that stopped reservoir development in New Mexico and Colorado. In 1905 the Bureau of Reclamation started the Rio Grande project which was designed to provide irrigation water for the lower Rio Grande Valley in New Mexico and the upper part of the Valley in Texas. Elephant Butte Reservoir was completed in 1916 as part of the agreement. The 1938 Compact made liberal use of the

Elephant Butte Reservoir in its provisions. Because the river is so variable in its flows, the Compact basically states that when the river is low during drought conditions, less water needs to be released by Colorado; when the river is high in a wet year, more water needs to be released. Both the Rio Grande and its principal tributary in the San Luis Valley, the Conejos River, are regulated separately. A very key provision in the Compact that has affected the Valley and will continue to do so in the future is that any deficit that Colorado provides to the lower basin states must be made up for in reductions in surface water irrigation by the users in the Valley. This provision is having a significant affect on the farmers in the Valley today and into the future.

Figure 1 – Rio Grande Compact Map

Because the surface water in the basin is over allocated, the water available to provide downstream water rights is almost always in deficit. A very complex, costly, and controversial fix to the problem starts in what is called the Closed Basin. From around 3 million years ago until 440,000 years ago (a short time geologically), most of the San Luis Valley was covered by a very large, shallow lake that we now call Ancient Lake Alamosa. This lake was dammed at the southern end of the valley just north of the New Mexican border by a series of volcanic hills. Evidence of its breaching can be seen near those hills, and depositional evidence of the lake's existence can be found throughout the flat terrain in the valley. These lacustrine, or lake, sediments have a particular pattern that could only be made by suspended sediments slowly coming out of suspension and creating very flat lying, fine deposited material. At this earlier time the valley was basically a flat plain tilted ever so slightly south. During the nearly 2.5 million years of the lake's existence, the Rio Grande rapidly eroded the unconsolidated glacial sediments formed in the San Juan Mountains and carried this material into the valley exiting the mountains near what we now call South Fork. As the river's velocity slowed when it hit the flatter topography of the valley, much of the load of river sediments was deposited along and next to the course of the river. These riverine or fluvial sediments produced a low ridge just high enough to block water flowing south from the northern third of the valley. This area north of the low ridge is now what we know of as the Closed Basin. Surface water does not escape from the basin. This basin with no outlets would soon become a lake in most environments, but the Valley's low rainfall precludes that from happening.

The surface of the Closed Basin is a desert, but below ground are huge aquifers that hold billions of acre-feet of water, and the water in these aquifers slowly moves south and becomes underground tributaries to the Rio Grande over long periods of time.

The aquifer system in the closed basin is complex, but basically there is an unconfined aquifer just below the surface – it even comes to the surface at the San Luis Lakes as the surface of these lakes is the top of the "underground" water table. There is also a much deeper confined aquifer. A confined aquifer means that there are impermeable layers of sediments, usually clay, both above and below the aquifer. Recent research has shown a possible connection between these two aquifers, and therefore both are considered "tributary groundwater" by the State Engineer and the signers of the Rio Grande Compact.

The soils in the San Luis Valley are actually quite fertile – add a little (or a lot of) water, and agriculture can be a very viable industry. In fact at any one time there are between 485,000 and 600,000 acres of farmland irrigated in the Valley. Aside from traditional acequia or irrigation ditches in many of the Hispanic communities in the south of the Valley, most of these irrigated acres are wetted by center pivot irrigation rigs attached to wells of various depths depending on which aquifer is being tapped (Figure 2). Since 1976 there has been so much groundwater withdrawal in the Closed Basin, the quantity of groundwater has deceased in the unconfined aquifer there by 1.2 million acre-feet. So much water is being removed that the flows of the Rio Grande are being altered. There are also nearly 3,400 wells drilled into the unconfined aquifer that adds to the lowering of flows in the river. Needless to say, reduced flows in the Rio Grande as it flows south out of Colorado to New Mexico, Texas, and Mexico have those entities very concerned over the lack of Colorado's adherence to the Compact. In many years Colorado is actually in deficit to its obligations to provide water to the downstream users.

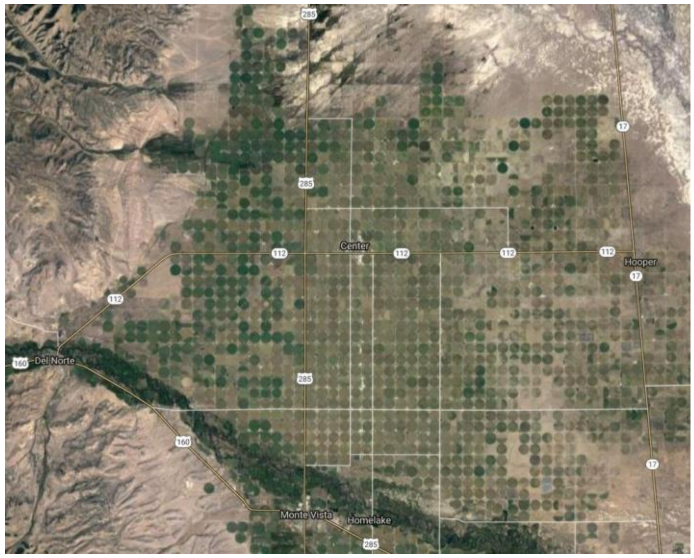


Figure 2 – A USGS satellite image of the extensive center pivot irrigation in the northern part of the San Luis Valley (courtesy of http://earthexplorer.usgs.gov/).

A partial yet substantial solution to this dilemma is the "Closed Basin Project." According to the U.S. Bureau of Reclamation, the overseer of the project, the purpose of the project is to "… salvage unconfined ground water and available surface flows in the Closed Basin that would otherwise be lost to evapotranspiration… ." This salvaged water is pumped from the area near the San Luis Lakes into a 42 mile-long channel to the Rio Grande. It also provides water to the Alamosa National Wildlife Refuge and the Blanca Wildlife Habitat Area. These two wildlife areas provide for groundwater replenishment as some of the waters in them soaks back into the unconfined aquifers below. The system for the project is complex with several observation wells used to monitor aquifer levels, lateral pipelines, a conveyance channel, and other structures that help to keep the balance of water use in check as battles over reduced water availability are waged in and between the states. Of course there is only so much water, so as the unconfined and confined aquifers are slowly depleted, decisions and compromises and legal battles will be the water future in the San Luis Valley.

In the early 19th century, most of eastern Colorado was either considered home to several Native American tribes including the Cheyenne, Arapaho, and Ogallala Sioux and therefore a difficult environment to settle, or it was considered too harsh a place to be used for anything related to agriculture. In 1820 Major Stephen Long led an expedition upstream along the South Platte and then southward paralleling the Front Range. Long's botanist/geologist was Edwin James, one of the first real scientists to accompany a U.S. sanctioned exploration in the West. James was not impressed with the landscapes of the eastern plains and coined the term "Great American Desert." A mere 23 years later, John C. Frémont saw the landscapes of the plains in an entirely different light; he saw that they were drained by innumerable streams capable of making this an important agricultural area. It seems in hindsight that Frémont was right (Figure 3).

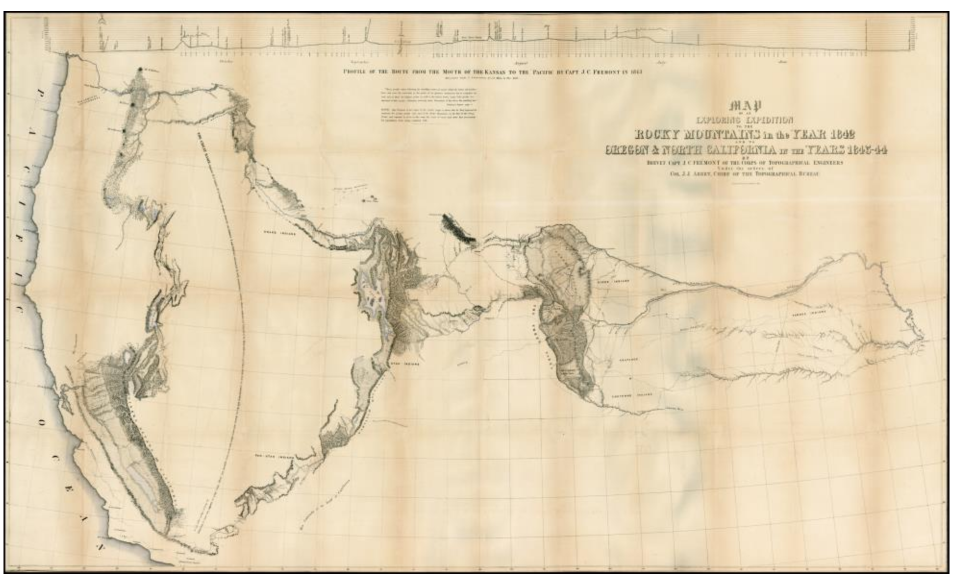


Figure 3 – A portion of the John Frémont map of the South Platte Basin in 1842-1844 (Fremont, 1845)

Over the years since 1843, the South Platte River and its basin have arguably become the most exhaustively used water source within Colorado. Sixty-eight percent of the state's population lives in the basin – that's 3.5 million people and is expected to go to 6.0 million by the year 2050. The basin land area is about 22,000 square miles, approximately 20% of the entire state, of which 1,300 square miles is irrigated. This is over 24% of all irrigated farm land in the state. The water is used intensively – in fact it has been estimated that the water in the South Platte is used seven times before it exits the state just downstream from Julesburg. A considerable amount of this reused water comes from return flows off fields that are being irrigated. Not all the water put on fields is taken up by evaporation or plant transpiration. What water is not used either runs off directly into surface water courses and eventually back to the river, or it infiltrates into the shallow aquifer below and slowly becomes tributary groundwater to the river.

By the 1890s the water in the South Platte was completely appropriated within Colorado. That meant, of course, that Nebraska as a downstream entity was literally left without water it could use from the South Platte for agriculture in that newly burgeoning farm economy. During that era there was a critical yearly cycle for the upper Platte – the river flowed beyond overflowing during the spring snow melt pulse, but without significant storage reservoirs, it was virtually a dry stream during the later summer months – just when irrigation is most needed. In 1916 Nebraska sued Colorado because of the lack of water getting across the border between the states, and Delph Carpenter became involved. Colorado would love to keep all the water in the river, but Carpenter knew that was not going to happen. He commenced a years-long study of the river and its basin. He concluded that the most intensely irrigated lands in the basin were from the mountain front where the South Platte and many of its tributaries enter the plains to a point that coincides with the western boundary of Washington County. To the east of that county line, the land consists of expansive paleo sand dunes that are both relatively infertile and too porous to hold much soil moisture making them ill-suited for significant agricultural development (at least at that time). With return flows such as those mentioned above and proper timing, both Colorado and Nebraska could get reasonable allocations of the water flowing in the river. With this in mind the two states agreed to the South Platte River Compact in 1923 (Figure 4).

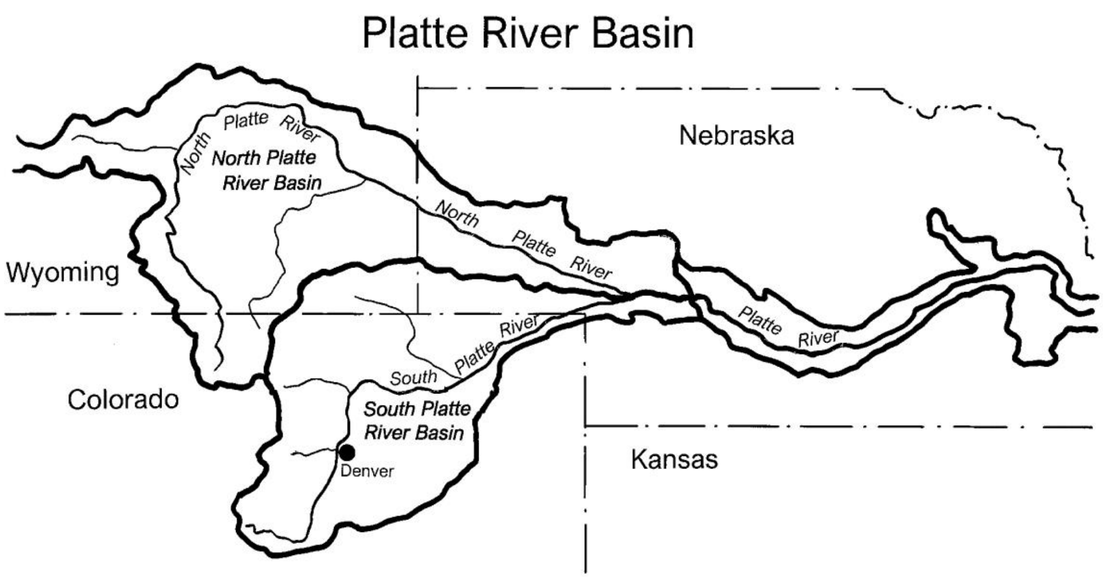


Figure 4 – South Platte River Compact map.

The main article of the Compact was based almost entirely on the yearly timing of water flow in the river. Between October 15th and April 1st, Colorado has the right to "full and uninterrupted" use of the water. There were a couple other caveats in this article concerning a possible, but still not built, canal (called the South Divide Canal or the

Western Irrigation Canal) near Ovid, Colorado. If the canal is built, then there is a complex arrangement for apportioning the waters provided by the canal. Small variations in water provided by Colorado were also exempt from litigation. One last major aspect of the Compact was splitting up the waters in Lodgepole Creek -- a major South Platte tributary near the border of the two states. Nebraska got all the water north of the border from this creek and Colorado received all waters south of the border between the two states. Between April 1st and October 15th each year, Colorado is to deliver at least 120 cubic feet per second to Nebraska. If flows fall below that amount, Colorado needs to start to curtail use by junior water right holders.

The South Platte's drainage basin is large, and the river itself is a major provider of water to farmers, ranchers, municipalities, and industry as well as for healthy riparian and stream ecosystems. But the Platte River is really made up of the South and North Platte Rivers – both of which start in Colorado. The North Platte flows north out of North Park into Wyoming. In fact there is nearly as much average yearly water flowing from the state in the North Platte (about 300,000 acre-feet per year) as there is in the South Platte (about 400,000 acre-feet per year). The North Platte flows from Colorado into Wyoming and then on to Nebraska where it joins the South Platte to become just the Platte River. The three states have never been able to agree about dividing the waters of the North Platte to create a Compact amongst the states. It has been left up to the courts to be the fabled King Solomon adjudicator. In 1945 in the case of Nebraska vs Wyoming (although Colorado was included), the court limited the amount of irrigation water Colorado (really just Jackson County) could take and limited the amount of water that could be transferred through a transbasin diversion. Wyoming vs Colorado in 1957 limited Colorado's diversions from the Laramie River – a major tributary to the North Platte in Wyoming.

The appropriations for the South Platte are way above the amount of water in the system. Only through the building of major reservoirs to save water in wet years can this whole scheme work. In the years to come, there will be acutely increasing pressure for re-appropriation of water for more intense uses such as municipal and residential. Agriculture is using more and more water from wells that tap the tributary groundwater that feeds the South Platte during drier runoff periods. But if cities buy up water rights from farmers and ranchers, maybe the South Platte basin will edge ever closer to becoming more what Stephen Long saw here than what John Frémont envisioned.

The Arkansas River basin makes up almost exactly half of the area of the state. Even though the river has its headwaters in the high mountains near Fremont and Tennessee Passes, the flows in it are significantly smaller than our other basins. Its annual average flow as it enters Kansas is barely half of the discharge for either the Rio Grande or the North Platte when these rivers cross into New Mexico and Wyoming respectively. It might be that the smaller the amount of water being fought over, the more intense the battles that ensue. Ever since the farmers at Rocky Ford started taking water from the Arkansas around 1874 for their melon crops, there has been contention, disagreements, lawsuits, and court decrees. At the turn of the 20th century, Colorado farmers were already using significant amounts of Arkansas River water. Little was making its way downstream into Kansas. This situation was taken to the U.S. Supreme Court by Kansas, and in its 1907 ruling in *Kansas v Colorado*, the court sided with Kansas in a major decision that said downstream users in a different state or states have the rights to their share of the water in the river. It became known as the doctrine of equitable apportionment for interstate rivers.

This 1907 court case did not stop the legal battles. In 1928 Colorado asked the Supreme Court to enjoin Kansas to preclude the numerous suits over water that were happening. Kansas answered by saying that Colorado was still taking more than its fair share of the Arkansas water. A Special Master was appointed by the court to be a mediator of sorts to solve issues before they got to the courts. In 1933 both states agreed to the Caddoa Project to build a large reservoir on the river. This reservoir was later named the John Martin Reservoir with an assumed supply of 237,000 acre-feet capacity. Colorado would get 160,000 acre-feet and Kansas would get the remaining 77,000 acre-feet. The reservoir was slow in coming and was not finished until 1943. After considerably more legal wrangling, the two states finally agreed to the Arkansas River Compact – a complicated document that includes an appropriation of water dependent upon season, the level of the water in the John Martin Reservoir, a divvying up of any "excess" water over and above what the reservoir can carry, and contingency plans if the water levels became so low that only a 14 day supply remains (Figure 5). The Compact also made mention of the very real possibility of water being diverted to the Arkansas from watersheds on the Western Slope of Colorado. That diverted water was not to be considered as part of the Arkansas' water.

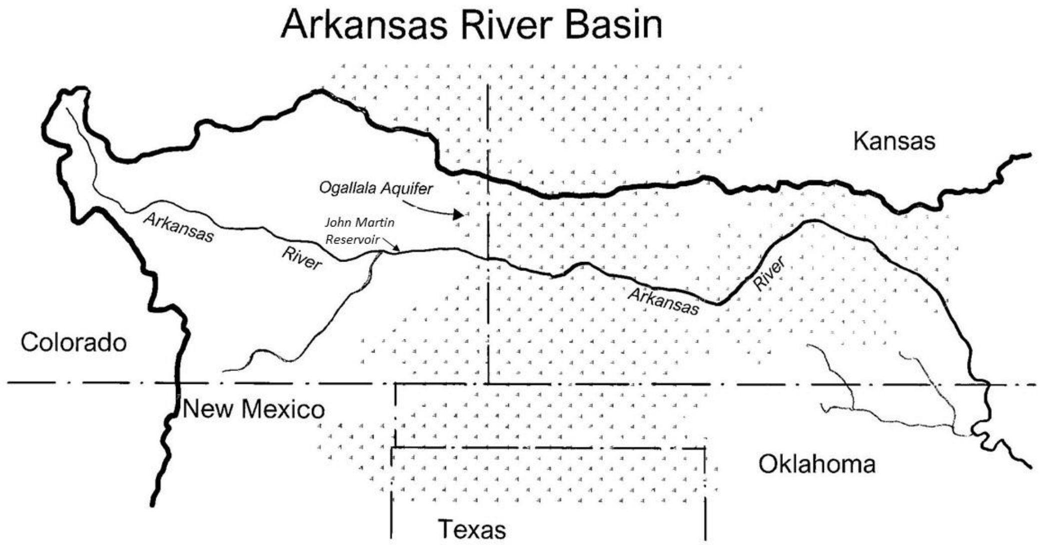


Figure 5 – Arkansas River Compact map.

Kansas still sued Colorado even after the Compact was signed. In 1985 Kansas again went to the Supreme Court accusing Colorado of not providing the agreed upon water to the border. This issue was a long-standing irritant to Kansas because since 1950, more and more wells were being drilled into tributary aquifers in Colorado which reduced the groundwater flows that helped feed the river and maintain adequate flows at the border. This disagreement dragged on for several years until 2005 when Colorado was forced to pay Kansas $34,600,000 – the first and maybe the only time a cash settlement was made from Colorado to another state for over-using water in one of its basins. This settlement was a wakeup call to both states which started to iron out the differences between them. Now there is a 10-year average that is used for accounting of the water, and if Colorado again runs a deficit over a given 10-year period, that deficit would be made up in water not dollars.

And finally, the Colorado. The Colorado River is sometimes referred to as the "American Nile", not because of the amount of water it carries, but because of the dramatic impacts it has on its arid and semi-arid region. It is estimated that 40,000,000 people depend on the Colorado to some extent for water, electricity, food, and/or recreation. That number is growing rapidly as the Southwest has one of the fastest growing populations in the country. The flows of all three of our other rivers in an average year are about 1,200,000 acre-feet – the flows of the main stem of the Colorado plus all of its major tributaries as they leave the state are approximately 8,900,000 acre-feet. The Western Slope of Colorado is entirely within the drainage basin of the Colorado, and most of the precipitation that falls on the state does so in the high mountains west of the Continental Divide in the form of substantial winter snowfalls. This snowy largesse is the envy of the populous Eastern Slope and all of the states and Mexico downstream of the state. It is no wonder that huge and expensive engineering projects have been built to move water both east over/through the mountains to the Front Range and west to the thirsty cities and farm fields of the Southwest.

Although the Colorado River basin contributes more than seven times the amount of water to our neighbors than do the rivers on the eastern slope, it probably has the simplest and most straightforward compact of them all. It is also the first compact of its kind in the West. Again, Delph Carpenter was the prominent figure in making the Colorado River Compact a reality. In the early 1920s, California was growing and developing at an astounding rate, especially when compared to Colorado, Wyoming, Utah, Arizona, Nevada, and New Mexico. This rapid growth also meant rapid increases in the need for water. Carpenter realized that if this continued, the other six states in the entire Colorado basin would lose their right to get water in the future because California would have all the senior water rights locked up early. He convinced the Federal government to urge all of the states in the Colorado watershed to come together and agree to equitable apportionments of the Colorado River water.

The salient points in the 1922 Colorado River Compact can be outlined in less than a page. The basin is split into an Upper Basin including Colorado, Utah, New Mexico and Wyoming with a small portion of Arizona upstream of the dividing halfway point at Lee's Ferry (Figure 6). The Lower Basin includes California, Arizona, and Nevada. Each basin was allocated 7.5 million acre-feet per year. Mexico, at this point, only received surplus waters. The Upper Basin had some leeway in their yearly commitment of 7.5 million acre-feet in case there would be drought years. They could satisfy the Compact if they provided 75 million acre-feet in any consecutive 10 year period. The Lower Basin was also given an additional one million acre-feet annually that would mostly come from tributaries of the Colorado that enter the river below Lee's Ferry. Twenty-two years later, Mexico finally got a committed amount of water from the Colorado through an international treaty. They were to receive 1.5 million acre-feet per year. That makes a total of 16.5 million acre-feet per year that was dedicated from the Colorado.

Figure 6 – Colorado River Compact map.

Unfortunately, it just so happens that the Compact designers used river discharges that were averaged over an outlier period in Colorado River flows. The early 1920s was a period of very wet years in the Southwest. The Colorado indeed had more than enough water to supply all of the Compact's allocations. The problem is that the more normal flows for the river are much closer to 13.5 million acre-feet per year or less. The math is simple – there is, on average, a 3 million acre-feet shortfall for all of the allocations. As an example of the seriousness of this fact, both Lake Powell and Lake Mead are already well below what is called the "normal condition" and have not been full since the year 2000. In addition to this sobering statistic, the conservative estimates for the Southwest, and especially the Colorado River basin, because of climate change are that precipitation in the region will be reduced by 20 percent on average in the next few decades. No one is certain how this will develop as the West keeps growing and with that growth, a need for more water.

The 1922 Compact merely cut the entire Colorado basin in two and allocated water to several states which would need to decide how that water was allocated within the basin. The Upper Basin realized that they needed a formal allocation process within the basin: these states assigned a percentage of the river's flow to each state so that no matter what the real flows were, everyone could calculate each state’s slice of the pie. Colorado got 51.75 percent, New Mexico 11.25 percent, Utah 23 percent, and Wyoming 14 percent. In addition that small portion of Arizona in the upper Basin upstream of Lee's Ferry would get 50,000 acre-feet per year.

We return to the fact that there are only three methods for water to be apportioned between states. One involves prolonged litigation in the Supreme Court, one involves getting Congress to agree with direct legislation, and the third is the interstate Compact. Delph Carpenter believed, and probably for good reason, that a mutually agreed upon Compact was the best way to solve issues between the states. It saves money, it saves time, and it is generally less contentious to work out problems within a Compact and amongst members, than to go either of the other routes. Because of the drop in water levels, the U.S. Department of the Interior put pressure on the seven basin states to come up with plans to appropriately share the pain. The result was a 2007 set of guidelines that may or may not be the answer. Add to all of this the fact that several Native American tribes hold senior water rights they have not yet been used – maybe up the 2.9 million acre-feet. There is little doubt that the future water story in the Southwest in general, and Colorado in particular, will only get more complicated as water resources decline and population keeps growing in the region. To quote an old saying, "May you live in interesting times." The next fifty years will certainly be interesting if not a little scary too.

But there are some small signs of hope. In March 2019 the seven Colorado River Basin states, after considerable pressure from the federal government, agreed to steps that might hold off the major water crises that loomed over the entire basin. All of the states conceded that there is going to be less water in the basin for the foreseeable future. Thoughts of boundless litigation, federal intervention, and empty reservoirs spurred an agreement in which all states will decrease their use of water from the river. There are still many problems ahead, such as demands by the Imperial Valley water users in California for more water, but at least there is a framework for moving forward.

Another strange but possible consequence of the rapidly decreasing water levels in the Colorado River Basin is now seriously being discussed. Edward Abbey, that iconoclast environmentalist, constantly talked about doing away with the Glen Canyon Dam that holds back Lake Powell. He and many, many others view that dam as an abomination to the sacred side canyons and ecosystem that the lake has drown. Because of the believed permanence of the decrease in water on the Colorado Plateau and the lowering of both Lake Powell and Lake Mead farther downstream, places such as Las Vegas are scrambling to get enough water. Lake Mead is in a decade long downward spiral that has its level at historic lows with little hope for relief any time soon. The Bureau of Reclamation is actually considering opening the ‘flood gates’ of Glen Canyon on a permanent basis. They probably will not dismantle the dam itself but return flows in that stretch of the river to near historical ones. This would drain Lake Powell, uncover the drown side valleys, add runoff and sediment to reaches downstream, and bring back over time a semblance of the important ecosystems along a very lengthy part of the Colorado. Abbey would have liked to see the dam gone, but this may be the next best thing if it really happens.

Too Little – Too Much

John Wesley Powell was an iconic and intrepid character in the lore of the West. He and a small group of mostly Civil War veterans traversed that blank space on the map where the Colorado River was assumed to flow. They dared to run the rapids and shoals of the unexplored river in 1869 where no other recorded visitors had ever set foot. But Powell was much more than just a courageous explorer. He was an example of an American 'renaissance man' who studied Native American tribes on the Colorado Plateau, became the first director of the Bureau of Ethnology (anthropology) at the Smithsonian Institute, was a geologist who directed the newly formed United States Geological Survey from 1881 to 1894, and wrote one of the most insightful and controversial reports ever penned by a government bureaucrat – the descriptively titled "*Report on the Lands of the Arid Region of the United States, with a more Detailed Account of the Lands of Utah*," (1st edition 1878; 2nd and revised edition 1879).

The post-Civil war era was one of rapid expansion to the West. Most of the highly productive land of the East and Midwest had already been settled by the Jeffersonian ideal of the yeoman farmer. And after the 1862 Homestead Act was passed, 160 acres of the public lands of the United States were available for ownership by the flood of settlers flowing west. That 160 acres is a number of convenience rather than any kind of rational thought – it is exactly one-quarter of a square mile which makes the geometry of land settlement quite Euclidian if not agrarian. One-hundred and sixty acres in the humid East was almost too much for a single family to farm completely in the 19th century. Plowing behind a mule or horse team is an arduous and time-consuming task. But in the much drier West, it was totally insufficient for a family to succeed at farming – there simply were not enough resources to create the irrigation system necessary nor was there enough water to put into the system if it ever were created. Most experts today would say that west of the 100th meridian, there simply is not enough consistent precipitation to farm without supplementary irrigation. And the farther west one goes, the lower the precipitation rate with the exception of high mountain areas that could not be farmed usually for other obvious reasons.

Powell understood this, and his *Arid Lands …* treatise was his philosophical and political exposure of that fact. One of the most divisive recommendations by Powell was to increase the 160-acre allotment of the Homestead Act for settlers in the arid to semi-arid West to 2560 acres – 16 times the original homestead land area, or to the western booster, 16 times fewer settlers. Powell made many enemies with this report, not the least of which were Congress, the railroads, local boosters, and land speculators. They wanted, believed in, the progress of settlement in the West, and climate should have nothing to do with that progress. The more people the better! In fact many believed, or were self-deluded enough to believe, that "rain follows the plow." William Gilpin was the first Territorial Governor of Colorado (1861) and a firm proponent of that illogical concept. But logic and politics had little in common, even in the earliest days of what we now call Colorado.

Powell was not exactly what we would today call a "tree hugger." He believed in the development and settlement of the West; he just wanted both of those to be based on rational analysis. He was a great proponent of the government in all its guises including being responsible for developing the infrastructure that was needed to save and move water to locations where it could be put to use on the land. It is ironic that it was in the year that Powell died (1902) that the U. S. government established the U. S. Reclamation Service tasked with the job of building dams, canals, aqueducts, and reservoirs that would do exactly what Powell suggested. The Service was renamed the Bureau of Reclamation in 1923, and the era of big dams in the West began. It is also a bit sardonic that one of the most controversial dams ever built on the Colorado River was the Glen Canyon Dam that created Lake Powell.

The users of weather and climate information eventually realized that real scientific data were too critical for any number of reasons to leave them up to over-enthusiastic boosters. The federal government eventually took a leading role in the science of drought. The federal agency that is tasked to predict weather, forecast storm events, tell us when drought is about to happen and for how long, and generally is responsible for all meteorological and climatic scientific activities is the National Oceanic and Atmospheric Administration (NOAA). NOAA is the latest transformation from the old U. S. Weather Bureau. Their mission basically includes everything from creating definitions for all types of weather and climate events, to forecasting weather, to predicting what is going to happen in the near/far future, to coastal management – in their own words, they are "an agency that enriches life through science." Of course they have a drought definition, although it is quite broad and not all that useful for any particular locale. To NOAA drought is "… a deficiency of moisture that results in adverse impacts on people, animals, or vegetation over a sizable area." This is a vague definition, but no one has been able to come up with a more specific and useable one because drought means so many different things to so many different people in so many different places. For example, this definition does not take into account where the "drought" is occurring.

Does drought really mean the same thing in Georgia as it might in Arizona? Is drought a significant change from the normal precipitation in a place or is it a general lack of moisture that is not place based? Should there be a time component that says drought only occurs with lack of precipitation over a certain number of years? Should this include economic impacts – if dry weather has little influence on the economy, is it really a drought? It is a complex issue and probably the measurement of the severity of drought is often left to one's own location and circumstances.

Although many climatologists and meteorologists have some issues with it, the most commonly used, scientific measure of drought is the *Palmer Drought Severity Index* (also called the "Palmer Drought Index" or the PDI) published by Wayne C. Palmer in 1965 for the Office of Climatology, U.S. Weather Bureau. The basic concept of the PDI is to compare the ongoing level of precipitation to that of a more "normal" year. He took into account the longevity of the lowered rainfall, what the region usually gets, and what the timing of precipitation during a normal year would be. It also uses the concept of potential evapotranspiration – the total of the possible evaporation and vegetative transpiration in a location if all the water needed were available (this seldom happens, especially in the West). All of this was put into a set of equations that yielded an index of drought from greater than +4 for extremely wet to -4 meaning extremely dry. This range has more recently been expanded from +6 to -6 on the wet to dry spectrum respectively. Figure 1 shows two maps of the continental United States – the one on the left is a map of the Palmer Drought Severity Index for 1934 during the Dust Bowl. The one on the right shows 1984 as an abnormally wet year in much of the United States. These two maps are but extremes in the entire spectrum of drought and its wet opposite.

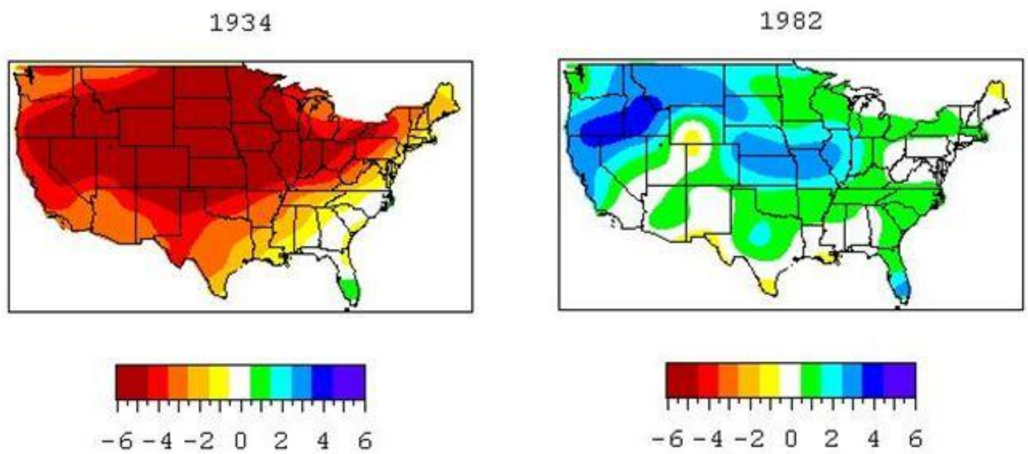


Figure 1 – Two U.S. maps showing the Palmer Drought Severity indices for 1934 and 1984 (Source http://www.ncdc.noaa.gov/paleo/image/pdsi/pdsi_in.mov, Accessed Oct. 6, 2015).

So what has all of this got to do with the four rivers of Colorado? Well, Colorado is well west of that symbolic and all important 100th meridian and, at least for the eastern plains, the San Luis Valley, and the entire plateau region of western Colorado, it is in the semi-arid to arid category. Powell in his *Arid Lands…* report lists 6 specific places in Colorado in his arid zone or in his low water supply category – Denver, Colorado Springs, Golden, and Ft. Lyon on the eastern plains and Ft. Garland and Ft. Massachusetts in the San Luis Valley. These six places are merely typical examples of the precipitation amounts for the entire state. With the exception of the higher mountains, Colorado gets sparse precipitation and what we do get is often too little for meaningful agriculture without augmentation – meaning irrigation using water saved from former wet years or more likely from the snow melt that flows into mountain rivers and streams where precipitation is generally higher or from groundwater aquifers tapped by powerful pumps.

We also must realize that the levels of precipitation for all of the places in Colorado for average precipitation are just that – numbers for the average year. And it is well understood by climatologists that the average precipitation for a year in a given place may never actually happen. There will be years with more (sometimes much more) and years with less (sometimes much less). The only constant in annual precipitation rates is that they are never constant and always trend in one direction or another away from this theoretical and elusive arithmetic mean. And there is a simple truth to the distribution of precipitation – it is least reliable where it is least available. The variation away from the average is actually a very important consideration for people – will I need to irrigate more this year, do I have the water rights (see the **Law** chapter) to do that, what about my Kentucky bluegrass lawn?

There is another index that has been developed to look at the variations in precipitation and tries to answer these questions. The "Standardized Precipitation Index" (SPI) was conceived at the Colorado State University's Colorado Climate Center in the 1990s (Mckee, Doesken, and Kleist, J., 1993). The SPI is based on whether the probability of a given precipitation at a given time scale for a place will occur. It really is using the number of standard deviations of probability for a specific precipitation level that will happen away from the average – positive numbers indicate higher than normal levels, negative numbers indicate lower levels of precipitation. For example an SPI of 3.0 for a place means that there is considerably less than 1% chance of that level of precipitation will happen – a pretty rare event. The usually accepted value of the SPI to declare drought conditions is -1 or below. When we look at the entire state of Colorado and its SPI values over time, we see a place where drought is an almost regularly occurring event. Figure 2 looks at the percentage of Colorado that is in drought conditions from 1900 to 2020 – it is a sobering sight that the occurrence of drought in so much of the state happens over and over again. Someplace in the state is almost always in drought, and most of the places in the state are often under drought, even severe drought conditions.

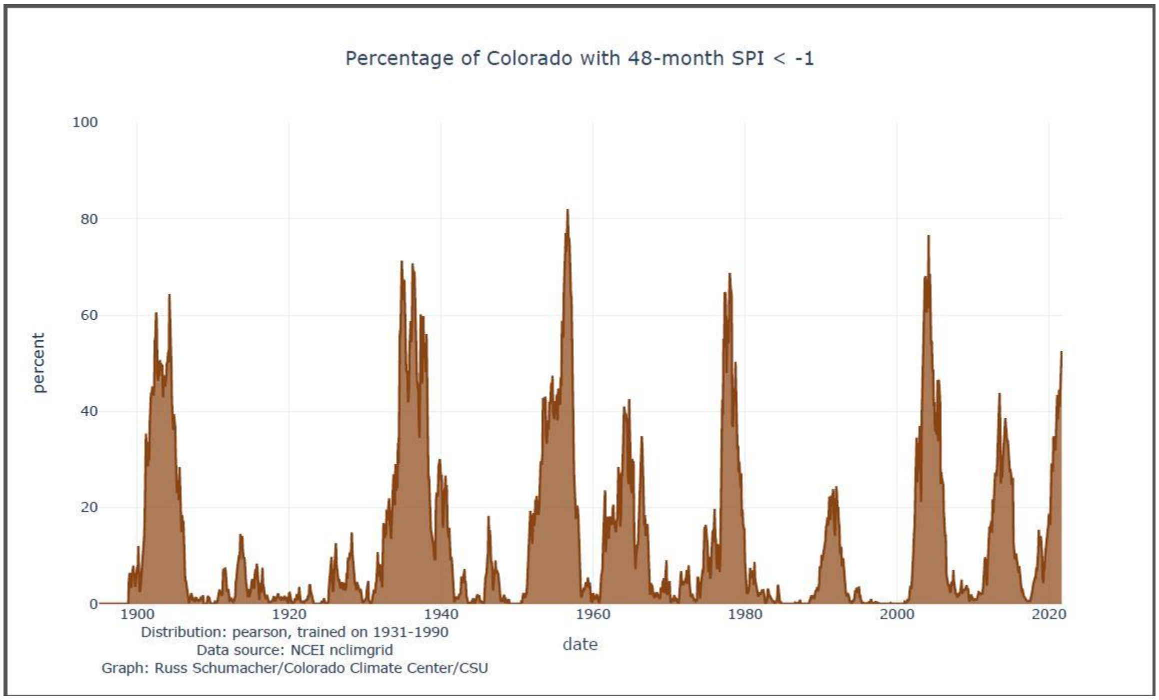


*Figure 2 – The Fraction of Colorado considered in drought conditions based on the 48 month Standardized Precipitation Index (SPI) from 1900 to 2020 (*courtesy of the Colorado Climate Center*).*

Our four rivers all begin in the high elevations and greater precipitation regimes of our mountains. Even though the mountains, on average, have more precipitation, they are not immune to intermittent drought – often in the form of low winter snowfall amounts. Snowfall in the mountains is critically important to everyone in the state. When snow falls, it stays in place for some length of time dependent upon season and temperature. But it slowly melts and much of it infiltrates into the ground to flow slowly through the subsurface and eventually into streams and rivers weeks, maybe months after the snow event. Rain on the other hand, usually runs off quickly and enters those streams and rivers quickly. Rainwater flows almost immediately down to lower elevations and either must be used immediately or stored for use later in the growing season. If we cannot store the water, it will be lost downstream. So winter snow acts as a bank account of water that is slowly doled out while rainfall is the spendthrift who never saves and "spends" all the water as soon as it gets it.

If there is drought in the mountains, everyone on the plains, in the San Luis Valley, and on the plateaus and mesas of the western slope feels it. In dry years at the lower elevations the increased need for water may come at exactly the time when the mountains are also in drought and the rivers go low, the reservoirs decline, and the irrigation canals are empty. Cities and towns also suffer along with the natural ecosystems, the recreation industry, and many, many others. All of these impacts have effects well beyond the dryness itself. Economies suffer, jobs are lost, species of plants and animals need to find ways to survive, and human health can even be affected.

The data in Figure 2 go back to 1890 when official long-term weather records based on instrumentation started – thermometers, rain gauges, anemometers, barometers, and other instruments. Thirty consecutive years of weather data are necessary for a "climate" to be defined. Weather is what we see out the window today; climate is taking those 30+ years of data and using it as an average or norm for a place. But what if we want to look at the longer-term trend, maybe even as far back as several hundred years ago? Reliable instruments did not exist, were often unavailable and unreliable if they did exist, or were very expensive. Little in the way of scientific observation of weather conditions took place. But necessity is the mother of invention – a very clever scientist in 1937 at the University of Arizona, A. E. Douglass, developed and advanced a technique to create climate data from a reliable surrogate. The Laboratory of Tree-Ring Research at Arizona is the world's premier tree-ring and climate facility. The surrogate used was tree-ring data or dendrochronology using the growth rings of trees over a long span of time. By carefully and meticulously measuring the thickness of the tree-rings, correlations could be made that informed the researchers what the weather had been during any given year in the past. By overlapping similar ring patterns using a technique called a skeleton plot, tree-ring data can give us high quality information on past climates in any area of the world that the technique is being used. It is standard practice to compare and correlate more recent tree-ring data to that obtained by instruments. This assures that the tree cores are actually telling us what we theorize that they are telling us – in reality it is a kind quality control mechanism.

The rings are exposed for counting and measurement by coring the tree. This process uses an instrument called an increment borer and consists of a long, hollow tube with a spiral blade on the end that goes into the tree. This blade is turned into the tree, aiming at the center of the tree – all rings from this year's to the first ring of the sapling are cut and revealed when we insert what is called the spoon, and pull the core out. Each normal year has 2 rings – an early wood ring that grows in the spring and early summer, and a late wood ring that shows the tree starting to shut down getting ready for winter. An example of a core (this one for a ponderosa pine) is shown in Figure 3.

Figure 3 – An example of a tree core from a ponderosa pine.

The National Oceanographic and Atmospheric Administration's National Climate Center in Ashville, North Carolina has developed tree-ring climate data back to at least 1700. The map format is identical to those in Figure 1; they are just using the tree-ring data instead of instrumentation. The tree core maps are an amazing compilation of climate data for the what we now call the United States – in the 279 years represented in the map base, 57 of those years had severe drought conditions in part or all of the land area of Colorado. Drought is not a recent occurrence in Colorado – in fact if we took tree ring data for the last 10,000 years, we would see regularly recurring drought in much the same pattern as we have seen in the instrumental data from 1890 and the tree-ring data since 1700. What is more difficult to observe, at least in the short run, is that drought in Colorado and much of the Southwest of the United States appears to be occurring more often and in greater depth than in decades and centuries past. The reason for these dry predictions comes from the intense analysis of how our climate is changing in response to dramatic increases in "greenhouse gases" that absorb more and more longwave (thermal) energy that should be emitted back to space.

Climate change is one of the most controversial topics in politics today. It is controversial, not because the science is unsure or bad, but because there are many well-funded people and organizations who intentionally obfuscate the scientific data. There is virtually no scientific argument that climate change is happening – almost 100% of the United States' and the world's climate and atmospheric scientists agree that climate change is happening now and will increase in intensity in the future. The only real questions are, what does this mean and what are going to be the consequences? We know from ice core data from Greenland and Antarctica that carbon dioxide levels over the past 800,000 years have never exceeded 280 parts per million of the atmosphere. Since the 1880s the concentration of carbon dioxide has been rising steadily at an exponential rate and went above 400 parts per million for the first time in 2015. The science is also very clear that carbon dioxide is a powerful greenhouse gas (GHG) that absorbs heat being emitted back out toward space from the ground. Carbon dioxide is not the only GHG; methane (what constitutes most of the natural gas that we burn in our furnaces) is even more powerful, but less plentiful than carbon dioxide. Water vapor is also a GHG, but there is a limit to the amount of water vapor in the atmosphere based on temperature – we call this limit 100% relative humidity. If the relative humidity tries to go above 100% it rains or snows and the atmosphere loses that vapor. There is no such limit for carbon dioxide or methane.

What does this mean for Colorado? In 2014 the Colorado Water Conservation Board commissioned a study about whether and how climate change was going to affect the state, especially its water resources. The result of that work is *Climate Change in Colorado* (2014) authored by Jeff Lukas aided by four other scientists from the University of Colorado's Cooperative Institute for Research in Environmental Sciences and from the Colorado Climate Center at Colorado State University. Their work came to several conclusions about the effects of climate change in the state. The first finding is that the average temperature for Colorado between 1977 and 2006 has already gone up by about 2º F, and it is predicted to increase by another 2.5º F by 2025 and by 4º F by 2050. The second finding is that the spring 'pulse' of winter snow melt has begun two weeks earlier than normal over the period of 1978 to 2004. This means that our rivers will receive more water earlier and less water later in the growing season. And there will probably be a reduction in the total runoff – the prediction for the upper Colorado River is for a 6% to 20% reduction in total water in the basin. It is a physical fact that with increasing temperatures there will be less precipitation even with the same absolute humidity (the mass of water in a given volume of air) available in the atmosphere. There is a complex process involving vapor pressure, the level of each gas in the atmosphere, and temperature that, when the temperature increases, more water vapor can be held in the air without getting to 100% relative humidity (the point that needs to be reached to get rain or snow). There is a broader prediction for the entire Southwest of the U.S. that by 2050 there will be 20% less water in the Colorado River than at the start of the 21st century. With so many people depending on that water (38 million by 2020), there are going to be some serious issues – legal, moral, environmental, economic – that will need to be addressed.

These predictions are wrong – wrong in the sense that it appears that sever drought conditions in the Southwest are occurring more rapidly and more intensively than projected. This is especially the case for the western slope of Colorado which we have already seen is the Colorado River basin (see the **Watersheds** chapter) in the state and in all the Colorado Compacts (see the **Compacts** chapter) states downstream. The two major reservoirs along the Colorado River downstream of Colorado are Lake Powell and

Lake Mead. These two mainstays of the Colorado River complex were last at capacity in 1999. As of late 2021 they are both at the lowest levels since the dams (Glen Canyon and Hoover Dams respectively) were constructed and the reservoirs were initially being filled. The situation is becoming dire in the Lower Basin states (California, Nevada, and Arizona). The Bureau of Reclamation and the compact states have signed a Drought Contingency Plan in May 2019. A new Drought Response Operations Plan is in place as of January 2022. For now reductions in water are being absorbed by dry-land farmers in Arizona. These farmers have junior water rights (see the **Law** chapter) and cities will be spared the worst of the water reductions, at least for now (Bureau of Reclamation, 2021).

“I'm stuck, I'm right in the middle of it, I can't get out...about half mile East of Drake on the highway. Tell them to get out of the low area down below. And soon as the water starts picking up … (static)… high ground… . " These were the last words ever heard from Colorado State Highway Patrol Sergeant Hugh Purdy who was stranded in the flood waters in the canyon of the Big Thompson River on the night of July 31, 1976. His patrol car was crushed under tons of water, large boulders, and other debris that flowed down the once tranquil channel of the Big Thompson. Purdy's body was eventually found eight miles downstream from where his car was buried. His was a dramatic and poignant story that really was emblematic of the toll on others in the canyon that night. There were a total of 144 killed during the flood in the canyon – the highest, by far, of any natural disaster in Colorado history. Almost all of these people were mangled by the rushing flood waters. Actually "flood waters" is a misnomer. What came down the valley that summer night was more a mix of mud, rock and boulders, trees, parts of destroyed houses, and any other debris caught up in the fast-flowing water. Only a massive amount of water moving very fast could erode and carry this load of detritus. The flood destroyed 418 homes, 52 businesses, all the bridges in the flood zone, and much of Highway 34 between Loveland and Estes Park.

Flows of rivers and streams in the United States are often put into the units of cubic feet/second (cfs) – in other words a cubic foot of water passing a given point in the course of one second. The long-term average flow for the Big Thompson River is 72.5 cfs. The maximum flow for the night of July 31, 1976 based on estimates since all stream gages were destroyed by the flood was 31,200 cfs, a 430-times increase. Many people felt that this flood was impossible until it happened. Considerable research by the United States Geological Survey after the flood estimated that this was a 10,000-year flood event. This figure does not mean that it will be 10,000 years before we see another flood of this magnitude; it means that there is only a 1 in 10,000 chance in any given year that this size event will occur.

The meteorology of the storm that caused the flood was nothing more than a very intense version of the kinds of storms we get often along the Front Range of Colorado. Most of us think that the precipitation we get in the state comes from the Pacific Ocean and is carried to us on the westerly winds that are the norm in this part of the world. But it often happens that a lot of moisture can be brought up from the southeast out of the Gulf of Mexico if the regional wind patterns are just right. In the case of the Big Thompson, the winds were just right with a vengeance. That day there was a very warm and moist air mass moving up against the Front Range from the east/southeast. There was a high-pressure ridge to the north of us with its clockwise air flow pushing the moist air upslope. There was also a low-pressure system just to the southwest with its counterclockwise air flow strengthening the upslope movement. As the air rose, it cooled, and the water condensed into rain. The air was unstable already and severe thunderstorms formed. Usually these mountain storms move relatively rapidly off to the east and we only get short term intense rain and/or hail. But there was a very light wind at altitude that allowed this air mass to be nearly stationary for several hours. Rainfall totals for the storm in a few places were as high as 12 inches in four hours. At the top of the canyon, 7.5 inches of rain probably fell in an hour. This was the major pulse of water that started the massive flows in the river channel and eroded masses of rock and soil from the mountain slopes above the valley bottom.

Floods of this scale have probably occurred before in the Big Thompson Canyon, but there were just no people around to witness them. One of the premier researchers and thinkers about flood disasters, Gilbert White, once said, "Floods are an Act of God, but flood losses are largely an act of man." Floods only really count in peoples' minds if they are seen as affecting people. Those probable paleo-floods may have been as large or maybe larger, but since no one was here to be affected, we assume that they are not that critical for us.

Thirty-seven years later a slow-moving storm system pulled moisture both from the tropical Pacific and the Gulf of Mexico into eastern Colorado. This particular storm lasted for days – from the evening of September 9 through September 13, 2013. One rain gage measured 14.71 inches of rain during that period, but there are plausible estimates of rainfalls of over 17 inches with at least 8 inches falling on much of the entire Front Range as far south as Colorado Springs and Pueblo. The hardest hit areas were the foothills of

Boulder and Larimer counties even though much of the Front Range north and south of those counties was also hit by heavy rains. The rainfall was not as intense as in the 1976 flood, but Boulder received 9 inches of rain in 24 hours – doubling the old 24-hour record. Adding to the flooding problem was the fact that significant areas within the flood zones had been burned by large wildfires over the previous two or three years. Without vegetation to slow the moving water, flooding was made much worse. At least eight people were killed, and there was an estimated damage total of over $2 billion.

The Big Thompson Canyon was again hit very hard, and significant damage again occurred. The maximum flows in the river in 2013 (18,400 cfs) were less than in 1976 but still at the 500-year flood level (1 chance in 500 in any year for this size flood). And again Highway 34 was destroyed in many sections just as in 1976. But the Big Thompson was joined by innumerable creeks, streams, and the South Platte River in spreading destruction far and wide. A list of the major flooding includes: Boulder Creek, St. Vrain Creek, Clear Creek, Bear Creek, the Cache La Poudre River, and Four Mile Canyon to mention only the hardest hit. All of these streams are tributaries of the South Platte River. The South Platte basin is probably the most impacted by flash floods in Colorado. Table 1 shows the 24 most damaging floods in the state – 14 of those 24 have occurred in the South Platte basin. Certainly there are other places in Colorado that have devastating floods, but the South Platte and the Arkansas River basin (5 of 24) to the south are the two main flood zones in Colorado since the 1860s. It is of interest to note that in the space of 37 years, the Big Thompson canyon has had a 10,000 year and a 500-year flood event – those probabilities can certainly be misleading and give people a false sense of security. Any size flood can occur in any year, the chances are just usually pretty low, but they are not zero!

24 Most Damaging Floods in Colorado

Date	Major Stream	Deaths	Damages (in 1999 $$)
May 1864	Cherry Creek at Denver	unknown	6,000,000
July 1896	Bear Creek at Morrison	27	6,000,000
Oct. 1911	San Juan River at Pagosa Springs	2	6,000,000
July 1912	Cherry Creek at Denver	2	120,000,000
July 1921	Arkansas River at Pueblo	78	760,000,000
May 1935	Monument Creek at Colorado Springs	18	52,000,000
May 1935	Kiowa Creek near Kiowa	9	15,000,000
Sep. 1938	Mostly the South Platte Basin	6	5,300,000
May 1942	South Platte River Basin	unknown	8,500,000
May 1955	Purgatoire River at Trinidad	2	36,000,000
June 1957	Western Colorado	unknown	18,000,000
June 1965	South Platte River at Denver	8	2,200,000,000
June 1965	Arkansas River Basin	16	205,480,000
May 1969	South Platte River Basin	0	21,500,000
Sep. 1970	Southwest Colorado	0	13,200,000
May 1973	South Platte River at Denver	10	388,800,000
July 1976	Big Thompson River Larimer County	144	85,200,000
July 1982	Fall River at Estes Park	3	49,080,000
June 1983	North Central Counties	10	26,250,000
May-Jun 1984	Western and Northwestern Counties	2	46,500,000
May-Jun 1993	Western Slope	0	2,140,000
July 1997	Ft. Collins & 13 Eastern Counties	6	169,367,000
May-Jun 1999	Colorado Springs & 13 East. Counties	0	100,000,000 est.
Sep. 2013	South Platte Basin, Front Range	at least 8	2,000,000,000 est.

Severe flash flooding in Colorado occurs relatively rarely, but it certainly happens more often than we would like. The two Big Thompson floods are evidence of that. But when it happens in the middle of one of the most severe, extended droughts in Colorado history, it is out of the ordinary. This is what happened in the Colorado Springs area in 1935. Extreme drought was firmly positioned in the southeastern Colorado area in addition to Oklahoma, Kansas, Texas and much of the Midwest from 1931 to 1940 with only a few small respites from the dryness in those years. The year 1935 was not the driest of that drought period, but it was not the wettest either. It was a tantalizingly small reprieve from relentless sun and wind.

The morning of Memorial Day 1935 dawned with light rain, not atypical of late spring weather in Colorado Springs, and the forecast for the day indicated that it would remain that way. Of course in 1935 there was not a single weather satellite in orbit nor any weather radar nor were there many ground-based weather stations to issue warnings of impending meteorological calamity. In the late morning, however, heavier storms clouds were already brewing north and northwest of the city. The rain intensified throughout the day and the water in Monument Creek started to rise noticeably. At its peak Monument Creek had an estimated flow of between 50,000 and 53,000 cfs – normal peak flow for the creek in late May is less than 300 cfs. Without accurate rain gages available in 1935, it is difficult to estimate the total rainfall for the storm. Some estimates are as low as seven inches and some as high as 24. Most likely the real amount of rain that fell is between these extremes. What makes this flood so destructive is that the rain came fast and unexpectedly.

Two hundred blocks of the city were wiped clean of houses, businesses, cars, trees, and anything else that got in the way of the flood water. A total of eighteen people died and there was a significant part of the city that needed to be totally rebuilt and protected from the next big one. City officials call this event the "flood of record" meaning that they hoped this is the biggest we needed to plan for. But as we have seen in many places in the state, one can never be certain what to expect or when to expect it.

This chapter has only looked at three of the most significant floods in state history. But there have been literally dozens of smaller floods not dramatic enough to make national news, but devastating to those affected by them, that have happened to creeks and rivers and communities. Floods happen, droughts happen, sometimes almost simultaneously. Often in Colorado we either have too little or too much. As the major effects of global climate change continue to magnify, we can expect more of the same only with increasing variability. We may get more of "too little" and less of "too much", but the seeming randomness and volatility of our climate and our weather will remain and most likely increase.

This brings us back to the main topic – our four rivers. Overall, a 20% reduction in precipitation in the Southwest United States is predicted by most climate change models in the next several decades. The strongest influence on river and stream flows will be drought, or reduction in total runoff. There may be some impact on the size and number of flash flooding events, and these events will be harder to predict. But these same drought conditions will also increase wildfire risk that in turn will affect the runoff of even small to moderate rain events. There is a complex set of relationships that will make the job of managing Colorado's water resources more difficult in the future.

The reduced flows of water in our rivers will also be critical because of the need to satisfy the requirements of the various river compacts (see **Compacts**). In many cases those compacts guarantee certain volumes of water to be delivered to downstream states. When there is a reduction, who suffers – Colorado, the downstream state(s), or is there shared pain? How will these decisions be made? Another example is the impact of reduced flows on the riparian and aquatic ecosystems. Ecosystems in and along the rivers have evolved over time in a certain way with a certain amount, or at least range, of water available. Do ecosystems get a say in how the reduced water volumes are allocated? Questions like this can be asked, if not answered, for the effects on invasive species, landuse, economics, community health, water recreation, and plans for the future of rivers and streams in Colorado.

Plans

A common theme seen either explicitly in chapters of this book such as "Diversions" and "Compacts" or implicitly in chapters such as "Recreation" is that there are many, many more demands on water resources in Colorado than there are supplies of this precious commodity. This gap between how much we have and how much we want/need sets up one of the Colorado's, and the entire western United States' for that matter, biggest areas of concern, conflict, and litigation. The list of people and organizations that are involved in using, supplying, contesting, and moving water is long and tangled at many scales from individual homeowners and farmers to cities, the state of Colorado, the U.S. Government and its myriad agencies, and even other countries. If any of these entities or individuals in Colorado thought that the water supply gap was not a very serious issue, the drought of 2002 to 2007 in the state put an end to that idea. Reservoirs were nearly depleted, crops were failing, cities were mandating water restrictions trying to conserve as much as possible, and the future took on a whole new, desiccated view. The precipitation came back to some extent; then the renewed drought that began in 2012 and has continued almost unabated and the massive wildfires of 2018 and 2020 provided new reminders and refreshed our collective angst about the future of water in the state.

Because there is so much riding on solving water issues in Colorado, new ways of thinking, and most especially acting, together are surely needed. Even though there is deep conflict and maybe even antagonism between people and organizations vying for the water resources of our four rivers, there must be some way to get all stakeholders (which means everyone in the state at some level) to the same table. This is precisely what Governor John Hickenlooper was trying to do when he signed an executive order in May of 2013 to create a statewide water plan. The Colorado Water Conservation Board was tasked with the job of getting state water users and providers together to do an overall plan for moving forward toward the middle of the 21st century. This was not an easy assignment, nor would it be without many inherent conflicts that could probably be predicted from the history of water in the state. But with almost lightning speed for state governments, the final *Colorado State Water Plan* (referred to as the **Plan** below) was completed in late 2015. How was this possible and what does the plan say and do?

As explored in various chapters of this book, each of our four rivers and their basins are unique in terms of water supplies, water use, water law issues, built infrastructure and future needs, urban growth and land use, environmental concerns, basin landscape character and many other matters. One of the key components of the Plan was to include as much input from the various constituents and individual basins as possible. That is why the Plan depends in very large part on the participation of each of nine basin groups that could fairly represent that basin (Table 1). These representative groups are known as the Basin Roundtables. For example the Rio Grande Basin Roundtable was tasked with coming up with its own Basin Implementation Plan (BIP) which outlines the basin's current status as far as water is concerned, what the major issues are and will be, and ways that these issues might be addressed in the future. The members of the Rio Grande Roundtable are similar to the membership for each of the other basins and include representatives from the counties and cities within the basin, state and federal resource management experts, water conservancy districts from within the basin, major water users and suppliers, and local and state political leaders who represent the basin. The BIPs from all the basins were used by the Colorado Water Conservation Board to draft the state Plan.

Table 1 – The Nine River Basins Represented that include Basin Implementation Plans

1. Arkansas River Basin BIP
2. Colorado River Basin BIP
3. Gunnison River Basin BIP (part of the larger Colorado River Basin)
4. Metro Basin BIP (embedded within the South Platter River basin)
5. North Platte River Basin BIP
6. San Juan and Dolores River Basin BIP (part of the larger Colorado River Basin)
7. South Platter River Basin BIP
8. Rio Grande River Basin BIP
9. Yampa-White-Green River Basin BIP (part of the larger Colorado River Basin)

The Arkansas River basin, with almost 28,300 square miles (27% of the state), is the largest basin of our four Colorado rivers. A comparatively small part of the basin is in the high mountains of the state with the eastern side of the Collegiate Peaks/Sawatch Range feeds the river and its headwaters starting just below Fremont and Tennessee Passes. But most of the landscape from Buena Vista to Cañon City is open grassland, and east of the mountain front it is predominantly dry, short grass prairie. A large irrigated agricultural economy prevails in this high-plains region near the river with dryland and irrigated farming using groundwater in areas away from the mainstream. It is overall the driest basin of our four river systems and may have some of the most intransigent problems. The only major tributaries that feed the Arkansas after it leaves the mountains are Fountain Creek coming from the north and the Purgatory River coming from the southwest (see Watersheds chapter). These facts might help explain why the Arkansas BIP is 799 pages long with over 500 more pages of appendices – both of these volumes taken together are larger than all of the other BIPs combined (Figure 1).

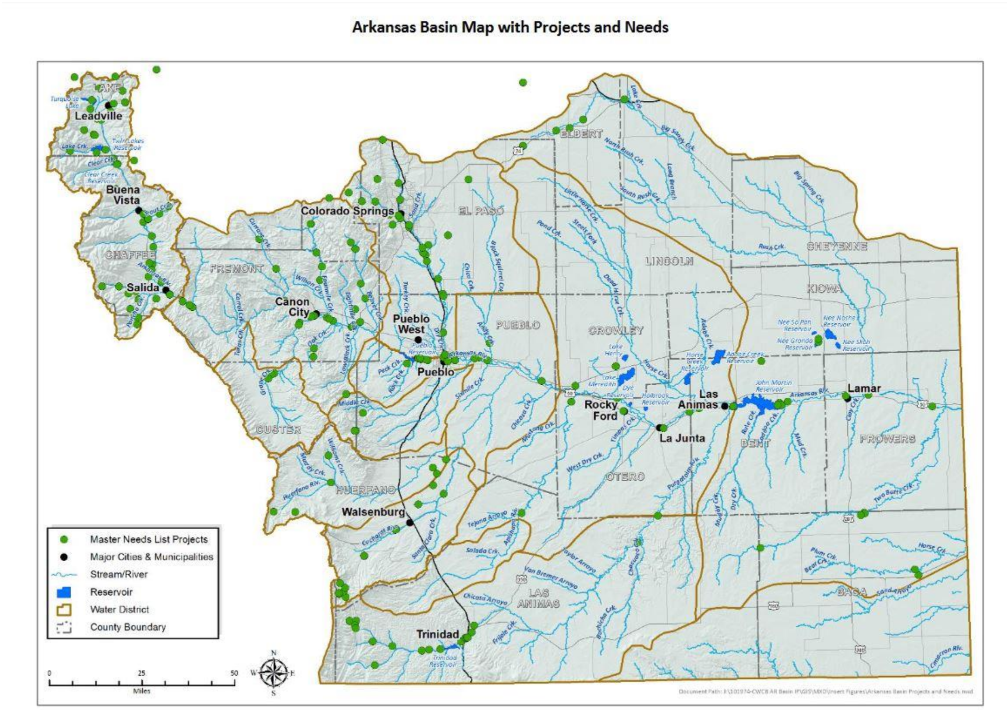


Figure 1 – Map of the main Arkansas River needs according to the Arkansas River Basin Implementation Plan. (courtesy of the Arkansas Basin Roundtable, 2015).

Three of the largest and most critical overriding issues facing the Arkansas basin include "buy and dry" transfers. Many farmers and ranchers in the basin see their ownership of significant water rights as their insurance policy of sorts for the future. These rights are worth a lot of money, and in some cases have been sold to cities, especially Colorado Springs and Aurora. These transactions are called "buy and dry" because that is what happens to the farms and communities where the water is transferred from irrigated fields to urban lawns. The second major concern is the basin's legal imperative that is outlined in the 1948 Arkansas River Compact with Kansas and the water that is mandated to go to Colorado's neighboring state to the east. Much of the Arkansas BIP discusses the issues and possible solutions for this problem.

The third big-picture issue is that there is little water naturally in the Arkansas River during normal times; a large segment of irrigated agriculture in the basin depends on the use of groundwater. There are several relatively small and one very large groundwater aquifers that are tapped for mostly center pivot irrigation in the basin. The largest aquifer is the High Plains aquifer (known regionally as the Ogallala aquifer, it is one of the biggest aquifers in the United States stretching from the Dakotas to Texas) (see Figure 5 in the **Compacts** chapter). It took thousands of years to fill this underground reservoir, and it is being depleted at alarming rates. In some places the aquifer is being lowered by five feet a year while it is being recharged at about 2/100ths of an inch a year. The simple yet sobering math tells us that the water in the aquifer cannot last very long at this rate.

The specific needs outlined in the Arkansas Basin BIP include the need for augmentation water – this is water that is mostly needed to fulfill the 1948 Compact with Kansas. As urban areas use more and more of the basin's water, and agriculture continues to irrigate, it is feared that there will not be enough to send downstream to Kansas to satisfy the Compact and the court decrees that have already cost Colorado millions of dollars in reparations. Another related concern is the growth of urban areas and the increasing gap between supply and demand in that water use sector. A third need is to keep adequate flows in the river near its head to supply the burgeoning recreation industry – especially rafting. It is estimated that from Leadville to the Royal Gorge, the Arkansas River is the most rafted stretch of water in the world! In addition to rafting there are the world Gold Medal trout fishing reaches, in particular the newly designated Brown's Canyon National Monument just upstream from Salida. Conservation and water quality are other issues that are gaining support. But if water use in agriculture or municipal areas is being used more efficiently, many ask where that saved water will be stored for other uses? In the view of the Arkansas River Basin Roundtable, all of the above issues depend on storage capacity. The current storage infrastructure along the Arkansas is aging quickly, and maintenance and rebuilding of these storage facilities is a priority; the Roundtable sees a desperate need for more new storage facilities in the coming years (Arkansas Basin Roundtable, 2015).

The metropolitan area of Denver has its own basin designation -- the Metro Basin. Here it and the North Platte basin will be included in the much bigger South Platte BIP. The South Platte watershed has a long history of irrigated agriculture. It is also the basin that has the most intensively irrigated agricultural land in the state. Beginning with the Union Colony and exponentially increased with the Colorado-Big Thompson project, the amount of water put on crops here is tremendous. In addition this basin has the highest population, by far, of any basin in Colorado. Eighty-five percent of the state's population lives along the Front Range. Three and a half million people live in the South Platte Basin alone with an estimated 6 million people by 2050. Agriculture uses the large majority of water here as it does in all our other river watersheds, but the urban population and its growth will have increasingly large impacts on the demand for water in the future (Figure 2).

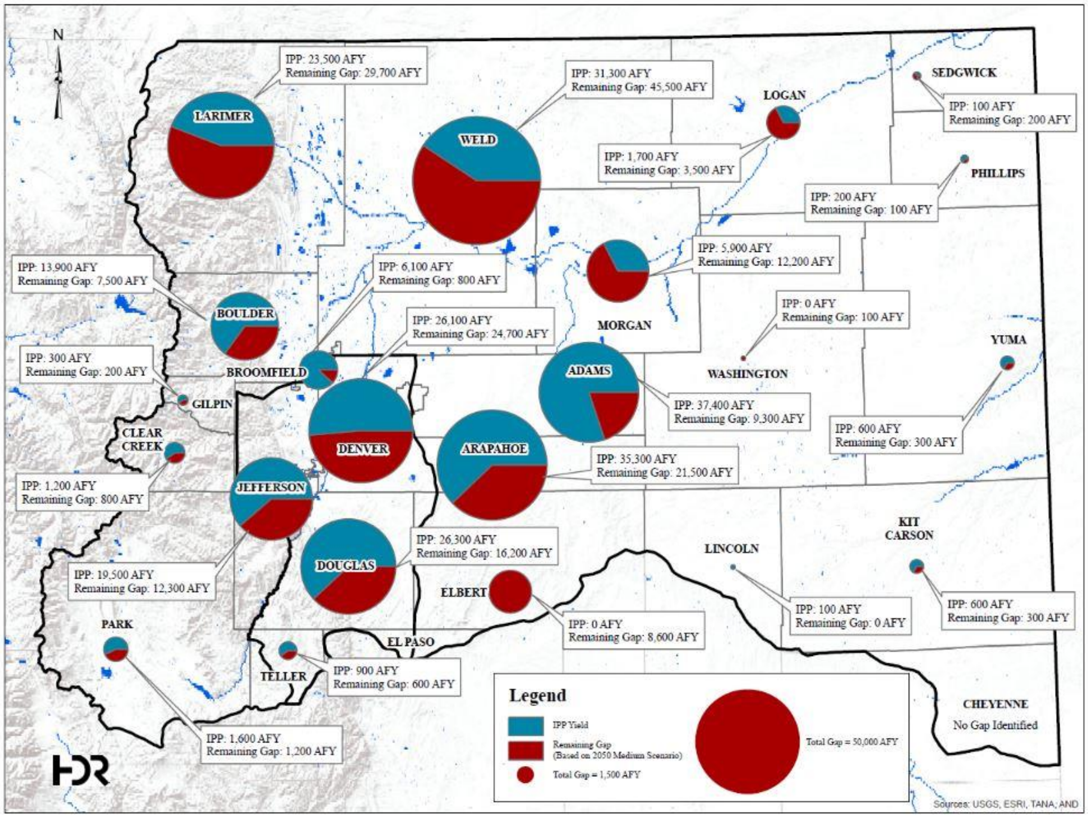


Figure S-3. Remaining Gap by county (65% IPP Success Rate in the South Platte Basin and 88% IPP Success Rate in the Metro Basin)

Figure 2 – The expected water supply gap by county for the near future. (courtesy of the South Platte Basin Roundtable, Metro Basin Roundtable, and West Sage Water Consultants, 2015)

The basic water issue here is the same as all our watersheds – there is much more demand than there is supply. In the South Platte and to a great extent the North Platte Basins, there is virtually no un-allocated/un-appropriated water. The only time the amount of water exceeds the appropriation is during severe flood events as seen in September of 2013. You can hardly plan for new water resources if the only flows available above appropriated levels are during high flood stages of your rivers and streams. Much of the water in the basin is already being used multiple times with reuse and return flows a large part of the water supply. Even these flows are appropriated for users downstream including the water that needs to flow into our neighboring state of Nebraska to satisfy Compact requirements.

The South Platte/Metro BIPs include some broad guidelines that address the major issues in the basin. The first of these is to minimize the impact on the agricultural sector. Even in this most urban of basins, agriculture is a huge contributor to the economy. Not only is it the most irrigated land in the state, it produces some of the highest value crops. Agriculture is not going away. The second guideline is to try to offset any decrease in water going to the agriculture sector and to ameliorate the loss of water from agriculture caused by increased urban usage and prolonged or chronic drought. Lastly, much like all the other basins, the South Platte and Metro Basins want to proactively protect and enhance the quality of the water in the basin and improve the environmental conditions of the basins' water resources to include improved recreational use of the water.

A critical and unique characteristic of the South Platte Basin is the geologically important Denver Basin aquifer system. The Denver Basin is a geologic structural basin that is not evident at the surface but resembles a buried bowl made up of several bedrock strata. Each of the layered strata is its own aquifer. The lowest of these strata is the Laramie-Fox Hill aquifer, with the Arapahoe aquifer above it. Above that is the Denver formation and finally the Dawson formation – each of these also are aquifers. The Denver Basin stretches from northern El Paso County in the south to the South Platte River and beyond in the north, and from the mountain front in the west to approximately the western boundary of Washington County in the east. It is big and deep and has been used for groundwater supplies for well over a century. Because so much water has been taken out of these four aquifers, there are serious discussions about using them as new storage for water, much like underground reservoirs where water can be stored during wet years and retrieved in dry ones. There are many unresolved issues with this approach but is a critical component in planning for the future of water storage and supply here.

Roundtables for all the basins were tasked with devising possible solutions to what seem the many, intractable problems. The South Platte and Metro Basins are no different. The Interbasin Compact Committee (IBCC) is a committee mandated by the Colorado Water Conservation Board to serve as the coordinating organization for all of the basin roundtables. The IBCC issued a suggested "four legs of the stool" approach to water planning for all of the BIPs. These four legs include enhancement of the conservation and reuse efforts, a basin-wide agreement on projects and processes the basin wants to go forward, a look at agricultural transfers, and, finally, acquiring new Colorado River supplies. This last item may be the most contentious as we will see when we discuss the western slope basin BIPs. The South Platte and Metro Basins have incorporated these four legs into their plans (South Platte Basin Roundtable, Metro Basin Roundtable, and West Sage Water Consultants, 2015).

The North Platte watershed in Colorado is essentially contained entirely in Jackson County and North Park. In 2013 the county population was estimated at 1,365, making this the least populated basin in the state. Nonetheless, the North Platte Roundtable has also developed a sophisticated and functional BIP. The county is very dependent on agriculture for its collective livelihood. It is no surprise that their BIP stresses the benefits of agriculture and the restoration and modernization of the infrastructure that allows irrigated agriculture to survive. They also stress the need to use their allocated water resources to the maximum extent possible. But the plan also stresses the commitment to maintain healthy river systems and wetlands. Several tributaries of the North Platte including the Michigan, Illinois, and Canadian Rivers create the most quintessential wetlands in the state. Sprawling and expansive willow carrs, perfect moose habitat, cover large areas of the valley bottom, especially on the east side of North Park. These wetlands are one of the main reasons the Colorado Division of Wildlife (now Colorado Parks and Wildlife) with the help of several Federal agencies reintroduced the first 24 moose here in 1978. This small reintroduced herd has become a relatively large population of moose numbering nearly 2,300 in 2016 now allowing for moose hunting in several game management units (North Platte Basin Roundtable, 2015).

The Rio Grande basin has at its core the San Luis Valley. The Valley lies at an average elevation of almost 8,000 feet, but it is essentially the only true desert in the state. It receives eight inches of precipitation or less in a normal year. The real water sources for the Valley are the San Juan and Sangre de Cristo Mountain ranges that define the western and eastern sides of the valley respectively. The basin depends to a large extent on a single economic source – agriculture. And with the Rio Grande the main water course in the central and southern part of the valley, farmers and ranchers must rely predominantly on groundwater to sustain its main source of income. This groundwater is replenished annually from the runoff of the two mountain ranges – without this large store of underground water, the valley could not sustain its current agricultural economy to any significant degree. Unfortunately, at the moment more water is being pumped from the aquifers below the valley than is being replenished. This is a dilemma much like we have seen in the other basins.

The Rio Grande Basin Roundtable realizes the fragile nature of their water narrative. In the Rio Grande BIP, there is a prominent list of the challenges facing the basin in the coming years. These include the commitments to the Rio Grande Compact (see the **Compacts** chapter), climate change and recurring drought, and significant declines in available groundwater. The roundtable also outlines some challenges that are very detailed including wildfire and forest diseases, especially in the mountains where most of their water comes from, dust on snow that causes the snow to melt too fast to be captured, and the need to plan for threatened and endangered species.

The BIPs are meant to outline challenges but also to provide solutions for how these issues will be addressed. The Rio Grande BIP defines 14 specific goals for the basin (Figure 3). The first goal reflects the same concerns as in all of the basins – protect and preserve watershed health and ecosystem functions. Unlike in decades past, the people in the Rio Grande basin are realizing that the health of their water systems, both flowing water on the surface and groundwater, is critical for the human and economic vigor in the long run. The BIP emphasizes the need to manage water to support the agricultural sector but also to explore projects and plans that will benefit multiple users including municipal, industrial, and recreational. Other goals of the plan deal with aging infrastructure; maintaining prior appropriation water rights; addressing water administration issues that arise from overlapping and contradictory rules and procedures; and, developing water education (Rio Grande Basin Roundtable, 2015).

TABLE 8. Basin needs and goals as met by identified projects, listed in alphabetical order.

	Project or Method	Basin Needs Met					Basin Goals Met														
		Ag	M&I	Env/ Rec	Water Admin	Total	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
1	Boatable Days Flow Evaluation			✓	✓	2	✓	✓				✓	✓			✓	✓	✓	✓	✓	9
2	Conejos River System Confluence Management Project	✓		✓		2	✓	✓		✓	✓	✓				✓	✓	✓		✓	9
3	Consolidated Ditch Diversion and Headgate Rehabilitation Project	✓		✓	✓	3	✓	✓		✓	✓	✓			✓	✓	✓	✓		✓	10
4	Closed Basin River/Creek and Wetland Water Table Study	✓		✓	✓	3	✓	✓	✓	✓		✓				✓	✓	✓	✓	✓	10
5	Doppler Radar Weather Forecasting Project	✓	✓	✓	✓	4	✓	✓				✓	✓			✓	✓	✓	✓	✓	9
6	Economic Impact Statement Analysis of the Effects of Reduced Groundwater Irrigation on the Rio Grande Basin	✓			✓	2		✓	✓		✓			✓							4
7	Groundwater Management Subdistricts	✓	✓	✓	✓	4	✓		✓		✓	✓				✓		✓			6
8	Hydrologic Recharge Feasibility Study for Rio Grande Basin Augmentation	✓		✓	✓	3	✓	✓	✓	✓	✓	✓				✓	✓				8
9	Increasing Water Holding Capacity of Soil for Agricultural Sustainability in the San Luis Valley	✓		✓		2	✓	✓	✓		✓	✓		✓	✓	✓	✓				9
10	Jim Creek Riparian Protection and Restoration Project	✓		✓		2	✓					✓					✓	✓			4
11	Kerber Creek Restoration Project—Middle Parcel	✓		✓		2	✓				✓	✓		✓	✓		✓	✓			7
12	Mountain Home Reservoir Dam Repair	✓		✓	✓	3				✓	✓	✓	✓							✓	5
13	The Plaza Project—Phase 3: Prairie Ditch Implementation Project	✓		✓	✓	3	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓		✓	11

table continues

Figure 3 – A partial example of the needs and goals for the Rio Grande Basin according to their implementation plan. (courtesy of the Rio Grande Basin Roundtable and DiNatale Water Consultants, 2015)

Although the basin of the main stem of the Colorado River is not nearly as large as either the Arkansas or South Platte basins, in reality, the entire western slope of Colorado comprises the Colorado River basin. The Gunnison, the San Juan/Dolores, and the Yampa/White Green River basins are major tributaries to the main Colorado, and their combined area (about 38,500 square miles or 37% of the state's land area) far exceeds that of any of the other watershed areas. Unlike any of the other basins, overall the Colorado River basin has a surplus of water, at least as far as developed beneficial uses are concerned. But that is, of course, before one takes into consideration the massive transmountain diversions that have been developed. Between 450,000 and 600,000 acre-feet of water is diverted from the West Slope of Colorado annually. These are the current rates, but water users in other basins are planning, or at least hoping for, more transfers in the future to help them with their supply/demand water resource gaps. Enough water rights are owned by people and organizations outside of the Colorado Basin, but still within the state, to divert 140,000 acre-feet more. All of the Roundtable groups on the West Slope identified as one of their top priorities making future water diversions from the Colorado basin a “last resort” for solving Colorado’s water problems. It is estimated that there will be a 630,000 acre-foot gap in water demand over water supply by 2030 in Colorado. These BIPs and the state Plan are meant to try to reduce that gap. If you are residents in a basin on the East Slope and dealing with water shortages (the South Platte Basin alone will need almost 410,000 acre-feet), the obvious solution would be to bring more water from the West Slope. The Colorado Basin BIP stresses that other basins in Colorado should focus on their own, internal solutions first and not merely depend on new transmountain diversions from the West Slope (Figure 4).

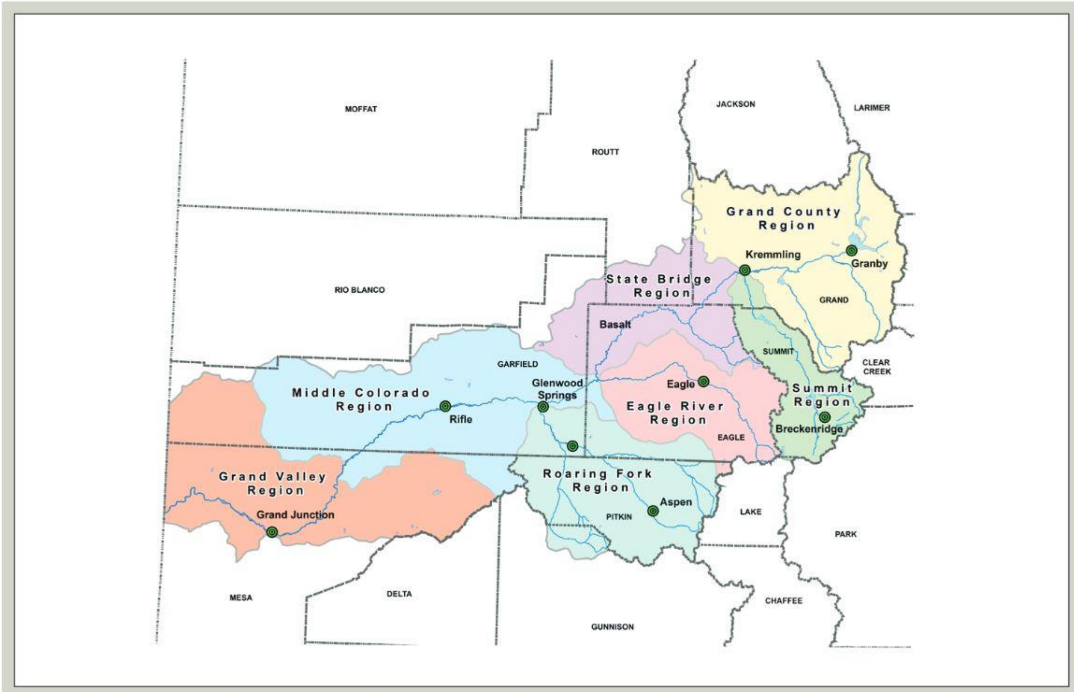


Figure 10. Colorado BIP Regions.

Figure 4 – Map showing the sub-basins that the Colorado Basin has been divided into. (courtesy of the Colorado Basin Roundtable, 2015)

The Colorado Basin has other significant issues because it is also the headwaters for the entire southwestern U.S. This large area of the U.S. is looking at a probable reduction in precipitation in the next few decades of at least 20% due to chronic drought caused by climate change. This means that the entire Colorado Compact (see the **Compacts** chapter) is in serious trouble. Most of the water in the Colorado Compact of 1922 comes from the upper basin states of Utah, Wyoming, New Mexico and especially Colorado. If reductions of 20% are realized throughout the Southwest, and commitments for the lower basin states (Arizona, Nevada, and California) cannot be met, serious curtailments of water use throughout the Compact area might be mandated. Lakes Mead and Powell are already at extremely low levels, and these reservoirs are meant to be the water rheostats used to even out the good and bad years for the Compact entities.

Most of the additional themes for the Colorado BIP are similar to the other basin BIPs. Ecosystem health, agricultural stability, clean water, conservation, and streamlined administration are all included. The West Slope feels that they need to be given the chance to develop their water systems just as the other basins have. For many years they lagged behind in water development because they had many fewer residents and water needs. But that situation is changing rapidly. Both agriculture and recreation are burgeoning economic sectors that the West Slope is relying on for its future. They are willing to cooperate with the rest of the state to create a stable and viable water future, but they are also leery because of past transmountain diversions taking place without them having much say in the process (Colorado Basin Roundtable, 2015; Gunnison Basin Roundtable, 2015; Southwest Basin Roundtable, 2015; and, Yampa/White/Green Basin Roundtable, 2015).

Residents and visitors to Colorado use an estimated 5 million acre-feet of water a year. On average one acre-foot of water is enough for a normal, urban living family of four for a year – so, if the water were to go only to residential users, we would have enough for about 45 million people. The state currently has about 5.759 million people (2020); where does the rest of the water go? Agriculture takes most of it. In some places in the state, farming and ranching account for over 80% of the water use. There are also many other uses including industrial, recreational, and environmental. With all this water use and all the pipelines, dams, reservoirs, and river systems, the state of Colorado only spends about one-tenth of one percent of the state budget on natural resources issues, and water is only a part of the natural resource picture. It is certainly a cliché, but water really is the life blood of the state, and it deserves much more widespread attention and care than we have given it in the past. The recent historical level droughts have brought that point home. The newly crafted *Colorado Water Plan* is intended to help increase the visibility of the importance of water, get people on the various sides of water issues talking and reasoning together, and improve the prospects that the water we need in Colorado in the decades to come will be available for all.

According to the Colorado Water Conservation Board (CWCB) (2015, p. 3), "This plan is a roadmap that leads to a productive economy, vibrant and sustainable cities, productive agriculture, a strong environment, and a robust recreation industry." To make this all-inclusive plan work in the coming years and decades, the voices of many people, organizations, conservancy districts, state and federal agencies, and others must be melded into a relatively unified vision. This is, after all, just a plan. The real efforts to make it a reality are yet to be seen, but it is at least a good faith effort at trying to start the statewide conversation to attempt to solve increasingly important issues for future generations of Coloradans.

The making of the plan is simple in concept – take input from all of the river basin roundtables (made up of various representatives from disparate constituencies) and look at concerns, possible solutions, and specific projects that might be doable. The CWCB defined three specific core values that were to be kept in mind during the writing of the plan. These values stress: 1) a productive economy that supports sustainable cities, productive agriculture, a robust skiing industry, and other recreation and tourism issues;

2) efficient and effective water infrastructure programs that support smart land uses; and, 3) a strong environment with healthy watersheds, rivers, streams, and wildlife ecosystems (2015, p. 1-6). The CWCB also outlined the six major, statewide water challenges they consolidated from the basin BIPs. These are:

- the growing water supply gap
- agricultural dry-up
- critical environmental concerns
- variable climate conditions
- inefficient regulatory processes, and
- increasing funding needs

The *Plan* is long and complex, but it has eight relatively simple and understandable measurable objectives. The first, and maybe the most important, objective is to reduce the potential 2050 water supply shortfall of 560,000 acre-feet to zero. This particular objective will not be an easy one to reach. With a rapidly growing population demanding more water, trying to keep irrigated agriculture healthy and increasing industrial uses, on top of a predicted decrease in precipitation for the state and region, reducing the gap between supply and demand by this much will test the cooperation of all the basins. But the consequences of not reducing this deficit are so dire, that the state needs to be up to the task.

One contributor to reducing the supply gap comes in the second objective – conservation. It is estimated that 400,000 acre-feet of water can be saved by municipal and industrial conservation measures. This number is an optimal estimate as many water users may not do their part to reduce their use of water. But the number also shows how much water is wasted in our very dry state. A barrier to increasing conservation significantly is that most of the conservation efforts have been done in urban areas. Denver has decreased water use per person by 25%, for example. But urban areas only use about seven percent of the water in the state. Most of the rest of the water is in agriculture where conservation measures are often viewed as risky at best. To get more water from the agricultural sector will be a real challenge going into the future.

The third objective is to realize the opportunities communities have for adjusting their land uses. The plan looks to urban/suburban land use development as places that might integrate water-saving designs. Urban infilling with smaller yards, new urbanism with multiuse structures incorporated from the planning stages to buildout, and landscaping with climate appropriate plants are some of the ways land use changes can save water or use it much more efficiently than we do today.

Examining agriculture and its water use is the fourth objective. It would be unrealistic and foolish to ignore the role agriculture plays in water in the state since it accounts for 70 to 80% of the water use in many areas. The *Plan* states that we want our agricultural industry to thrive too. It outlines a desire for our farms and ranches to keep pace with national and global production rates even if we reduce agricultural acreage in some cases. The *Plan* also realizes there will be transfers of water from farms to cities, but it promotes alternative creative, transfer methods doing so such as re-leasing back to farms. It estimates that without implementing some of the proposals in the overall *Plan*, we could lose up to 20% of our agricultural land and 35% of our production by 2050.

Many of the BIPs highlighted the need for more and better maintained water storage. The *Plan* promotes an additional 400,000 acre-feet of storage to manage and share some of the water freed up through the hoped-for conservation strategies. This will not be an easy objective to attain for several reasons: one, we may not get the full 400,000 acre-feet of conservation planned for; another is who decides and pays for this new storage, and where will it be built? Finally, the most optimal sites for storage facilities are already used. Finding appropriate new sites will be a physical and fiscal challenge.

A goal in every BIP was to improve water quality and environmental and watershed health. This is also one of the objectives in the state *Plan*. It is hoped that at least 80% of locally prioritized water quality and health issues will be addressed in future water projects and at least 80% of the designated critical watersheds are protected through these efforts by 2050.

The seventh objective may be the most problematic to attain. This objective declares that the state and the basins need to raise $100 million a year, for a total of $3 billion by 2050, to help pay for all the other objectives listed. With much less than one-tenth of one percent of the current state budget going to water issues, a many order of magnitude increase in funding needs to occur. Where will this money come from? Some of the proposals include a guarantee fund and green bond program for environmental and recreational uses. There may be some money reallocated from the state Severance Tax Perpetual Fund. There is also a consideration for the state bonding projects that may have some payback funding possibilities. These money issues will be hotly debated in the years to come, but the funding needs to be available if any of these objectives are to become reality.

The last objective and possibly the one that will allow the other objectives to occur, especially the funding issue, is one of education. The Colorado public is mostly woefully ignorant of water issues. If they get water out of their tap, what is the big deal? The goal of this objective is to significantly increase the level of public awareness of water issues by 2020. One part of the strategy is to involve outreach experts, educational and research institutions, and the Governor's Colorado Innovation Network to help create new ways of getting the public involved in water matters (CWCB, 2015).

Many people involved in water issues in Colorado are concerned that the *Plan* stresses the ideas of collaboration and discussion with few specifics about how exactly we will deal with the issues in the various basins. The *Plan* was also based on relatively older data that is woefully optimistic. There are proposals to update the data in the next few years, but there is no guarantee that the new data will spur more aggressive and controversial fixes to the multitude of issues.

Nonetheless, work on the Water Plan has been robust. The current governor, Jared Polis, has been very supportive of the plan and is putting considerable effort into getting specific results. In 2020 he said:

> The Colorado Water Plan provides an actionable vision for protecting Colorado's most precious natural resource – its water. Updating the plan to include the latest science, align with climate planning, and better prepare Colorado for the future is critical to our shared success. This requires our combined efforts to enhance project planning and set bold actions that support all areas of the Water Plan. My administration is

proud to be working with you to address our water challenges head on and find collaborative solutions that work for everyone. (CWCB, 2020)

Significant progress on the Plan has been made. On the fifth anniversary of the Plan in 2020, The CWCB published a list of accomplishments to date. These included: 1) 76% of all shareholder proposed actions have been completed or at least begun; 2) 241 water projects across the nine regions have been funded by grants from the state; 3) $420 million has been loaned from the CWCB money to 82 statewide projects from the Water Project Loan Program; and, 4) CWCB has granted $62.5 million to water projects across the state. The CWCB has also set up a seven-year cycle of updates to the Plan. The first of these will be done by 2022. (CWCB, 2020).

The *Colorado Water Plan* and all of the BIPs have started the necessary conversations, and they have taken a tremendous amount of work, cooperation, understanding, and discussion to create. When one thinks of what the water future, really just the future, of the state will be a few decades down the road, these plans are the best hope that we have of making that future livable. This chapter will end with the opening quote from the state Plan. It is optimistic and forward looking. May it come to pass.

> People love Colorado. Our iconic mountains, rivers, minerals, plains, communities, forests, snow, wildlife, and wilderness have drawn people by the millions to our centennial state. Our population has ballooned from 1 million in 1930 to over 5 million today and could nearly double by 2050. Sustaining this growth requires water. While we grow at this pace, how do

we preserve what we love about our state? Colorado’s Water Plan has answers (CWCB, 2015).

Towns

There are river towns, and then there are river towns. Almost everyone knows that Paris and the Seine, London and the Thames, Cairo and the Nile, and St. Louis and New Orleans and the Mississippi are river towns of international repute. The scale of these waterways is large, and the cities basically exist only because they were born on their respective rivers – they are defined by them. The flows of these globally scaled rivers dwarf those we have in the West of the United States. The discharge for the Seine, for example, is more than 2.6 times that of our four Colorado rivers average discharge combined; the Nile's discharge is well over 13 times our four rivers total; and, the Mississippi is nearly 80 times what our rivers discharge. The world renown river towns above have, in large part, built their economies around the commercial river traffic that comes in the form of ocean-going vessels and massive barge tows with dozens of barges being pushed by a single pusher tug. Huge quantities of commodities go into and out of these ports every day.

Our Colorado river towns are a bit different. None of our rivers are accessible to anything remotely resembling an ocean-going vessel or barge tow. The state of Colorado is the "Mother of Rivers", but these rivers have miniscule flows with extremely shallow channels in comparison to the rivers mentioned above. Our rivers are much more suited to rafts, canoes, and kayaks than to tow boats and tankers. Our river towns, consequently, have none of the normal port paraphernalia of docks, jetties, railroad connections, or cranes – instead they may have a nice flat rock to launch a kayak at the edge of the river or, if they are really river oriented, maybe a boat ramp. But Colorado's rivers have a much more intense and human scale about them that make these waterways personal and approachable.

Some of Colorado's towns and cities that lie athwart our four rivers embrace them with enthusiasm and delight – others look at the water in the river as a commodity to be used, often only for irrigation of adjacent lands. And still others seem to ignore the river in their own backyard. All of these towns and their river connections are intriguing and useful for understanding how we see and use the landscapes of our waterways.

Even though the Colorado is by far the largest of our rivers, there are few major towns along its route from the Continental Divide to the Utah border. A list of the small towns along the river's course include Grand Lake, Mineral Hot Springs, Rifle, Parachute, De Beque, and Palisade. The two larger towns that dominate along the Colorado are Glenwood Springs and Grand Junction.

Glenwood Springs is truly of the river, not just by it – from its early history it has had a singular relationship with its water course. Ute bands who lived and hunted in the vicinity of what has become Glenwood Springs knew from early times that there were healing mineral hot springs, especially the Yampah spring, that flowed out of the hills just north of the river. Over centuries, as they passed through this area in their yearly movements, they would stop and use these natural spas. When the area was opened to homesteading in the 1880s, it could have been expected that settlers would find the locale appealing. The first recorded land acquisition in the future Glenwood Springs was at the confluence of the Roaring Fork and Colorado Rivers by James Landis. He was soon bought out by entrepreneurs who saw the potential of the hot springs, if not the river, to establish a resort. In fact these developers actually moved the river to the south in order to incorporate a large island into the north shore to make a larger plot of land for the planned resort. Once the Denver and Rio Grande Railroad came in 1887, the resort town of Glenwood Springs boomed. Local coal mining and nearby silver mining in Aspen and Leadville also fueled the growth of the town. The first road from Denver to Grand Junction ran through Glenwood Springs and was not completed until 1899. Because of the very steep and narrow Glenwood Canyon to the east of the city, the engineering marvel of I-70 was not finished through the canyon until 1992.

The river itself was used for irrigation of crop and grazing land during these early years, but there was little use of the river in more focused ways. In the last few decades there has been some rafting and kayaking through the canyon and the town, but no concerted effort to tie the community to the river more strongly. Then in 2008 things changed. Jason Carey saw the potential to create a water amenity that kayakers and surfers (of all things) could use. The Glenwood 'Wave' was built just to the west of the city at the Midland Avenue Bridge and is part of the Glenwood Springs Whitewater Park (Figure 1). Numerous different waves can be surfed depending upon the flows of the river (RB Team, 2017). There is a website-users can access to find out current the flow status of the river (www.riverbrain.com/run/show/200).

Figure 1 – Glenwood Springs whitewater park with the "surfing" wave.

There are new plans for three more potential whitewater facilities in the Colorado as it runs through Glenwood. These parks are tentatively called "No Name", Horseshoe Bend", and "Two Rivers." The issue that is delaying progress on these facilities is water rights (see the chapter on Law). Colorado Springs and Aurora own water rights upstream on Homestake Creek and in Homestake Reservoir. To make one or more of the whitewater parks viable, they need intermittent releases of water from Homestake Reservoir at certain times when demand for the parks is highest. Thus far the two cities and the Colorado Water Conservation Board have denied the requests, but the plan proposed by Glenwood Springs is now being adjudicated by a water court. No one is sure if or when the decision will be made (Gardner-Smith, 2016).

Grand Junction got its name not so much for a really grand junction of rivers that occurs there but for the fact that one of those rivers was called the Grand River – the other was its major tributary the Gunnison River. That was the original Anglo name of what was renamed the Colorado River during the negotiations on the Colorado River compact in the early 1920s (see the **Compacts** chapter). The Gunnison River is most famous for its larger than life Black Canyon, and the Black Canyon of the Gunnison National Park, that the river has cut deeply just south of the West Elk Mountains.

Grand Junction is by far the largest city on the Western Slope of Colorado. It sits at the southwestern edge of what is known as the Grand Valley – a wide, naturally dry expanse rimmed on three sides by the Book Cliffs to the north, the Grand Mesa to the east-southeast, and the far northern edge of the Colorado Plateau to the south. The city was established in 1881 just after the Meeker "Massacre" in 1879 that doomed the Utes to removal from western Colorado and marked the end of at least 10,000 years of Native American presence in the region. By 1881 the area was open for settlement by miners, ranchers, and farmers; all of these industries would depend on their ability to use the water in both of the rivers flowing into and through the valley.

River infrastructure such as the Roller Dam on the Colorado upstream of Palisade and irrigation canals siphoning water out of the rivers allowed Grand Junction and the small farming communities up and downstream from the city to thrive. Water drawn from the Colorado has made the towns such as Clifton, Palisade, Fruitvale, Orchard Mesa, and Fruita and their surroundings the orchard and vineyard capital of Colorado. As seen in the **Compacts** and **Diversion** chapters, there is a limit to the amount of water that can be used from the river. Much of the Colorado's flow is legally owed to the downstream states of Arizona, California, and Nevada, and there is more and more competition for the limited water available. The growth of towns and cities in the region, for example, produce an increasing demand for residential water use. Recreational water demands have also increased, especially the desire for more free-flowing river water for kayaking, rafting, and boating. In addition in more recent years energy development has become almost an equal partner with agriculture in the area's economy, and water is an absolute necessity for fossil fuel development in whatever form that development takes.

If you spend any amount of time in and around Grand Junction, you will soon notice the significant presence of the oil and gas industry. Oil field supply companies, transient oil field workers, and the flow of trucks carrying the necessities for the hydraulic fracturing (fracking) sites throughout the region are signs that energy development is big in the Valley. Fracking uses a mixture of water and fracking 'fluid' under very high pressure to fracture the petroleum bearing rock formations deep underground, thus releasing the oil and/or gas from the rock and forcing it to the surface. A fracking well can be fracked multiple times, and each time it uses between 2 and 8 million gallons of water. Eight million gallons of water is enough to supply 25 four-person households for a year. Because that water is infused with highly toxic fracking fluid (the composition of which is mostly a secret because it is considered private corporate intellectual property), it must be disposed of, usually forced under very high pressure into deep wells where it will remain locked away in near perpetuity. There are literally thousands of fracking well pads in the Grand Valley and on the Roan Plateau to the north of the city. The math about how much water is removed long-term is staggering. This means that very large amounts of water and their rights are now taken permanently out of use from the Colorado River and its basin in far western Colorado.

There are a few pilot projects aimed at cleaning this water enough so that it can be reused for non-potable purposes, but large-scale treatment is still only a distant hope.

Another "on again, off again, on again..." energy issue that will impact water in and around Grand Junction is the potential for oil shale. Oil shale is not really "oil" shale but rather a pre-oil substance called kerogen. It exists in vast amounts in the rock formations of the Roan Plateau, especially in the Piceance Basin north-northeast of Grand Junction. There have been attempts since 1917 to invent a process for getting this hydrocarbon substance out of the rock and produce useful oil. Booms and busts have been the norm in the region in this quest. But if ever there is an engineering solution to this dilemma, it will create at least two major environmental concerns: the first is the gigantic refuse pile that would necessarily be created – literally mountains of material that will need someplace to be deposited; and, the second, and more to the point of this book, is the need for water to develop the industry. It is estimated that it would take up to 500,000 acre-feet of water a year to get full production from the shale in the region. To put that into perspective, the entire allocation of Colorado's share of all Colorado River basin water in the 1922 compact is about 3.9 million acre-feet/year. And currently nearly every drop of that allocation is already being used. The profound question then is, where does that additional water come from and who will be the water losers in this scenario?

Aside from these major water concerns in the Grand Junction area, there is also the use of the river for recreational purposes. Grand Junction does not have the intense recreational vision for the river that other towns have. It might be that the river is just too big at this point to have an intimate relationship with it. There are no kayak courses, few rafting companies are run out of the city, and there is no significant civic push for these activities to be more highly developed. Grand Junction does have the Colorado Riverfront Trail, and there are certainly people who fish and boat in the river, but river sports are not a central theme here as they are in Glenwood Springs or other towns discussed below (Figure 2).

Figure 2 – Grand Junction's Colorado Riverfront Trail.

The Colorado, at least by the standards of western waterways, is a big river along this stretch and thus not of the scale that invites someone to literally immerse oneself into it or play along the banks. The Arkansas River, however, by the benchmarks of most of the rivers in the humid eastern U.S., is really not much more than a large stream. Men, women, and children feel comfortable getting into the water and playing. In contrast to the Colorado, it is intimate and inviting. Certainly there are stretches of the Arkansas that are too fast moving and turbulent to swim or wade in, but much of the river is "user friendly." That is unquestionably true in the town of Salida where the river is considered a communal recreation amenity that all can share, and most do.

Like many of the mountain towns in the state, Salida began as a combination mining and ranching center. Only a year after it was incorporated, the Denver and Rio Grande Railroad arrived and made an immediate and important impact on the community. Salida became one of the railroad-maintenance centers with railyards and machine shops. Being a rail center was a big deal for the community as it spurred employment. In time the city and railroad made the town a center of industry for the Arkansas River Valley. One prominent component of this was the Ohio-Colorado Smelting and Refining Company that built its facility just northwest of the town center. A vibrant industrial village called Smeltertown grew in the shadows of the large reduction facility. Over time the smelter served to concentrate ores from a multitude of various minerals – gold, silver, lead, and zinc were predominant. But just like so many of the mining centers in the state, this extraction industry waned in the 1920s. Today all that is left of this industrial legacy in Salida is the 365-foot tall smokestack that dramatically marks where Smeltertown once sat.

This industrial history of the city has been overtaken in the last 40+ years by tourism, outdoor recreation, and river amenities along the Arkansas. The old and attractive downtown of Salida has been preserved as the state's largest historic district. The town has become an epicenter for the arts and culture in the Upper Arkansas Valley with its many artist studios, music venues, and famous Art Walk. But the main attraction in the Salida area, especially for younger generations, is the river that skirts the downtown (Figure 3).

Figure 3 – This view from the F Street Bridge in Salida shows a typical summer morning in the Arkansas River in Salida.

But the Arkansas River is much more than a beautiful stream that locals use as their playground. It is also a major whitewater venue for rafters and kayakers. In fact it is the most commercially rafted whitewater stream in the United States. At maximum flows just after snowmelt in the mountains, this river is a formidable whitewater haven. Because the river is so important, in 1989 the U.S. Bureau of Reclamation and then Colorado Parks Department worked together to create the Arkansas Headwaters Recreation Area that stretches from Leadville all the way down to Pueblo. This joint venture was established to promote the use of the fast-flowing river for boaters and, at the same time, help maintain the world class trout fisheries along the water course.

Salida has embraced this rafting and kayaking legacy as its own. A prime example is the Fib Ark (First in Boating the Arkansas) festival that started in 1949. This was a boating/kayaking/rafting/just-about-any-water-craft race from Salida to Cañon City. It was a 47-mile run during the highest water of the year; it was dangerous; and it was the highlight of the river year for the city. It was so dangerous at times that the FibArk now only runs 25.7 miles from Salida to Cotopaxi – considerably west of the Royal Gorge. This festival brings world-class whitewater enthusiasts from around the world. The city also hosts innumerable kayak races down its ½ mile kayak course and more 'freestyle' events where boaters demonstrate their more acrobatic moves in the swift currents near the F street Bridge.

An additional amenity for the Salida and Arkansas headwaters was the designation by President Barak Obama of 21,586 acres of the narrow defile of Brown's Canyon just upriver from Salida as the Brown's Canyon Nation Monument in 2015. This Monument is a unique joint venture between the U.S. Forest Service and the Bureau of Land Management. This area was so designated because of its legacy of gold medal fishing, whitewater stretches, and difficult access to the more or less pristine Monument lands.

People in the town of Buena Vista (or BV as many residents call it) would also claim Brown's Canyon National Monument as their own. Buena Vista is about 25 miles upriver from Salida and is near the northern end of the Monument, but until relatively recently, the river history of Buena Vista was quite different from that of Salida.

Buena Vista was incorporated in 1879 as a center for farming and a supply center for the burgeoning mining industry in the Sawatch Mountains, especially the St. Elmo area at the upper reaches of Chalk Creek and for the huge mining complex in Leadville near the sources of the Arkansas River about 35 miles to the north. Early in the town's history, three separate railroads arrived, making Buena Vista a major mountain transportation hub. The Denver and Rio Grande; the Denver, South Park and Pacific; and, the Midland railroads all were focused on supplying the innumerable mines with materiel and food supplies and on hauling out the mineral largesse of the region. During these early years, the Arkansas did supply water for the town and eventually electricity with an early hydroelectric power plant powered by the flows of river water but played little role in other aspects of the town's activity.

But the mining boom faded in the late 1800s and early 1900s leaving the town without a major economic driver. The population was reduced by more than half – in 1880s the population was about 2,100; it plummeted to about 750 in 1930 and did not get back to the 1880 number until nearly the year 2,000. The Arkansas has been a natural presence, but only in the last few decades, has there been a surge in the use of the river, mostly by a number of rafting companies using the swift flows of the river. These rafting companies are spread all along the banks of the river from several miles north of Buena Vista to many miles south of the town. The influx of tourists floating the river and recreating in the mountains nearby has given a boost to the local economy – after all, the sign as you enter Chaffee County does say without any false modesty – "Now this is Colorado." The river itself, however, was not really a part of the town's consciousness.

In 2003 that consciousness level started to have a revolutionary change. A sister and brother team of professional kayakers bought a 40-acre tract of land right along the river on the edge of downtown with a long water frontage and big plans. Kate and Jed Selby had a vision for a completely new kind of development – in the city planning and landscape architecture jargon it is called 'New Urbanism'. According to the Congress for

New Urbanism this "is a planning and development approach based on the principles of how cities and towns had been built for the last several centuries: walkable blocks and streets, housing and shopping in close proximity, and accessible public spaces." The siblings started by hauling away dozens of truckloads of trash that had collected in this informal garbage dump. In 2005 Kate Selby wrote a Great Outdoors Colorado (GOCO) grant proposal that helped build three new whitewater features in the river adjacent to their property and started a trail system along the river. In 2008 there was another GOCO grant that added more water features and some climbing structures in the development's internal park.

The development, called South Main for its location along that city street, is itself progressing at a measured and intentionally moderate pace that includes housing, coffee shops, retail facilities, and strong recreational components such as trails, open spaces, public venues, and of course access to the water. Because of the design components of the New Urbanism concept, the river is the focal point of the housing and other structures. In the minds of the Selbys, the real-life aura of living here is the closeness and accessibility of the river at all times and the fostering of neighborhood cohesion around the river and the accompanying amenities. The established parts of Buena Vista were somewhat concerned that South Main would just be an appendage of high-end housing that would not be a part of the community as a whole, but what has been slowly happening instead is that this development has also spurred civic and commercial engagement in other areas of town. The long-term verdict on whether the Selby's gamble will pay off in a more walkable, sustainable, and river focused community is still out, but the promise of a new and vibrant way of connecting with their river seems bright (Figures 4 and 5).

Figure 4 – The South Main development is new urbanism taken straight from the textbook. Shops, housing, and recreation come together at the Buena Vista Whitewater Park.

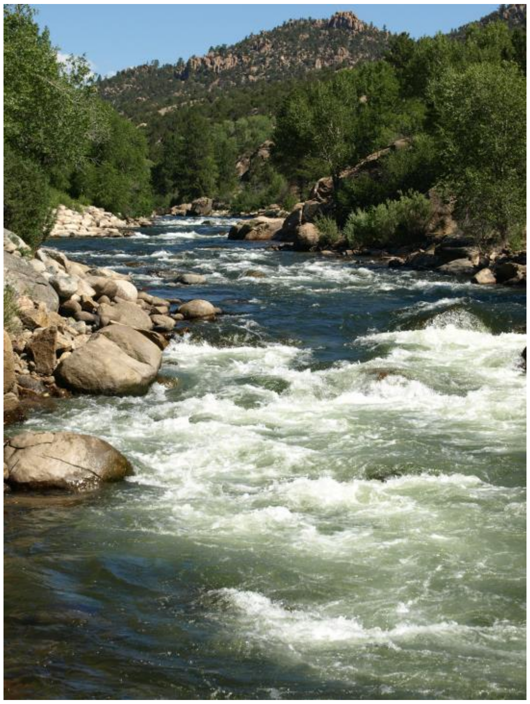


Figure 5 – This is a stretch of the whitewater structures along the riverfront in Buena Vista as part of their whitewater park.

Pueblo was the western equivalent to the quintessential river town. It sits at the confluence of the Arkansas River and one of its largest tributaries on the eastern plains, Fountain Creek. After many fits and starts about its name including North Pueblo, South Pueblo, Bessemer City, and a few others, it became just Pueblo – although in the second half of the twentieth century, it again added Pueblo West. The need for a reliable and large water source, especially after the steel industry located there, was the impetus for the city's development. Pueblo is definitely a plains city sitting many miles from the mountain wall to the west. The rapids and swirling flows of the Arkansas as a mountain stream are nearly non-existent. But being built in this flatter environment also made the city much more flood prone. The flood of 1921 (see the **Too Little, Too Much** chapter) was the second largest flood in terms of deaths in Colorado History. It was such a massive flow of unrestrained water that the permanent channel was moved a half-mile south to the position it still occupies today on the southern edge of downtown instead of through the middle of downtown.

In the many decades following this massive event in the city, at least three major engineering projects were built. One of these was the Pueblo Reservoir (completed in 1975) a few miles west of the city. The reservoir was built to capture flood waters before they hit the city and to be a storage facility for water that cities such as Colorado Springs and Aurora owned the rights to. The second of the engineering structures was the channelization of the river as it flows through the city – the original concrete channel that was built soon after the flood and has since been rebuilt. This created a substantial concrete lined channel that restricts the natural movements of the river as its flows wax and wane. Anyone driving through the city along Interstate I-25 will note the parade of murals painted on the angled walls of the channel visible as you cross the river.

The third project did not occur until the very end of the twentieth century. In 1982 there was a severe contraction in the American steel industry that significantly affected the steel mills in Pueblo. The city was in its own mini-depression with the resulting job losses and population decreases that accompany severe economic downturns. The city formed a "Historic Arkansas River Task Force" which devised plans to revamp the entire area of downtown Pueblo along the river frontage. They felt that they could create a multi-use river park and revitalize the downtown at the same time. The result was the opening of the Historic Arkansas Riverwalk District in 2000 (Figure 6). This development is not exactly on the river as water was diverted into sculpted channels amid walkways and commercial establishments. There were also a series of eight whitewater structures for kayaking, rafting, and river surfing constructed in the river itself. It is not the intimate setting of Buena Vista or Salida, but it is an attempt to use the river amenities as thoroughly as possible.

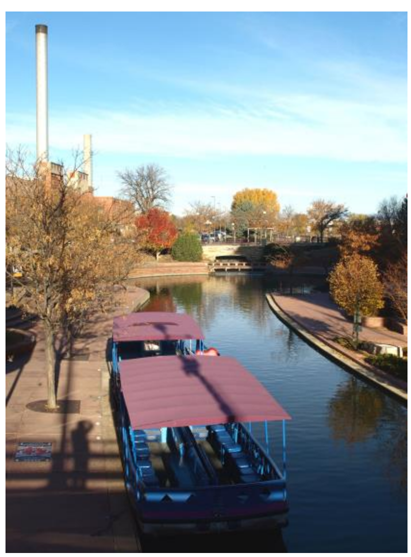


Figure 6 – This is part of the Pueblo River Walk near Union Avenue in early morning.

Denver is by far the largest city in Colorado that lies on the banks of one of our rivers. Long before it became a major urban area, Denver and Auraria claimed land on the northern and southern banks of Cherry Creek respectively at its confluence with the South Platte River. Minor finds of placer gold were found there in 1858. These finds were a lure to gold seekers although they finally ended in little development of any mining in the local area. They did, however, spur the search for gold upstream and into the mountains, and major gold strikes occurred in 1859 near the current sites of Central City and Blackhawk – the dash to these gold fields became known as the "Pikes Peak or Bust" gold rush even though Pikes Peak was 70 miles to the south.

Denver was born on the banks of the South Platte River, but the river for many years was only viewed as a source of water for the rapidly expanding urban area. The river was never large, and it was soon overwhelmed by the shear size of the megalopolis that surrounded it. It wasn't until the last part of the twentieth century that Denver and its many suburbs realized the value of the river as a water amenity valuable enough to invest time, money, and expertise. The results of these investments are numerous and still ongoing. One example is the 18 mile-long South Platte River Trail which hugs the banks of the South Platte, mostly through Denver itself. This trail links to a trail system in Adams County to the north and Arapahoe County to the south. All of this trail system is part of the much larger Front Range Trail that is planned to eventually stretch from the Wyoming Border in the north to the New Mexico line in the south.

The river itself is the focus for myriad whitewater parks and structures built in the river to provide kayaking and rafting opportunities. Many of these structures are parts of the park systems of Denver and its suburbs. The most urban/visible one is Confluence Park that sits at almost the exact spot where the City of Denver began at the confluence of Cherry Creek and the South Platte (Figure 7). Like many of the smaller communities discussed above, Denver has started to appreciate the value of the major water course running through its urban area. The city and its suburban neighbors are putting considerable resources into making the river the amenity that attracts locals and visitors alike. Of course there are issues that arise as in any urban setting. These include homeless camps along the banks of the waterway, urban blight in some areas, and the occasional industrial sites in close proximity to the river. These issues are always vexing and need community involvement and resources to solve.

Figure 7 – This is Confluence Park in Denver where Cherry Creek and the South Platte River come together to create a significant recreation amenity.

The towns along the Rio Grande in the San Luis Valley all have a legacy of being railroad towns. Del Norte was a supply center for the mining camps of the San Juan

Mountains to the west with the railroad being a critical operation. Monte Vista was also a railroad stop and watering hole for the railroads. Alamosa became a very active and important rail maintenance center for the entire southwestern corner of the state. None of these places thought of the river that ran through, or at least near, them as much of anything but a water source for their municipal needs. There was, and still is, a large agricultural component to the use of the river – in fact often more water is taken out of the river for irrigation today than can be sustained in relation to the Rio Grande Compact (see the **Compact** chapter). The flow levels of the river are now augmented by water drawn from the San Luis Lakes area some 25 miles northeast of Alamosa to satisfy compact obligations. There are a few city parks along the river and fishing is an active source of recreation, but no infrastructure has been built to promote the kinds of water sports the other river towns promote. In the future there might be some recreational opportunities developed along the Rio Grande, but there are no definitive plans for these in the near future.

Colorado's rivers have already become a significant recreational resource for the state. Fishing, rafting, swimming, and tubing are popular activities in and along our four rivers (more in some than others). With rapidly increasing population increases, these uses of our waterways will only gain strength and popularity. People move to the state for many reasons, but one of the most powerful is the area's attraction for outdoor enthusiasts. This trend will only get more intense in the years to come.

Too Many – Too Few

All four of our rivers create ribbons of life along their lengths from the headwaters to the sea. The riparian and aquatic organisms that line and inhabit the waters and the banks of the rivers are some of the most fecund and biodiverse landscapes in Colorado. Most people think of the well-forested montane and subalpine zones in our mountains as the essence of plant and animal life in Colorado. But the mountains are, in reality, relatively sterile environments in comparison to the intense variety and biomass production of the river zones. Not only are our riparian areas rich in total biomass produced, they are also teeming with a high diversity of plant and animal species. Biodiversity is considered a hallmark of healthy natural and human systems by conservationists, ecologists, biogeographers, and a myriad of others knowledgeable about how the ecological systems of the world work. Biodiversity is a key link in the chain of organisms and processes that keep the world a viable place for humans and animals, plants, and all other creatures.

A well-meaning question that is often asked is, what is biodiversity and why should we care about it? The simple answer is that it is a term that defines how the multitude of organisms at all scales work together to make a particular place function naturally. In a real way it is an umbrella term that encompasses all the varied ecosystems in a place or region that create the natural world we see and sense. To understand more, you must understand the concept of an ecosystem. An ecosystem is the complete set of physical processes, climates/microclimates, and organisms that function to create a specific landscape – a landscape that can extend from a few millimeters across to one that stretches for tens of miles. The quintessential point is that it is a system of interlacing and interacting energies, molecules, and creatures from the microscopic to the megascopic that function together. If some part of the system is changed or removed or some new component is added, the system may have a hard, if not impossible, time to continue to function normally. Removing or changing one element from the system may not alter it much. Removing a second element may have some effect. But eventually if you remove that 'one more thing' from the system that creates a threshold, it collapses – more often than not we cannot predict where that collapsing point is until it happens. Usually, the more diverse the system, the less the impact there is from altering just one thing. Being more diverse allows the system to fend off failure from small variations better than a system that is less diverse.

Our rivers and their environs are naturally biodiverse and robust. They have been evolving and functioning as natural systems for millennia. But today there are many outside influences on them that are increasing the number of impacts that can have potentially critical results. These impacts come in many forms. Two of the more critical ones come simply from having too many of certain species in our systems or from having too few of others. With our ever-shrinking world of high-speed air travel, containers coming from a multitude of countries, and our desire to import exotic plants or animals, we are often inadvertently introducing organisms that are not native to the new place. Three things can happen when we intentionally or inadvertently bring in outside organisms into our natural ecosystems. The first is that these newcomers cannot survive or at least cannot reproduce effectively in this new environment. It may be too wet, too dry, too hot, or too cold for them to get established here. In this case nothing really changes. The second thing that can happen is for these new organisms to fit into our ecosystems, but they do not compete very well, so are not much of a threat to the natural systems. They may grow and reproduce but are kept in check by the circumstances of the local environment. Again, not much changes and the local or regional habitats remain relatively intact and functioning.

The third thing that can happen is much less sanguine. In this case the new arrivals have found an environment where they can flourish and as a bonus, they have left behind all their own natural competitors and pathogens that normally keep the invader in check in its original natural location – they are freed from the natural controls they once had. These new arrivals are officially called 'invasive species,' and we now realize the damaging impacts of many of them. In fact in 1999 the President Bush issued Executive Order 13112 that officially defined what an invasive species is and what steps were to be taken to ameliorate their impacts. According to the Executive Order, an invasive species 1) is non-native (or alien) to the ecosystem involved, and 2) its introduction causes or is likely to cause economic or environmental harm or harm to humans. They can be animals, plants, or other organisms such as bacteria or fungi. A framework of government organizations was established with the Order, and this collection of entities is charged to deal with the threat of the various invasives around the country. Some invasive species are well known to the average person. Kudzu, for example, is often referred to as the vine that ate the South; the intentional introduction of the starling has had devastating effects on songbirds throughout the country; and, Dutch elm disease virtually made the American elm extinct.

Although not as famous or widespread as the examples above, the riparian and riverine zones along our Colorado rivers have also felt the impact of a variety of invasive or noxious weed species. The main responsibility for controlling invasive plants in Colorado lies with the Commissioner of the Colorado Department of Agriculture. The commissioner and the staff of the department have defined four levels for what they call the Noxious Weed List. List A are those plants listed for eradication; List B are plants that are to be kept from spreading; List C includes plants that are not designated for eradication or to be kept from spreading, but are a problem to be met with education, research, and some biological control measures; and, the last designation is the Watch List Species which is an advisory list of potentially harmful plants (Colorado Department of Agriculture, 2016, https://www.colorado.gov/pacific/agconservation/noxious-weed-species).

There are three invasive plants on the List A for the riparian areas along our rivers. The first of these is purple loosestrife (*Lythrum salicaria*) which is native to Europe and introduced as an ornamental plant for gardens (not an unusual occurrence) (Figure 1). It loves wet areas and spreads rapidly. One of the more daunting characteristics of the purple loosestrife is that a single plant can produce up to 3 million seeds in a year. And if it gets under stress, it produces an even more extensive root system than normal that gives it a significant competitive edge over native species. Once it gets established it can out-compete local wetland species and virtually become a monoculture of loosestrife. This destroys any habitat for other native plant and animal species in the area. Purple loosestrife is found in almost every state, but in Colorado it is mostly an ecological problem along the North and South Platte Rivers as well as the main stem of the Colorado.

Figure 1 – Purple loosestrife -- By David Whelan [CC BY 2.0 (http://creativecommons.org/licenses/by/2.0)], via Wikimedia Commons

The second riparian List A plant is the myrtle spurge (*Euphorbia myrsinites*) that is native to Eurasia and is popular for xeriscapes and rock gardens – another imported ornamental plant that spread rapidly to natural areas (Figure 2). It particularly likes disturbed stretches along river banks. Its milky white sap is actually toxic and may cause poisoning in livestock. Because of this it is not eaten by cattle and, therefore, often spreads into forage areas along the river banks. It is most abundant along the banks of the North and South Platte Rivers. Several municipalities in Colorado have established their own local bans on myrtle spurge and require landowners to remove it from gardens and yards.

Figure 2 – Myrtle spurge -- By PlantGeek (Own work) [CC BY 3.0 (http://creativecommons.org/licenses/by/3.0)], via Wikimedia Commons

The third riparian plant on the List A in Colorado is the giant reed (*Arundo donax*) that was again intentionally introduced as an ornamental and erosion control plant in California in the early 1800s (Figure 3). This native of India reproduces mostly vegetatively by underground rhizomes. It is a perennial grass that grows up to 20 feet tall. It crowds out native species and can actually become a fire hazard if not controlled. The reed displaces and destroys habitat for riparian animal species. It is so pervasive that it can alter the stream flow characteristics and increase drainage and flooding problems. Giant reed is primarily a problem along the Colorado River.

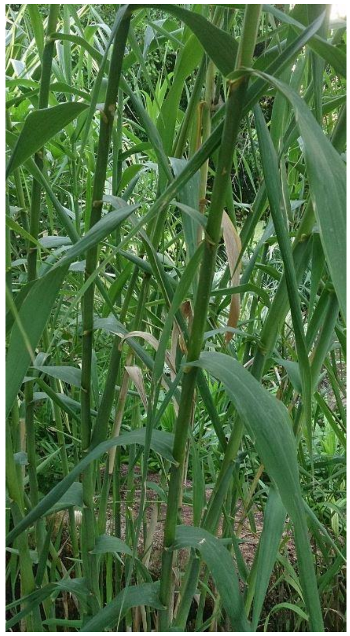


Figure 3 – Giant Reed --By Mokkie (Own work) [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

There are several riparian plants on Colorado's List B, but the most recognized and probably most important is the Tamarisk, also called salt cedar (*Tamarix spp*) (Figure 4). Similar to those plants on List A, someone thought it was a good idea to import the tamarisk into the U.S. from central Asia as an ornamental. Admittedly, it is a very handsome plant with its feathery, almost ethereal foliage swaying gently in the breeze. It is most obvious along the Arkansas River and in the upper reaches of some of the main tributaries of the Colorado, especially the Dolores River. It has several characteristics that make it a truly noxious plant. First, it uses huge amounts of water – up to 200 gallons a day for each plant. In our water starved state, this is a significant issue. It is also called salt cedar for a reason; it can tolerate saline soil conditions and it concentrates salt in it foliage. Tamarisk literally destroys an areas ability to host other plants because it raises the saline level too high for native species to compete, or in many cases, to even survive.

Figure 4– Tamarisk -- By Dinesh Valke from Thane, India (Indian Tamarisk) [CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons

The attempted eradication of tamarisk has taken a large infusion of resources, with little success. Removing the plant with heavy machinery or controlled burning works to some extent, but the saline soil remains. The U.S. Department of Agriculture has tried to do organic control by introducing the tamarix leaf beetle into tamarisk stands. The beetle is a natural pathogen to the tamarisk, and some die back has occurred. There is an ongoing study of this practice by Professor Shane Heschel of Colorado College; he has shown that the stress caused by the beetle stimulates the plant’s use of water. He suggests a better strategy is to flood the plant at least annually because the tamarisk is weakened by the flood waters, and this allows native willows and cottonwoods to get reestablished (Heschel, 2016). The flooding gives the added benefit of dissolving and removing some of the excess salt from the soil.

It is not just plants that invade and cause problems for our waterways. In May 2008 the Colorado State Aquatic Nuisance Species Act was enacted. The Act, managed by the Colorado Parks and Wildlife Division of the Colorado Department of Natural Resources, put a face and definition to plant and animal species that were considered threats to the actual watercourses of Colorado's streams and rivers. A nuisance species is probably much more than a nuisance – in some cases it can destroy or at the very least greatly impact several fish species and the habitat that supports them. The initial impetus for the Act was probably the potential invasion from zebra mussels (*Dreissena polymorphalarvae*) (Figure 5). These animals have already become a critical threat to many lakes and rivers in the Great Lakes region and the entire Midwest. Zebra mussels have been discovered in eight reservoirs around the state. The mussels grow rapidly and attach to any object underwater including the bottoms of boat, intake pipes for water systems, and other submerged structures. The mussels also feed on the micronutrients and plankton that all other trophic levels of aquatic species depend upon. They literally destroy the foundation of aquatic ecosystems. Thus far they have only seriously affected a few select waterways – Pueblo Reservoir on the Arkansas River is probably the most critical area where the zebra mussel is found.

Figure 5 – Zebra mussel -- United States Great Lakes Environmental Research Laboratory (GLERL)

At least two other fauna species are of major concern with the Aquatic Nuisance Species program. The first of these is the invasive New Zealand mudsnail (*Potamopyrgus antipodarum*) (Figure 6). It is an aggressive competitor for other invertebrates in our streams. The snails are voracious and can consume up to 75% of the primary production in a stream or river. They are relatively small and almost impossible to contain once in a watercourse. The Nuisance Species program is relying on boaters to rid the snail from boat bottoms before launching boats into unaffected water. We do not really know the full impacts of the mudsnail because it takes many years for the full impact of the invasion to become known. For now it is impacting only the South Platte River near Eleven Mile Reservoir.

Figure 6 – New Zealand mudsnail --

http://fl.biology.usgs.gov/pics/nonindig_mud_snail/mudsnail/mudsnail_3.html

The final faunal species that is a significant problem is an unlikely suspect. It is the Daphnia waterflea (*Daphnia lumholtzi*) – a small insect with considerable impact (Figure 7). The waterflea can out-compete small fish fry for food. They also have sharp barbs that can get caught in the throats of older fish and diminishes the fish's ability to eat. The waterfleas have long spines that can even foul fishing lines and reels. Once the waterflea infects an area, it quickly becomes well established and almost impossible to eliminate. Currently the waterflea only affects parts of the Arkansas and South Platte Rivers.

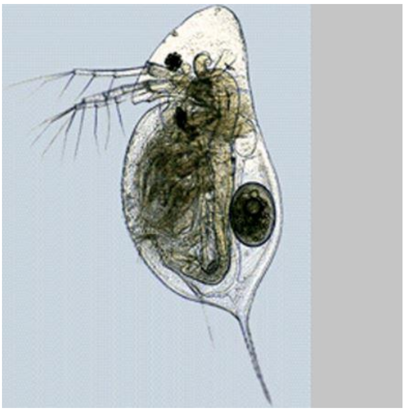


Figure 7 – Daphnia waterflea -- NOAA Great Lakes Environmental Research Laboratory

Another quintessential pest in our streams and rivers is not exactly an invasive species – it exists in just about every waterway in the country – it is a protozoan parasite not visible to the naked eye. Giardia (*Giardia lamblia* and several other scientific names) is spread by animals that have drunk water that has the parasite in it (Figure 8). Much of the spread of it was initially from cattle that have defecated in mountain streams, but now almost any wild animal will carry and spread the organism. In humans the giardia protozoan can cause severe intestinal problems including acute diarrhea, cramping, nausea and vomiting, and debilitating dehydration. Having a case of giardiasis probably will not kill you, you just wish for a quick end. You must assume any open water source in Colorado, no matter how clean it looks, has the parasite. The only way you should drink water straight out of that clear, cascading, beautiful mountain stream is to filter it with an EPA approved filter or water purifier. All municipal water in the state goes through massive filters before it gets to your tap. There really is no such thing anymore as 'pure' mountain water – a sad state of affairs.

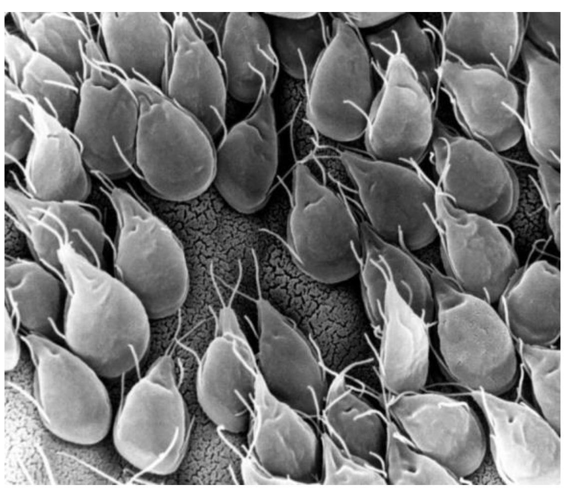


Figure 8 – Giardia -- Dr. Stan Erlandsen (1988) - Public Health Image Library (PHIL)

Just as there are often too many invasive species along, and in, our rivers, at times there are too few of the species that naturally belong. Native and endemic plants and animals have evolved to function in the local aquatic and riparian ecosystems. Federal government agencies and state institutions are tasked with monitoring the condition of many of these native plants and animals. When these native species populations get to a point where they are in danger of collapse or disappearing altogether, either locally or in the larger environment, the federal and/or state government agencies responsible can act to work at stabilizing and restoring them to functioning levels. Both the state and federal agencies can designate a species as 'threatened' or 'endangered'. According to the 1973 Federal Endangered Species Act, an endangered species of plant or animal is one that is in danger of going extinct in all or a portion of its range. A threatened species is one that is likely to become endangered within the foreseeable future in part or all its range. Either of these classifications prompts action to try to preclude the particular plant or animal from declining toward extinction. These actions might include working to increase and enhance the habitat that the species needs to function naturally. They may also include breeding programs that attempt to create stable population numbers. A species can be on the federal endangered or threatened list, the state list, or both. There are other categories such as the Colorado designation of 'species of special concern' that do not reach the level for threatened species, but are decreasing in population size or habitat loss and are trending rapidly downward toward levels unless action is taken.

There are two mammals that live along the river systems in Colorado that are on the state threatened species list. The first is the river otter (*Lontra canadensis*) that has become very rare in Colorado (Figure 9). Although the otter population in other places in the United States is healthy, there have been few Colorado sightings of this graceful member of the weasel family. The other mammal is also on the federal threatened list – it is the Preble’s meadow jumping mouse (*Zapus hudsonius preblei*) that is found nowhere else in the world but along the small headwater streams and wet meadows in Colorado and Wyoming (Figure 10). The Preble’s mouse lives mostly along the willow- lined riparian zones of the very upper reaches of these streams. It might seem like a small thing to lose a little rodent along our river and stream systems, but the Preble’s is a bit like the canary in the coal mine. Its loss or deep decline is an indication that the riparian ecosystems could also be in decline. And the natural functions of these ecosystems affect the entire chain of riparian and aquatic habitats and ecosystems that are along and downstream of these small headwaters.

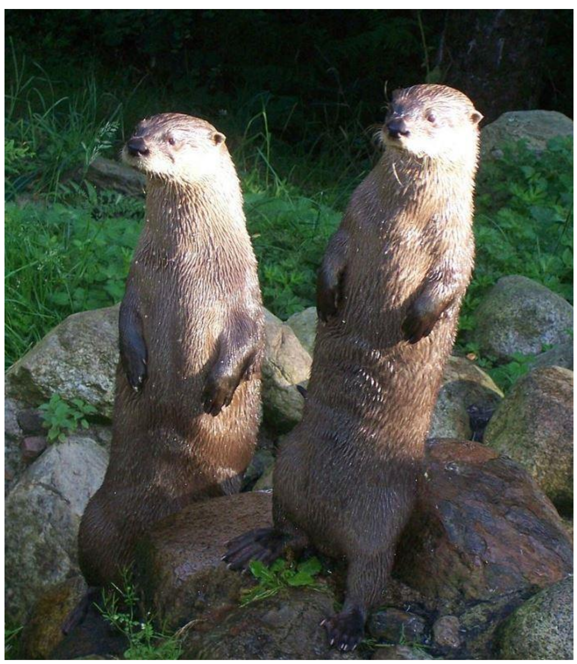


Figure 9 – River otter -- By User: (WT-shared) Nicolesabrina at wts wikivoyage (Own work) [Public domain], via Wikimedia Commons

Figure 10 – Prebles meadow jumping mouse -- By U.S. Fish and Wildlife Service (http://mountain-prairie.fws.gov/preble/) [Public domain], via Wikimedia Commons

There are five fish that are on the state and/or federal endangered or threatened lists. The first is the bonytail (*Gila elegans*) which is one of the most endangered species of fish in North America (Figure 11). It once inhabited both the upper and lower reaches of the Colorado River. It is now so rare in the state and elsewhere that fish ecologists are not even sure of what its best natural habitat is because no one has observed young bonytail in the wild. The only fry of this species that we are sure of are those that are being raised in special hatcheries. They are an elegantly streamlined fish that can grow to almost 22 inches in length. Recovery actions include restoring flows in the upper reaches of the streams that make up the upper and lower stretches of the Colorado and providing passages at major dams to allow the fish to be able to migrate to other critical habitat areas (for all of these fish, see the **Eco-Matters** chapter for information on flows).

Figure 11 – Bonytail -- By Brian Gratwicke [CC BY 2.0 (http://creativecommons.org/licenses/by/2.0)], via Wikimedia Commons

The second of these fish is the razorback sucker (*Xyrauchen texanus*) that has been swimming in the upper Colorado River for the last three to five million years (Figure 12). It is also on both the federal and state endangered species lists. It is one of the largest suckers in North America and can grow to three feet long. The razorback is not in as dire straits as the bonytail, but populations are kept viable only through the hatcheries that stock the Colorado, Green, and Gunnison Rivers. Recovery options for the razorback are similar to those for the bonytail including increased floodplain habitat protection and flows in the upper reaches of streams. There is some optimism because the razorback is now migrating between streams and sexually mature fish that were restocked are spawning in the wild.

Figure 12 – Razorback sucker -- By U.S. Fish and Wildlife Service Headquarters (Razorback Sucker-adult) [CC BY 2.0 (http://creativecommons.org/licenses/by/2.0) or Public domain], via Wikimedia Commons

The humpback chub (*Gila cypha*) is another fish native to the upper Colorado watershed (Figure 13). It is on both the federal and state endangered lists in Colorado. There are a small number of localized populations in the Colorado watershed near the Utah border. The fish may be more viable in the lower Colorado near the Grand Canyon and the Little Colorado River. The hump on the humpback is thought to be a stabilizer in the rapid water that the fish usually inhabits. The numbers of the humpback in the wild seem to be growing with approximately 7500 now living in the river. There is hope that enough individual populations will keep increasing to be able to delist the fish in the future.

Figure 13 – Humpback chub -- By Melissa Trammell, NPS [Public domain], via Wikimedia Commons

The Colorado pikeminnow (*Ptychocheilus lucius*) is the largest minnow in North America (Figure 14). It can reach 80 pounds but is more often in the 20-pound range. It is an aggressive fish as an adult. Anecdotes about the fish include it eating mice, other small rodents, and even small rabbits. Its natural prey for the young are plankton and insects while adults feed on other fish. It is on the Federal endangered list but was taken off the Colorado endangered list and downgraded to threatened status in the state in 1998. The pikeminnow migrates hundreds of miles to spawn, so one of the main tools for their recovery is to establish passages and screens to allow them to bypass major dams.

Figure 14 – Colorado pikeminnow -- By J. E. Johnson, U.S. Fish and Wildlife Service [Public domain], via Wikimedia Commons

Probably the most well-known, most complex, and at times most controversial story of all threatened and endangered species is that of the greenback cutthroat trout (*Oncorhynchus clarki stomias*) (Figure 15). This species (subspecies really) of fish is both native to and endemic along the Arkansas and South Platte Rivers. Unbeknownst to the majority of anglers, all those beautiful rainbow, brown, and brook trout they may have been catching for years are not native to the state. Our only native trout are the greenback cutthroat on the East Slope, the Colorado River cutthroat on the West Slope, and the Rio Grande cutthroat trout in the headwater streams surrounding the San Luis Valley. Although the populations of both the Rio Grande and the Colorado River subspecies of cutthroats are small and at times unstable, neither is listed as threatened or endangered by either the state or federal government. The Colorado River subspecies is listed as a species (subspecies) of concern and the Rio Grande subspecies has been determined under the Endangered Species Act to not warrant threatened or endangered protection.

Figure 15 – Greenback cutthroat trout -- By Rosenlund Bruce, U.S. Fish and Wildlife Service [Public domain], via Wikimedia Commons

The story for the greenback cutthroat trout is a different, and in many ways, a more complex story. Ever since the first white settlement in Colorado, the greenbacks have been caught in the many cold-water stream tributaries of the upper Arkansas and South Platte. But there were never many of these beautiful fish, and by 1937, they were thought to be extinct. From that time on, only the introduced rainbow, brook, and brown trout were found in the mountain streams in this part of Colorado. That is until the late 1950s when several small populations of the greenback were discovered in the high-altitude headwaters of the Arkansas and South Platte basins. Even in that era before major conservation efforts were common, there was an immediate push to try to save and promote the increase in greenback populations. When the Endangered Species Act came into effect, the greenbacks were quickly listed as endangered. Conservation efforts, especially raising greenbacks in the state hatcheries, started to be successful, and the classification of the greenbacks was eventually lowered to threatened. In a gesture that implied the importance of the fish to the state's heritage, in 1996 the legislature designated the greenback cutthroat trout as the official state fish of Colorado.

All of the conservation efforts at this point had taken place before the common use of DNA testing. The genetics of the populations of almost all the greenbacks that were being stocked were looked at and found to be more complicated than first thought. Most of what we thought as greenback fish stock were really hybrids and not pure greenbacks. In fact these hybridized greenbacks may eventually get a new name to differentiate them from the unhybridized genetic subspecies. According to extensive DNA testing of museum examples of greenbacks, there is only one population of about 750 fish that are now considered true greenback cutthroat trout. This small, isolated, and solitary population of pure greenbacks owes its existence to a hotel owner in the late 1880s who stocked them in the upper reaches of Bear Creek southwest of Colorado Springs.

This recent discovery of the only un-hybridized greenbacks has created quite a stir amongst U.S. Fish and Wildlife officials, Colorado state resource agencies, and Trout Unlimited. There is strong movement to re-listing the fish as endangered – a population of 750 is extremely small and thought to be very tenuous. The Center for Biological Diversity has filed a suit to re-list the fish as endangered, and the re-listing would start a series of very big steps in the upper Bear Creek drainage. This is an area of heavy trail use by hikers and off-road motorcycle riders. Some of the land along the creek is owned by Colorado Springs Utilities, other parcels are U. S. Forest Service property. The intense trail use, especially from motorized trail users, has caused heavy erosion of sediment into the creek that damages the habitat for the fish. There are many volunteer efforts arising from hiking groups, biker organizations, and the motorized community to move the trails away from the creek so these recreational activities can continue in this beautiful and rugged mountain area. Others are calling for the complete shutdown of all trails in the area. Until decisions are made by the U.S. Forest Service about land use issues and trails and by U.S. Fish and Wildlife on the re-listing of the fish as endangered, these trail controversies will continue. In the meantime very aggressive efforts to breed and reintroduce these fish are underway. This population of fish is a very important part of the heritage of the state, and the entire scenario of how this situation is handled may become the prototype for other similar circumstances that are sure to arise.

In addition to these problematic situations, there is also a good news story, however. Although not strictly an aquatic species, moose (*Alces alces*) definitely depend on the riparian ecosystems along our rivers and streams (Figure 16). Moose have had a long history in Colorado, but never a large one. Most moose that were in the state in the past were transients who wandered in from Wyoming. Since the 1950s wildlife officials in Colorado have been working on introducing a breeding size population of moose to the state. There was some opposition by ranchers who thought the large herbivores would compete with their cattle herds. The Colorado Division of Wildlife (now Colorado Parks and Wildlife) worked for decades to convince state residents that introducing moose to Colorado would be a good thing.

Figure 16 – Colorado Moose – (courtesy of the National Park Service and Rocky Mountain National Park)

Finally in 1978 the state officials transplanted a mix of 24 male and female moose into the riparian rich reaches of the Michigan and Illinois Rivers (both major tributaries to the North Platte River) of North Park. Subsequently, more moose were introduced to other appropriate areas in the state. State wildlife professionals now estimate that there are over 2,300 moose in several parts of Colorado. These areas include the Grand Mesa with its innumerable lakes and streams, the upper Rio Grande Valley upstream of Creede, the Flattops of northwestern Colorado, and the San Juan Mountains. These moose populations are now large enough that there is a hunting season for them, and there is a very competitive scramble for the licenses from residents and non-residents alike.

Many of us love the idea that we can go to places in Colorado that are wild and untamed. We envision the purity of unaltered nature and our ability to access it if only we make the effort to climb that mountain, reach that special stream, or hike in that primordial forest. Much of that environment still exists to some extent. But to be honest and scientific, there are no environments in Colorado that are untouched by human activities including our streams and rivers – maybe especially our streams and rivers. This does not mean that we have lost all of our untainted natural environments, but it does mean that what we have left should be treated with care and knowledge and that maybe we should try to re-establish some those natural characteristics that make Colorado and its rivers special.

The world of today is super interconnected with high speed plane travel to and from nearly every conceivable environment, vast container ships delivering untold products to all corners of the globe, and more and more people traveling to places that once were remote. This interconnectedness is a good thing in many ways. It allows us to have products and experiences that our parents and grandparents never knew. But it also opens the ecological gates that provide access to sensitive ecosystems for species of organisms that may or may not be harmful. Federal and state agencies are officially responsible for protecting our natural resources from invasive and toxic organisms and trying to restore or recover the threatened and endangered species that we should value as part of the natural systems in the state. But it also the responsibility of the public to be aware and concerned for the ecological health of our aquatic and riparian landscapes. Checking that boats are clear of organisms such as zebra mussels and New Zealand mudsnails and being careful and thoughtful about the ornamental plants we buy for our yards are simple but needed actions to keep Colorado waterways and all other environments healthy for future generations of Coloradans. You could also become involved in organizations that are dedicated to conserving and improving our native waters and drainage basins. These might include the Upper Colorado River Endangered Fish Recovery Program or Trout Unlimited or the Coalition for the Upper South Platte or the Colorado Native Plant Society. This is only a very short, but hopefully tantalizing list of mostly private groups who work hard with few resources to make and keep Colorado ecosystems and landscapes strong and viable.

Eco-Matters

The issues of invasive plants and animals and the threatened or endangered species in our four rivers are of critical concern. They are the most obvious and visible threats to the quality of waterways in the state. But there are many other environmental matters that are important in our understanding of the streams and rivers of Colorado. Almost all of these arise from our use of the water and how we manage it in mega-ways that involve other states and nations all the way down to the micro-ways of how an individual farmer or rancher manipulates his or her irrigation water. Whether large or small or somewhere in between, these varied environmental matters affect our use of the water and often the health of the ecosystems and human communities that depend on it.

The legal obligations that requires Colorado to share our river waters with downstream users are discussed at length in the **Compacts** chapter earlier in the book. Up to 75% of the water that runs in our four rivers until they empty into the Gulf of Mexico or the Gulf of California comes from the high mountains of Colorado. But legally we are required to allow much of that water to go to the other states and Mexico. The most significant of the agreements with these other entities in terms of water flows is the Colorado River Compact. The compact created two parts of the Colorado River watershed – the upper basin of Colorado, Wyoming, Utah, and New Mexico and the lower basin of California, Nevada, and most of Arizona. The lower basin was able to use more of its allocated water sooner, mostly because California was growing rapidly even in the 1920s and 30s. The upper basin was very concerned, and rightfully so, that it might lose some of its allocated but, as yet, unused waters to the faster growing lower basin. But it was not until the 1956 Colorado River Storage Project Act that any major legislation was enacted to attempt to help the upper basin develop and manage its allocated water.

The Act created one of the most complex systems of river management units that included reservoirs, dams, electricity generating, and flood control facilities in the world. There are four major units in the Colorado River Storage Project (CRSP) – the Flaming Gorge Unit on the Green River in Utah, the Navajo Unit on the San Juan River in New Mexico, the Glen Canyon Unit on the main stem of the Colorado River in Arizona, and the Aspinall Unit on the Gunnison River in Colorado. These are all very large, often multiple reservoir/dam units along the Colorado and its major tributaries. Each of these units has its own set of requirements and obligations to the overall system of water management in the upper basin. The Aspinall Unit is the only one of these that is in Colorado, and its various functions are an example of the intricate nature and interconnectedness of all of these facilities.

The Aspinall Unit consists of three dams and their associated reservoirs. Most Colorado residents are familiar with Blue Mesa Reservoir, the largest body of water fully contained in Colorado and just upstream from the Black Canyon of the Gunnison National Park. The Blue Mesa Dam is a large, earth embankment dam completed in 1966. It is capable of holding 829,500 acre-feet of water, although most often there is less water than this in the reservoir. It also has a hydroelectric power plant that can generate 86.4 mega-watts of power. All dams in the CRSP are designed to generate power that is sold to offset operating expenses and to help fund the projects. Blue Mesa is the reservoir that is designed to be the storage facility or storage battery that can be called upon quickly to release water that goes down the Gunnison and into Morrow Point Reservoir, the second part of the Aspinall Unit.

The Morrow Point Reservoir is about one-seventh the size of Blue Mesa, but it has the critical functions of supplying consistent flows downstream and for generating electricity on short notice for peak power transmission throughout the regional electricity grid (Figure 1). The United States Bureau of Reclamation is particularly proud of the Morrow Point Dam. This structure was an experiment. Most dams use their massive weight and size to hold back water; the Morrow Point Dam uses elegance. It is the first high thin-arch double-curvature dam built in the U.S. This technical description means that a very thin (in relative terms) concrete dam that bends horizontally and vertically upstream is able to hold back large amounts of water because the stresses put on the upstream side of the dam by the mass of water in the reservoir actually make it stronger (Figure 2).

Figure 1 – Power station at Morrow Point Dam.

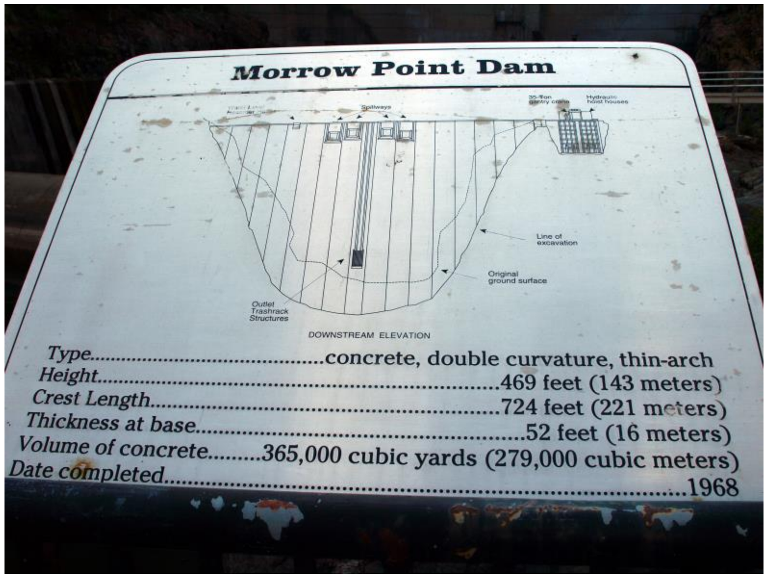


Figure 2 – Plaque with Morrow Point Dam dimensions.

The third and final major component of the Aspinall Unit is Crystal Reservoir and Dam. It too is a thin-arch double-curvature dam – the experiment at Morrow Point obviously worked out -- that holds back a tenth the volume of the water that Morrow Point Dam does. But this small facility is very critical to the entire Colorado River Compact as it is designed to provide the needed water for Glen Canyon Dam and Lake Powell that in turn are responsible for providing compact water allocations to the lower basin, especially Hoover Dam and Lake Mead. For about the first 25 years, the Aspinall system was operated for the sole purpose of maximizing water storage and electricity generation. This, after all, was what the entire CRSP system was designed to do. But in the 1990s the federal government and Colorado began to have a more ecological mindset with regard to environmental issues that the rivers management affected.

Government agencies and private organizations were realizing the importance of diverse ecological systems in our rivers and streams. The 1988 Upper Colorado River

Endangered Fish Recovery Program was established to help recover the dwindling populations of the endangered and threatened fish discussed in the **Too Many – Too Few** chapter. The pikeminnow and razorback sucker were two of these endangered fish that were native to the lower Gunnison River – that stretch below the Aspinall Unit's three dams. The natural and unimpeded hydrograph of the main stem of the Gunnison included large, flushing levels of the river in the late spring and early summer that moved sediment through and out of the system and lower water levels the remainder of the year. In the early 1990s the agencies and organizations agreed to test releases of reservoir water that would mimic the more natural flow rates that had been muted by the management of the river with the dams and reservoirs while still providing the water demanded by the interstate compacts. This was not a perfect answer for the fish stock, but the concept was successful enough that by 2012 these specially timed releases had become normal operating procedures.

The Black Canyon of the Gunnison was declared a National Monument in 1933. National Monuments in general have fewer environmental restrictions than National Parks. Little was done to preserve water flows in the Gunnison River through the canyon until the 1970s when the environment started to become a public area of concern. In 1999 over 48 square miles on either side of the most dramatic portion of the Black Canyon was finally declared a National Park. The Act that created the National Park also increased the size of the adjacent Gunnison Gorge National Conservation Area. The Curecanti National Recreation Area borders the National Park to the west. All three of these entities depend on the flowing waters and reservoirs of the area to provide for large numbers of recreational users throughout the year. In 1978 the Park Service was granted a conditional right to a minimum instream flow of the river through the canyon. At that time there was no absolute agreed quantity. The Park Service wanted to remedy this issue, finally, in 2003, the Park Service received a 300 cubic feet per second (cfs) minimum instream flow or whatever the natural water flow was with a 1933 priority – a somewhat senior water right. And they received a much larger instream flow right for up to 14,500 cfs – this larger water right, however, had severe restrictions.

What all this means is that the Aspinall Unit will continue to provide water and electricity as originally designed, but it also means that through careful planning by water managers of the system and all water users along the Gunnison, timed releases will partially emulate natural flows for threatened and endangered fish and provide for minimum flows for recreational uses in the Black Canyon. These annual plans are done well in advance of each spring thaw but are often modified as the runoff season waxes and wanes throughout any given year.

The late 1960s and early 1970s were an era of dramatic changes in how we look at and interact with the environment. The U.S. Environmental Protection Agency in 1970; the 1970 Clean Air Act; the Marine Protection, Research, and Sanctuaries Act of 1972; the Endangered Species Act of 1973; and the 1976 Resource Conservation and Recovery Act were just some of the legislative accomplishments of this environmental protection surge. One of the most critical laws passed during this period was the 1972 Clean Water Act that was intended to protect the chemical, physical, and biological make-up of the nation’s waters. This was a massive and complex bill tried to cover nearly all aspects of pollution in the lakes, streams, and rivers of the country. Naturally there ended up being gaps in what was regulated and what was not. One of the areas of concern for the Colorado River regarding the 1972 law was the lack of control of pollutants, especially salt, that was coming from irrigated agriculture and hot springs in the Dotsero and Glenwood Springs areas. Almost all agriculture in Colorado and the entire Southwest needs to be irrigated – much of that irrigation water contains high concentrations of salts. In 1977 the U.S. government passed an amendment to the Clean Water Act that did address this issue.

One might reasonably ask, what is the connection between irrigated agriculture and salt concentrations in our rivers? The geology of Colorado is extremely complicated, but the simple fact is that many of the sedimentary rocks that are found in the state were deposited originally in salty marine environments, and the soils that are now derived from those rocks still contain a high percentage of salts such as sodium chloride and calcium sulfate. When irrigators put ground water on their fields, that water almost always has significant concentrations of salt in solution. The plants use some of the irrigation water, some of it evaporates leaving the salt behind, and the remainder of the water goes back into the soil carrying the higher concentrations of salt. Eventually, that water makes its way into the groundwater table and to the nearby streams or rivers or is held in the soils. There are innumerable fields that have been made unsuitable for growing crops in places such as the San Luis Valley because of high salt concentrations – these are easily visible as white layers on the surface of the land. The only way for the salt content of the soil to be reduced seems like an ironic paradox. The farmer needs to put large, additional quantities of water onto his or her fields to dilute and try to remove the salt near the surface and force salt laden water deeper into the ground out of reach of plant roots.

The 1977 Clean Water Act amendment requires that the salt levels in the river water that is delivered downstream are lowered to more tolerable limits. At least 50% of the salts in these rivers comes from natural ground water seepage through saline rock formations. This water emerges as seeps or springs that empty directly into the rivers. But irrigated agriculture is the place where we can actually have an impact by reducing the amount of land under cultivation. This is a major problem in both the Colorado and the Arkansas Rivers. In the higher reaches of the headwaters of the Colorado, for example, the salt content in the river is about 50 parts per million, but by the time that water reaches southern Arizona it has reached 400 parts per million. Neither river is in compliance with the law, but there is very little that can be done save eliminating some or all irrigated agriculture in the region – a step that is not going to be taken any time soon. Most of the proposed solutions are taking place in the lower Colorado watershed in southern Arizona. Two examples of these solutions are a large, potentially useful de-salinization plant near Yuma (it was built years ago but never became operational) and an increase in concrete lined canals (to prevent leakage and increase water to dilute the salt). As climate changes in the Southwest, this problem will only become more acute as higher temperatures evaporate far greater quantities of water resulting in higher salt concentrations in the water left behind.

Salt is one major issue in the quality of water in our rivers; selenium is another. Although there are innumerable pollutants that exist or might exist in the waters of our rivers including sulfates, nitrates, coliform bacteria, or suspended sediments, selenium pollution is something that reveals the complexities of modern life and our watercourses. Selenium is a non-metal element that is a close kin of sulfur. It is an essential micronutrient in all animals and many plant species. In fact it is often added to products such a baby formula to help developing cells function properly. But in too high a dose, selenium can become toxic, especially to the fish in our rivers. Humans can also suffer from selenosis; extreme cases of selenium toxicity can cause cirrhosis of the liver and pulmonary edema.

The release of excessive selenium into the environment is a particular problem in the underdeveloped, potential agricultural lands in the semi-arid and arid regions of the West. Much of the excess of the element comes from selenium containing pyrites and shales that have high levels of it in the silts that originally formed the shales. When irrigation water is introduced to the soil in these dry regions, the selenium oxidizes and goes into solution as the irrigation water seeps deeper into the soil. This selenium carrying groundwater slowly migrates into low-lying sumps and wetlands where it gets concentrated – the levels of selenium in these pools can be more than ten times higher than normal. The headwaters and tributaries of the Colorado River, especially the Gunnison River, have high levels of selenium that come from irrigated fields that drain into the river. The Arkansas River reach that runs from the mountain front all the way to the Kansas border also has a serious selenium problem because the basin that drains into the river lies over large expanses of selenium containing shale. An added complication is that when the selenium is in the soil in combination with high organic carbon, it becomes even more concentrated. Most healthy soils have relatively high organic carbon levels – so good soil makes the selenium problem worse. There are few good solutions to the selenium problem that do not entail buying up and drying out many thousands of acres of irrigated agriculture.

Mining, especially hard rock mining for precious metals, is a major part of the history of Colorado. There was some placer mining in the state; one major placer mining example is near Fairplay on the Middle Fork of the South Platte River (Figure 3), but hard rock, underground mining of minerals is really the legacy we carry with us as residents of the state. To put the influence of mining in the Colorado and the West into perspective, we need to understand the legal framework into which mining fits. When mining of minerals, especially gold, began in the West in California and Nevada, there were few rules governing who owned the rights to mineral bearing lands, how the minerals could be extracted, and what happens to those lands after mining was done. That all changed in 1872 with the passage of the federal Mining Law of 1872. This law was passed by Congress to explicitly encourage mining in the West. The organized extraction of mineral wealth was essentially its only goal. It worked like a dream come true for those wanting to 'get rich' in the freewheeling lands of the sparsely populated West. One of the provisions of the law established that a mining claim of up to 20 acres could be patented on any federal land open to mineral exploration for the cost of $5.00 per acre for underground mining and $2.50 an acre for placer mining. That cost has not changed since 1872 although a $100 holding fee for claims was established by Congress in 1992. There was also no provision in the law requiring payment of royalties to the government for any minerals extracted – in other words, gold, silver, copper, zinc, lead, uranium, or any other mineral could be taken with no reimbursement to the people of the U.S. whatsoever. There were also no environmental regulations governing the mining operation or the remnants of mined land after the mining was finished or the claims were abandoned.

Environmental regulations have been established with the several laws passed in the 1970s such as the Clean Water Act, the Clean Air Act, and others, but these are not specific to mining and have little effect on environmental situations caused nearly 100 years earlier.

Figure 3 – Fairplay placers.

The high value minerals that we mine in Colorado include gold, silver, zinc, cobalt and others. When these minerals form deep within the earth, they often occur in conjunction with non-metal elements such as arsenic, selenium, mercury, and sulfur. Ore deposits in most of Colorado occur in areas that are highly fractured from various geologic processes. Often super-heated water laden with dissolved minerals rises up into these fractures where the minerals are accumulated and often concentrated. Mining operations add to the porousness of the area by putting in shafts and adits that perforate the underground rock and allow surface and near-surface water to flow into the mine. As the non-metal elements are exposed to this water and air that fills the tunnels, they often oxidize to form acid solutions – sulfuric acid dissolved in water is the most common and best known of these chemical cocktails. Controlling these hazardous concoctions is a significant issue especially when the mining operations are finished and the mines are abandoned. There are thousands of these abandoned mines in Colorado where the potential exists for this water to escape the mining claim lands and move into the natural watercourses that drain our high mountains (see the section on the North Fork of the South Platte River in the **Origins** chapter). Sometimes this hazardous potential is realized.

The eastern side of the San Juans was an area of intensive volcanic activity for several million years during the last half of the Tertiary period. Innumerable volcanic intrusions in the area over this relatively short geologic timespan created large landforms called calderas. The calderas were very large volcanic structures that collapsed into themselves as great masses of magma and gas were expelled. These collapsed volcanic systems produced extensive fracturing and faulting that facilitated the movement of superheated fluids and gases from deep within the earth to move vertically upward bringing dissolved minerals. As the water evaporated, the minerals and chemicals were deposited amongst the fractured rock creating rich ore lodes.

The Summitville mine took advantage of one of these fracture zones adjacent to Wightman Fork, a small creek flowing into the Alamosa River that is a major tributary to the Rio Grande. Even before the 1873 Brunot Treaty that took the area from the Utes and essentially gave the San Juans to the U.S. government, the Summitville was being mined – mostly for gold although there were traces of other valuable minerals such as copper in the ore. A significant amount of gold was taken from the mine using underground mining techniques that honeycombed the mountain. The underground mining continued until the early years of the 20th century. There was still a considerable amount of low-grade gold ore at Summitville, but the low concentrations and high-water tables in the mine made for difficult and unprofitable mining.

It was not until the 1980s that the mine and its low-grade ore once more became a valuable asset. New large-scale above ground (mountain top removal) mining and heap leaching with massive amounts of a dilute alkaline cyanide solution released the minute amounts of gold from the crushed bedrock (Figure 4). The cyanide would seem to be a major environmental concern, but in reality, cyanide decomposes rapidly in sunlight and the leach pits are lined with fairly strong material to theoretically keep the cyanide solution from going into the groundwater. Another significant problem with the mine was the toxic water that had been contained in the mine after it was abandoned in the early 1900s. The high sulfur content ore created large amounts of sulfuric acid and other oxidized chemicals and heavy metals that were a witch's brew of toxic fluid. Some of this contaminated cocktail of cyanide solution, acids, and heavy metals started to leak from the site almost as soon as the surface mining started its operations (Plumlee and Edelmann, 1995).

Figure 4 – Summitville open pit mine, 1999 (courtesy of Colorado Department of Public Health and Environment).

The owner of the mine at the time, Summitville Consolidated Mining Company, Inc., started a small remediation effort but their system was overwhelmed by water flowing into and out of the mined land. Many releases of the acid/heavy metal/cyanide concoction released into Wightman Fork and the Alamosa River. The company filed for bankruptcy in 1992 and abandoned the site. As the state and the EPA took over the remediation, leaks continued and the mine was declared an EPA superfund site. Work is still ongoing in the area to try to determine the extent of damage done by these releases. A major concern is the irrigated agriculture that exists along the Alamosa River and possible effects on the Rio Grande itself. In addition the Alamosa River is the source for almost all the water in the Alamosa National Wildlife Refuge, a major sanctuary for migrating birds especially the sandhill and whooping crane. In spite of the fact that Summitville is now a superfund site, this is a continuing slow-motion disaster of unknown proportions or results. The effects of this relatively slow leakage of toxins for many more years are, as yet, not very well understood (King, 1995).

A slow leakage was not what happened on August 5, 2015 at the Gold King Mine near Silverton. Reclamation efforts by an EPA contracting team opened a blocked portal of the mine and released the toxic mix of water, acids, and heavy metals that was being held back by the blockage. Three million gallons of the vivid orange slew traveled down Cement Creek into the Animas River and by August 14 into Lake Powell, a major reservoir on the Colorado River in Utah. Many people want to put the blame squarely on the EPA, but this disaster took years to develop, and the EPA was in the unenviable position of trying to ameliorate decades of environmental abuse caused by earlier mining operators at the site when the collapse finally came.

There are several abandoned mines in the upper Cement Creek basin including the Sunnyside, Mogul, and Red and Bonita mines in addition to the Gold King. All of these mines are in close proximity and often shared water drainage systems. The lower level of the Gold King was actually turned into a major drainage tunnel (called the American Tunnel) for mines in the area. The area along Cement Creek was already a naturally contaminated site because of the high acid content of the native bedrock. The addition of so many mines in such a compact area only added to the problems. The increased pollution from the mines had always been an issue. In fact in the early 1900s, Durango, located downstream from the Silverton area on the Animas River had to construct a new water supply system for the city because the water they were using was so polluted from the upstream mining. The 2015 accidental release of the water from the Gold King was made into such a big media event because it was an EPA sponsored project that was the final cause of the release and because of the brilliant orange hue that the Animas River took on (Figure 5). One ironic fact about this entire process is that the communities downstream of the Cement Creek mines did not want the area declared a superfund site because it might hurt the tourism business – thirteen months after the release, the area was finally a designated superfund site. No one knows whether or not the spill would have occurred if the area had had the designation before 2015, but most certainly the result would have been less catastrophic.

Figure 5 – The orange water of the Animas River, August 5, 2015 (courtesy of U.S. Environmental Protection Agency).

The Colorado Division of Reclamation, Mining and Safety estimates that there are about 23,000 abandoned mines in the state. The federal and state regulation of these mines is minimal at best and non-existent at worst. The 1872 Mining Act put into place a system that was set up to promote mining at all costs with the mine owners able to walk away from the results of their mining activity with few to no regulatory restrictions or obligations. As stated in the report on the Gold King Mine release from the Bureau of Reclamation (2015), "mine safety regulations that **active** (emphasis is this author's) mining operations must follow have evolved as the result of numerous catastrophic releases of mine water. These regulations are administered by (1) the Mine Safety and Health Administration (MSHA) for active mines, but not abandoned mines, (2) the Office of Surface Mining for coal mines, and (3) various State mine inspector organizations throughout the country for active mines." Notice that the words 'abandoned mines' are not used. Even after the devastation of events such as Summitville and Gold King and many others, abandoned mines are still not a large part of federal or state mining regulations.

The Bureau of Reclamation report on the Gold King release commissioned by the EPA contains some sound advice and generally accepted operating procedures, but no real advocacy to create comprehensive regulations and/or laws that affect how abandoned mines are handled. Their four recommendation points include such common sense ideas as 1) reviewing the records of the mine company including size of the workings and material involved before work begins; 2) determining the water conditions and amounts within the mine before excavating a blocked adit; 3) looking at what might occur if a flood would ensue after opening the blockage; and, 4) getting independent verification of the potential implications of a significant release of mine water. These are all good ideas, but stronger regulatory and legal protections for our rivers need to be a part of the legacy of these disasters.

Before the Clean Water Act of 1972, many of the rivers in the United States were used as convenient dumping grounds for the waste materials of our society. The Clean Water Act did a considerable service in helping clean up major pollution in many of our rivers, streams, and lakes. But there are many areas that were not included in the Act that are now becoming evident. Some of these issues are highlighted in this chapter, others such as the expansion of hydraulic fracturing (more commonly called 'fracking') in the increased development of oil and gas throughout Colorado have not been discussed. We all need to understand that the water we have for all of society's needs is all that we have – we are not making any new water. Populations are growing, our natural ecosystems are becoming stressed, climate change is a fact that needs to be understood, the estimated 23,000 abandoned mines with their highly polluted water in Colorado need to be regulated, and the rivers of our state are intimately involved in all of these issues.

Epilogue

Much of what occurs in the natural world is defined by rivers. The four rivers in Colorado are no exception. Rivers are the collectors and transporters of water, especially in the wetter regions of our high mountains. Since all life needs water, one role of the river and its innumerable tributaries is to move water from areas of at least relative abundance to areas of more significant need. Water is also the main driver in eroding and shaping landscapes. Whether as a solid (glaciers) or a liquid, water and its downhill flows provide the power to literally shape the ground we and all terrestrial beings live on. The water in our rivers helps create the verdant ecosystems that provide the most fecund habitat for plants and animals in the state. We have all seen the long, linear, green verges along the banks of our rivers where vegetation grows in relative abundance and where many animals find shelter, food, and migration routes. So much of the physical and human worlds depend on rivers doing their job.

Human society also depends to a large extent on rivers for innumerable governmental, economic, social, and environmental issues that confront it. As Martin Doyle (2018) discusses in his book *Source*, America's rivers have determined many aspects of culture, law, and human development. Rivers were a significant reason and a main mode of transport for the "Corps of Discovery" that Thomas Jefferson sent under the leadership Meriwether Lewis and William Clark to explore what became the Northwest of the country. The major river system of the Mississippi/Missouri was a prime motivator for the purchase of Louisiana from the French – again a Jefferson initiative. In fact rivers were an important component of our entire westward expansion. Explorers such as Pike, Long, Fremont, Gunnison, and others sought out rivers and their sources as prelude to the concept of "Manifest Destiny." River transport was all important in the institution of laws and the oversight of the federal government in interstate commerce. They provide convenient and ofttimes controversial and shifting borderlines between counties, states, and countries. Doyle makes the very blunt and definitive statement that, "Rivers are the defining feature of America's landscapes." Others may disagree with Doyle, at least in degree, but one just has to look at and think about any landscape in the United States to see the multitude of influences rivers have on our lives and communities. David Owen, in his book *Where the Water Goes*, makes an even starker, yet true, statement, "Water problems are straightforward in one way: without water we die, and not centuries from now. When supplies are short [and they almost always are], people have no choice but to find solutions, one way or another, in real time."

For at least the first two decades of the twenty-first century, drought has been relentless in Colorado, especially on the Western slope and the southwestern side of the state. Realistically, the "droughts" of these years should prompt us in the state to admit to a new normal – one of permanently lower levels of water for the entire region. The Colorado River basin is in dire straits from the four states of the upper basin (Colorado, Wyoming, Utah, New Mexico) to the three states of the lower basin (California, Arizona, Nevada). It has been predicted that this river basin will get twenty percent less precipitation on average in the twenty-first century than in the twentieth-century. In western Colorado and the entire Southwest we have already reached that mark. All indications are that the twenty percent estimate in precipitation reduction was overly optimistic. And this is one of the fastest growing population regions in the country. We need more water, but we also suffer from too many people in an arid and semi-arid land. As William deBuys says in his book *A Great Aridness*, we suffer "not so much from a shortage of water as from a *longage* of people" (deBuys, 2011).

The decrease in usable water has many sources, but the elephant in the room is global climate change. Some people do not want to believe in or admit it, but the science is in, it is real, and the impacts of climate change are moving faster than anyone could have predicted. The Colorado River Research Group issued an assessment in 2018 that lays out the physical reasons why our drought conditions are now our normal (Colorado River Research Group, 2018). There are innumerable, interacting factors in climate change that work at a multitude of scales -- locally, regionally, nationally, and globally. But one of the biggest impacts going into our future is the idea of "runoff efficiency." One factor of runoff efficiency is that with higher temperatures, there is higher evaporation – it is a simple, recognized, and irrefutable physical reaction as warmer air holds more water vapor than colder air. Higher temperatures increase evapotranspiration -- the evaporation of water and the use of water by plants as they grow and attempt to stay cool. There will be lower snowfall amounts in the high country with an accompanying increase in rainfall. Snow packs act as natural water reservoirs over the year as the snow slowly melts and provides water long into the summer. Most rain runs off immediately and, unless captured somehow, leaves the system. All of these factors create less water available for all the things that need it, including the streams themselves, natural ecosystems near the watercourses, agriculture, and of course municipal and industrial uses.

In 2014 the Colorado Water Conservation Board produced the second edition of their *Climate Change in Colorado* report (Lukas, 2014). The report acknowledges that the average temperature for the state has been steadily increasing over the last few decades. But the report does not definitively aver that we will have less water; it does say that how, where, and when we get water during the coming years is changing. Less snow, later snowfall, earlier snowmelt, and more rain during the winter months in the high country are all going to affect water availability. We are already seeing this happen, and the trends will only get stronger as time moves forward.

Some people could reasonably say that our water resources in general and our rivers in particular are in crisis now and for the foreseeable future. The state leaders realize there are significant problems, and these problems need to be addressed now. This is why the *Colorado Water Plan* is of such importance. But the plan has many inadequacies, not the least of which are some of the more draconian water laws that need to be dealt with by water right owners, water managers, and the courts. As discussed in various places in this book, by Acts of Congress and U.S. Supreme Court case law, Colorado is a part of several compacts that commit the state to export about two-thirds of the water in our rivers. Some of these compacts and the Law of Prior Appropriation make a challenging mix for the state. With the Colorado River compact, for example, Colorado has junior rights to water that goes to California which has much more senior rights. When the inevitable water crunch comes, California, by law, will get their water over other users. There is some movement on this issue as the seven states that are part of the compact have been in serious discussions about what happens going forward. As of now there are general agreements for what the upper basin states and the lower basin states will contribute to solving the problem of too little water as shown in the 2019 Drought Contingency Plan and the 2022 Drought Response Operations Plan produced by the Bureau of Reclamation.

The Eastern Slope of Colorado has its own severe problems. Today, even under normal flow conditions, the Arkansas, Rio Grande, and South Platte are already over-allocated. More people want more water; water that does not exist. The *Colorado Water Plan* has put forward some ideas, but there is still the serious issue of not enough water to satisfy the various compacts Colorado is a part of with states such as Nebraska and Kansas.

We as a society have come to realize that we cannot use up a river – there needs to be flows guaranteed to keep rivers flowing. The recreation and tourism industry is a huge part of the state economy, and fishing, boating, rafting, and other river amenities are a crucially important segment of the economic engine. There is also a significant requirement to keep water in our rivers that is needed by riparian and riverine ecosystems and the plants and animals that use the rivers need for survival.

One of the most critical parts of our water law that will have important impacts, especially on the conservation side, is the idea that water rights owners must put their water to beneficial use or lose those rights. This means that a farmer, for example, who does not use all of his or her water, and who may release some of it sporadically as a conservation measure, may end up losing those rights. Often this leads to the overuse and waste of water, just to satisfy the letter of the law. These issues are being discussed at the highest levels of water management in the state. But water law is not easy to change because there are usually winners but also losers with any decisions. Another issue of water law that concerns agricultural users is that, in a real emergency situation, municipalities can use eminent domain to take needed water for city populations from the agricultural sector. What this does is add another level of uncertainty to farmers' and ranchers' control over the resources that they deem are their own.

This book is about the rivers of Colorado, but we should look at other places around the globe to see what can, and probably, will happen in Colorado's water future. In 2018 Cape Town, South Africa—a city the size of Colorado Springs in a climatic region not dissimilar to eastern Colorado – ran out of water. A series of intense droughts left the city scrambling to provide the most essential city service – clean drinking water (the drought was eventually ameliorated by significant rainfall). No city in Colorado is anywhere near that kind of crisis yet, but many eastern plains towns and their surrounding farmlands are moving in that direction. The conflict in Syria is not all about water, but drought and widespread crop failures have exacerbated the already crisis situation. Again no places in Colorado are going to war over water, at least the shooting kind, but the conflicts over water, those of rural versus urban and West Slope versus East Slope, will intensify even with possible agreements made in the state water plan. Water in all of its guises will be one of the most important issues in the state for the foreseeable future – maybe for centuries, as the very real aspects of climate change play out.

All the water we have on earth now or will have in the future is already here. With extremely miniscule exceptions (new volcanic eruptions for example), there is no source of new water. And as far as we can know, all life on earth needs water for its very survival. The problems concerning the rivers of Colorado outlined in this book are all core issues of the amount, timing, and location of how we get the water we need to survive. William deBuys in his book, *A Great Aridness*, gives us a sobering reminder of how serious our river/water problems can be and what we can do about them. He simply states,

> Ultimately, the best answers to the climate change predicament in the North American Southwest lead back to mundane matters: we need to get on with what we should have been doing all along, including limiting greenhouse gases. We need to take care of unfinished business on the border, in our forests, and in water management. It wouldn't hurt to love the desert – there will be much more of it –and to protect the rivers and to give the diversity of nature our serious respect.

We need to respect the natural characteristics of our rivers and what they give us. The solutions will not be easy, but they will be vital to the future of our state and to those who come after us.

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References

Arkansas Basin Roundtable, 2015. *Arkansas Basin Roundtable Basin Implementation Plan*, Colorado Water Conservation Board, Denver, CO, pp. 799.

BBC Research and Consulting, 2013. *Public Opinions, attitudes and Awareness Regarding Water in Colorado*, Colorado Water Conservation Board, Denver, CO, pp. 147.

Berwyn, Bob, 2014 "Sides Agree to Innovative Fraser River Deal to Help Slake Denver Water Thirst," *The Colorado Independent*, March 5, 2015.

Bureau of Reclamation, 2015, *Technical Evaluation of the Gold King Mine Incident*, U.S. Department of the Interior, Technical Service Center, Denver, CO, pp. 132.

Bureau of Reclamation, 2021, Colorado River Fact Sheet, U.S. Department of the Interior, https://www.usbr.gov/ColoradoRiverBasin/MediaKit/20210800-ColoradoRiverBasinFactSheet-August2021-508-UCRO.pdf.

Chapman, S.S., G.E. Griffith, J.M. Omerick, A.B. Price, J. Freeouf, and D.L. Schrupp, 2006. *Ecoregions of Colorado – map*, U.S. Geological Survey, Reston, VA.

Colorado Basin Roundtable, 2015. *Colorado Basin Implementation Plan*, Colorado Water Conservation Board, Denver, CO, pp. 147.

Colorado Department of Public Health and Environment, 2012. *Summitville Mine Superfund Site, Remedial Action Completion Report, Operable Unit 5,* EPA Region VIII Superfund Remedial Program, Denver, pp. 25.

Colorado Parks and Wildlife, 2013. *Moose Reintroduction Fact Sheet*, CPW, Denver, CO, pp. 2.

Colorado Water Conservation Board, 2015. *Colorado's Water Plan*, Colorado Water Conservation Board, Denver, CO, pp. 419.

Colorado Water Conservation Board, 2020*. Colorado Water Plan – Celebrating the 5th Anniversary*, CWCB, Denver, CO, https://dnrweblink.state.co.us/cwcbsearch/ElectronicFile.aspx?docid=213417&dbid=0

Colorado Water Research Group, 2018 (March). *When Drought is not a Drought? Drought, Aridification, and the "New Normal"*, Colorado River Research Group, Denver, CO, pp. 4.

Congress for the New Urbanism, n.d. *What is New Urbanism*, Washington, D.C., https://www.cnu.org/resources/what-new-urbanism

de Buys, William, 2011. *A Great Aridness*, Oxford University Press, New York, NY, pp. 369.

Doyle, Martin, 2018. *The Source: How Rivers Made America and America Remade Its Rivers*, W.W. Norton & Company, New York, NY, pp. 349.

Fremont, J.C., 1845. *Map of an Exploring Expedition to the Rocky Mountains in the Year 1842 and to Oregon & North California in the Years 1843-44*, Topographic Bureau, Baltimore.

Gardner-Smith, B., 2016. "Glenwood Springs still facing challenge to water rights for new whitewater parks", Aspen Journalism.

Grantham, Joseph J., 2016 (revised edition). *Synopsis of Colorado Water Law*, Colorado Division of Water Resources, Denver, CO, pp. 40.

Gunnison Basin Roundtable, 2015. *Gunnison Basin Implementation Plan*, Colorado Water Conservation Board, Denver, CO, p. 198.

Hopkins, Ralph L. and Lindy B. Hopkins, 2000. *Hiking Colorado's Geology*, The Mountaineers, Seattle, WA, pp. 239.

King, Trude, V.V., 1995. *Environmental Considerations of Active and Abandoned Mine Lands – Lessons from Summitville, Colorado*, U.S. Geological Survey Bulletin 2220, U.S. Government Printing Office, Washington, D.C., pp. 43.

Korte, N.E., 2000. *Selenium Poisoning of Wildlife and Western Agriculture: Cause and Eff*ect, Environmental Sciences Division Publication No. 4979, Oak Ridge National Laboratory, TN, pp. 54.

Lavender, David S., 1982. *Colorado River Country*, E.P. Dutton, Inc., NY, pp. 238.

Logan, William B., 1995. *Dirt, the Ecstatic Skin of the Earth*, Riverhead Books, New York, NY, pp. 203.

Lukas, Jeffery, 2014. *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation.* 2nd. Ed., Colorado Water Conservation Board, Denver, CO, pp. 107

Matthews, Vincent, Katie KellerLynn, and Betty Fox, eds., 2003. *Messages in Stone – Colorado's Colorful Geology*, Colorado Geological Survey, Denver, CO, pp. 157.

Mckee, T. B., Doesken, N. J. and Kleist, J.,1993. *The relationship of drought frequency and duration to time scales*, in proceedings of 8th conference on applied climatology, Anaheim, California, U.S.A: 179-184.

Natural Resources Conservation Service (NRCS), 1999. *Soil Taxonomy*, 2nd ed., AH 436, U.S. Department of Agriculture, Government Printing Office, Washington, D.C., pp. 869.

Owen, David, 2017. *Where the Water Goes*, Riverhead Books, New York, NY, pp. 274.

Palmer, William C., 1965. *Meteorological Drought*, Research Paper #45, U.S. Weather Bureau, Washington, D.C., pp. 58.

Plumlee, Geoffrey S. and Edelmann, Pat, 1995. *The Summitville Mine and its Downstream Effects* -- An ON-LINE UPDATE of Open File Report 95-23, U.S. Geological Survey, Denver, CO, pp. 12.

Powell, John Wesley, 1879. *Report on the Lands of the Arid Region of the United States*, U.S. Department of the Interior, Government Printing Office, Washington, D.C., pp. 195.

Pritchett, James, Alan Bright, Andrea Shortsleeve, Jennifer Thorvaldson, Troy Bauder, and Reagan Wascom, 2009. *Public Perceptions, Preferences, and Values for Water in the West*, Special Report #17, Colorado water Institute, Ft. Collins, CO, pp. 35.

RB Team, 2017. "Glenwood Springs Whitewater Park," *Riverbreak Magazine*, http://riverbreak.com/spots/glenwood-springs-whitewater-park/

Rio Grande Basin Roundtable and DiNatale Water Consultants, 2015. *Rio Grande Basin Implementation Plan*, Colorado Water Conservation Board, Denver, CO, pp. 170.

South Platte Basin Roundtable, Metro Basin Roundtable, and West Sage Water Consultants, 2015. *South Platte Basin Implementation Plan*, Colorado Water Conservation Board, Denver, CO, pp. 360.

South Platte Working Group, 2014. *South Platte River Run Park*, Arapaho County Open Spaces.

Stegner, Wallace, 1992. *Beyond the Hundredth Meridian*, Penguin Books, New York, NY, pp. 438.

Wilkinson, Alec, 2018. "Drip ... Drip ... Drip," (September issue), Esquire, pp. 132-155.

Wilshire, Howard G., Jane E. Nielson, and Richard W. Hazlett, 2008. *The American West at Risk*, Oxford University Press, NY, pp. 619.

Zappia, Natale A., 2014. *Traders and Raiders – the Indigenous World of the Colorado Basin, 1540-1859*, University of North Carolina Press, Chapel Hill, NC, pp. 240.