Colorado River in Eagle County Inventory and Assessment

Report prepared for the

Eagle River Watershed Council

June 2014

By

Colorado State University

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Executive Summary

The Colorado River corridor through Eagle County is a unique ecosystem that offers a multitude of valuable resources, services, and amenities. Owing to a largely confined valley surrounded by a relatively arid and mineral-poor landscape, local human influences in the Eagle County portion of the upper Colorado are relatively modest despite direct encroachment by road and railroad corridors. Yet its remote and picturesque setting belies mounting pressures from upstream; namely, the fundamental societal challenge of meeting increasing demands for water supplies while simultaneously providing flows necessary to sustain aquatic and riparian ecosystems. Finding this balance rests squarely upon future water-management decisions throughout the Upper Colorado River basin.

This report describes the results of the *Colorado River in Eagle County Inventory and Assessment* (CRIA), a joint effort of Colorado State University (CSU) and the Eagle River Watershed Council (ERWC), to assess the current state of the Colorado River corridor within Eagle County. The overarching goals of the project were to: 1) conduct a systematic inventory of channel, riparian, and upland characteristics in the main stem river corridor and 2) use data collected and analyzed during the inventory to assess pertinent parameters and characteristics that affect the ecological integrity, recreational amenities, and aesthetic values of the Eagle County portion of the river. The specific objectives of the inventory and assessment were to:

- Perform an analysis of existing monitoring data and information to assess the status of river corridor. Existing water quality data may be used to “bracket” sources of nonpoint source pollution and to identify the spatial distribution of water quality influences and biological stressors.
- Conduct synoptic field surveys of riparian condition, chemical, physical, and biological water quality, and geomorphic attributes to supplement existing information. The spatial domain of this survey was defined as the Colorado River main stem from Pumphouse to Dotsero.
- Identify and describe candidate rehabilitation projects (structural and non-structural) and link to current issues and likely outcomes based on:
    - field reconnaissance,
    - meetings with watershed stakeholders,
    - meetings with local, state, and federal scientists,
    - Geographic Information System (GIS) inventory and analysis (e.g., riparian conditions, land cover, geomorphic processes, etc.), and
    - scientific assessment.

ES.1 Main Stem Corridor Overview

The study area for this project encompasses the 60-mi main stem corridor of the Colorado River from Pumphouse boat launch downstream to the confluence with the Eagle River. In general, the river is mostly confined by canyon and steep-sided topography.

Pumphouse is located at the bottom of Gore Canyon where the Colorado River runs steeply out from the narrow canyon onto flatter, less confined topography. From here, the river travels through Lower Gore Canyon before Blacktail Creek enters from the north. The river continues downstream where Sheephorn Creek merges from the south before reaching Radium. Below Radium, Red Gorge Canyon offers a steeper decent before mostly flatter water presides until State Bridge. Just upstream of State Bridge, the largest tributary in the study area, the Piney River, enters the Colorado River. Downstream to Rock Creek the river alternates between steep-walled canyon and less confined valley. Areas with wider floodplains in this reach are mainly used for growing hay. Catamount boat launch is located at the junction of Big Alkali Creek and the Colorado River. From Catamount downstream the geologic setting becomes more sedimentary-dominated and the river valley alternates between relatively steep canyon-like sections and flatter yet still confined areas. Land cover within watershed below Pumphouse is 36% evergreen forest, 28% shrub/scrub, 14% grasslands/herbaceous, and 14% deciduous forest. A brief description of nine perennial tributaries is provided below. A more in-depth analysis of tributary water quality and its influence on the main stem are discussed in Chapter 4.

ES.2 Analysis of Watershed Characteristics

ES.2.1 Land Use

Land use change within the study area has remained relatively modest due to steep topography and aridity. Ranches and irrigated pasture have encroached upon the river floodplain in the wider valley bottoms; however, 65% of the river runs through public land managed by the Bureau of Land Management (BLM). Future opportunities for development along river corridor appear minimal and are primarily focused on opening up recreational opportunities. A recent proposal from Grand County to build a whitewater park upstream of Pumphouse is being reviewed by the BLM and other resource agencies. Currently there are no oil and gas leases within the study area (BLM, 2013a). Most of the area has no known or low potential for gas occurrence except for one medium potential section around Cabin Creek and Big Alkali Creek watersheds (BLM, 2013a).

ES.2.2 Water Rights

The first water rights in the Colorado River basin within Eagle County date back to the 1880s when settlers began ranching in the area. The arid land required settlers to divert water by ditch, well, and pump in order to ranch. As of 2005, there were 496 diversion structures within the study area (Colorado Decision Support System (CDSS), 2013). Of these, only 151 have an absolute water right rate greater than 3 cfs. The largest single diversions in the study area occur in the Derby Creek (32 and 29 cfs) and Rock Creek (25 and 22 cfs) watersheds. The most important water rights for maintaining flows in the main stem river are actually located downstream. The water rights held by the Shoshone Power Plant and the “Cameo Call” are two of the oldest held on the Colorado River and make up a large portion of the water in the Colorado River year round. However, the Shoshone rights can be shutoff during runoff and "relaxed" during times of drought to allow more junior rights held by reservoirs upstream to store water.

An agreement made in 2010 by East Slope and West Slope water providers will guarantee flows in the late summer months to help with recovery of four federally endangered fishes that inhabit a 15-mi reach of the Colorado River near Grand Junction. The four species of fish, Colorado pikeminnow (*Ptyochocheilus lucius*), razorback sucker (*Xyrauchen texanus*), humpback chub (*Gila cypha*), and bonytail chub (*Gila elegans*), will benefit from an additional 10,825 AF of water. Initially, water was provided from the Williams Fork and Wolford Mountain Reservoirs which provided the benefit of additional late summer flows to the Colorado River through Eagle County. However, in 2013, two permanent sources, Ruedi and Granby Reservoirs, were designated to each release half of the 10,825 AF of water. Only Granby Reservoir is upstream of the study area; thus, less water will be sent through the area than in previous years under the new operations.

ES.2.3 Upstream Reservoirs and Diversions

The Colorado River basin has an extensive history of water storage and diversion. Some diversions are inbasin (the water never leaves the watershed). In contrast, transbasin diversions move water outside of the watershed where it fell as precipitation. Finally, transmountain diversions are transbasin diversions that move water from the West Slope of the state, over the Continental Divide, to the East Slope.

The largest transmountain diversion project in Colorado, the C-BT Project built between 1938 and 1957, originally came about to deliver water from the West Slope to the East Slope primarily for agricultural purposes. Today, 12 reservoirs, 35 mi of tunnel, and 95 mi of canal deliver 213,000 AF of water per year to the East Slope to provide for agricultural and municipal uses.

A more recent addition to the C-BT Project is Windy Gap Reservoir. Built in 1985, Windy Gap Reservoir is a small impoundment (445 AF) used to pump water from the Colorado River, below the confluence with the Fraser River, up to Lake Granby. Windy Gap delivers an average of 48,000 AF/year of water. A new firming project for Windy Gap has been proposed and is currently under review. This would provide an additional 90,000 AF of storage allowing for the Northern Colorado Water Conservancy District (NCWCD) to fully utilize the 90,000 AF/year that can be diverted by Windy Gap. These additional water withdrawals from the Colorado River can have direct impacts on the river downstream of Windy Gap including through the study area. Possible impacts could include reduced flows in general but especially peak flows which could exacerbate sedimentation issues.

Within the Colorado River basin, Denver Water owns and operates two reservoirs and four tunnels that deliver water out of the basin to the Eastern Slope. A proposal put forward by Denver Water to enlarge Gross Reservoir by 72,000 AF is currently under review. Enlarging the reservoir means that Denver Water would be able to divert more water out of the Williams Fork and Fraser River basins. Reducing flows on these two major tributaries to the Colorado River could possibly impact peak flows and late summer water temperatures downstream including the study area.

ES.2.4 Hydrology

The hydrologic regime of the Upper Colorado River is dominated by snowmelt from higher elevations in the watershed. Certain climatic factors that control snowpack influence how the hydrologic regime behaves in any given year. One of the more crucial factors determining the water quantity available to the Colorado River in any year is the peak Snow Water Equivalent (SWE) in the watershed. Six Snow Telemetry (SNOTEL) sites within the Upper Colorado River watershed were analyzed for upward or downward trends in SWE and average air temperature during their period of record. Overall, four of six sites showed a decreasing trend in SWE with two of these being statistically significant. Five of six sites showed an increasing trend in average air temperature and these were all statistically significant. Basing future projections of SWE and temperature on these periods of record is questionable; however, if these trends continue it could mean less overall water for the Colorado River and earlier peak flows which could possibly result in lower and warmer flows in late summer.

Flow alterations within the Upper Colorado River began with the construction of the numerous diversion structures and reservoirs that are present today. The largest diversions exported water out of the watershed. Direct discharge measurements of these diversions were compared for the period between 1961 and 2011. Results indicate that the Moffat, Adams, and Roberts tunnel diversions exported 29% of the total yield at the Colorado River at Kremmling gage (U. S. Geological Survey (USGS) #09058000) (Figure 3.23). The majority of the water rights are diverted during spring runoff, effectively reducing annual peak flows.

The current flow regime within the study area during the post Windy Gap (1985-2013) period shows the annual average peak discharge at the Kremmling gage is approximately 2,240 cfs. The average annual peak flow (1985-2013) for the Colorado River above the confluence with the Eagle River is approximately 3,660 cfs. Tributaries within the study area on average (1985-2013) contribute up to 46% of flows during spring runoff, but tributary inputs decrease to a low of 16% during the summer months. Flow contribution from the Piney River, the largest tributary, peaks in spring runoff at 12% and decreases to an average of 2% in summer.

Changes in streamflow characteristics (magnitude, frequency, duration, timing, rate of change) from pre- to post-development were analyzed using the Indicators of Hydrologic Alteration (IHA) program (Mathews and Richter, 2007). The streamflow gage records at Kremmling date from 1904-1916 and from 1962-2013. The period from 1904-1916 was used streamflow analyses performed in this study as an approximation of pre-diversion and reservoir flows on the Colorado River. The period from 1962-2013 is representative of post-development flows in a period of evolving water operations and management.

The climate between 1905 and 1931 is characterized as a long wet period with brief dry periods in the early teens (McKee *et al*., 1999). When examining peak flows from the years 1905-1918, the maximum peak flow was 21,500 cfs in 1912 and the minimum peak flow was 6,690 cfs in 1908. The brief dry period in the early teens is most likely referencing the peak flow of 7,860 cfs in 1913. Although the peak flows may be slightly higher than average conditions due to the long wet period, a peak flow greater than the minimum peak flow of 6,690 cfs from 1905-1918 has only occurred six times between 1962-2013.

The construction of major reservoirs within the watershed has increased minimum flows on the Colorado River. Reservoirs tend to increase base flows on a river due to the storage of water allowing for more flow to be released during what are normally low flow periods. The 1-day, 3-day, 7-day, 30-day, and 90-day minimum flows have all increased post-development by an average of 27%. If the increase in minimum flows is occurring during the low-flow summer months it could help keep water temperatures below the critical threshold for trout. However, post-development median flows during July and August were 43% smaller than the wet pre-development period. Meanwhile, post- development median flows between October and March are 19% larger than pre- development. Therefore, increases in minimum flows due to reservoirs seem to be occurring primarily during the winter months.

Maximum flows on the Colorado River have been substantially altered by transmountain diversions. The 1-day, 3-day, 7-day, 30-day, and 90-day maximum flows have all decreased post-alteration by an average of 74%. The overall hydrograph from the two periods of record breaks flow into different environmental components including large floods (>17,900 cfs), small floods (>11,700 cfs), and high-flow pulses (>1,800 cfs) (Figure 3.26). During the pre-development period, 8 of 14 peak flow events were considered a small flood or larger and the remaining six were high-flow pulses. Applying the same thresholds to the post-development period indicates the occurrence of one small flood, 31 high-flow pulses, and 19 peak events below 1,800 cfs. Comparison of exceedance probabilities for all pre- and post-development flows indicates that flows with an exceedance probability greater than 57% (~700 cfs), post-development flows are on average 51% smaller than pre-development. This reduction in peak flows post-development becomes more apparent when comparing the exceedance probability of flows in June when the peak usually occurs. For all exceedance probability values in June, post-development flow values are on average 78% smaller than pre-development. The durations of these peak flow events have also decreased substantially. The median duration of the pre-development small flood peak flows was 91 days. The median duration of post-development peak high-flow pulses is 12 days. The timing of the peak flow event has also shifted. Pre-development, the average peak flow occurred on June 13. Post-development, the average peak flow occurs on June 2.

ES.2.5 Riparian Analysis

Field-based analysis of the riparian corridor was conducted between September 26 and October 2, 2012 and from October 1 to October 4, 2013 while floating the river through the study area. Every instance of accelerated bank erosion or failure, riparian buffer encroachment, or sparsely to unvegetated riprap was documented with photographs and GPS. Sites where riprap banks had vegetation established were not designated as potential restoration sites due to the low feasibility of either eliminating or reducing encroachment by the road or railroad. Russian olive (*Elaeangnus angustifolia*) was also noted but was not a focus of the analysis as Russian olive was widespread from Two Bridges to Dotsero (~35 mi) making eradication possibly unfeasible. Tamarisk (*Tamarix aphylla*) was documented with GPS; however, the resulting estimates of impacted bank lengths do not represent dense stands as tamarisk was not observed to be continuously established along any banks. Rather, individual plants were spotted either infrequently. Overall, the estimated percentage of impacted riparian area is low at 8%. Most of the riparian impacts stem from human activities on private land. In general, the impacts from these riparian encroachments appear minimal and rehabilitation efforts in these areas, although desirable, provide limited local ecological benefits compared to system wide management efforts (e.g., environmental flows).

ES.2.6 Water Quality

Water quality is strongly influenced by interactions with water quantity (streamflow) in the study area. The two primary issues identified in this study are elevated water temperatures, especially during low flows of late summer, and deposition of fine sediment. Water temperatures were recorded in 2012 and 2013 by the Wild and Scenic (W&S) Stakeholder Group at three locations within the study area: 1) State Bridge, 2) Below Red Dirt Creek, and 3) Dotsero. In 2012, the data logger below Red Dirt Creek was buried by sediment and the resulting data were unusable. Hence, the analysis of temperature data performed in this study focused on the more complete data set from 2013.

As expected, results indicate that water temperatures increase moving downstream. In 2013, temperatures at Dotsero were on average ~4°F warmer than at State Bridge (3/29-11/7). Compared to water temperature data from the Colorado River at Kremmling, Dotsero was 3.1°F warmer (3/28-9/30). Between July 1 and September 30, Dotsero was 5.6. F warmer than Kremmling and 6.3°F warmer from July 1 to August 31.

Temperatures for the three sites in the project area were compared to Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Commission (WQCC) standards for Cold Water Tier II Aquatic Life streams. CDPHE WQCC standards exist for two parameters: 1) the DM and 2) the MWAT. During 2013, the most-upstream W&S temperature monitoring site at State Bridge recorded no observations exceeding recommended state standards. At Red Dirt Creek, sedimentation at the probe site rendered a portion of the mid-season data unusable, but generated a viable record overall. During the period from June 29 to July 22, observations exceeded MWAT standards for 4 weeks. In the final week of July, upstream water releases increased and temperature concerns abated; this time period in 2013 also featured plentiful monsoonal moisture in the mountain region, easing diversion pressures and temperatures on many streams across the West Slope. At the Dotsero site, observations exceeded MWAT standards for 4 weeks between June 29 and July 30. DM exceedances also occurred for a shorter period within that time, surpassing the 23.8°C threshold for 8 days from July 15 to 24. Analysis of a limited subset of data from 2012 shows a similar MWAT exceedance for nearly 6 weeks between July 4 and August 15. Taken together, these observations support the conclusion that warm temperatures, associated with low flows, are a continuing concern to aquatic ecosystems in the Eagle County reach of the Colorado River.

Single point water temperatures were collected between September 26 and October 1, 2012 in all perennial tributaries to determine if they were contributing to increases in water temperature on the main stem. Results indicate that all tributaries were colder than the Colorado River except for Sheephorn Creek which was 1°F warmer (Figure 3.73). Combining these single point measurements with the fact that on average the largest tributary, the Piney River, only contributes 2% of flow to the main stem through the summer months, it appears unlikely that any single tributary, nor the cumulative contribution of all tributaries, would have a substantial effect on main stem warming during the period of observation. Additional analyses described below suggest that elevated temperatures within the study area are primarily a consequence of tributary influences and reservoir operations the upper watershed. Further investigation during the summer months by collecting continuous data from each tributary and in the main stem above and below each tributary, especially in August, is recommended to fully understand the influence of tributaries on main stem temperatures.

A GIS time-series animation was created to explore water temperature dynamics in the Colorado River watershed upstream of the study area. Water temperature and discharge data collected between 2010-2012 by the USGS and Grand County Water Information Network (GCWIN) for many of the tributaries and locations along the main stem were used in this study to develop three GIS animations depicting spatial and temporal temperature patterns. The animations show both the daily maximum temperature and daily average flow. Overall, it appears that the Fraser River is contributing more flow and is substantially warmer than the Colorado River at their confluence. Below the Fraser confluence, water temperatures again become elevated in the Colorado River prior to reaching the Williams Fork. The Williams Fork does appear to substantially decrease water temperatures in the main stem when the flow being released is a substantial portion of the total flow. If the Williams Fork is not contributing enough flow to cool the main stem, temperatures remain elevated and continue to increase upstream of Muddy Creek. Thus, water releases from the Williams Fork Dam appear to play a pivotal role in moderating summer temperatures along the main stem Colorado River.

GIS animations indicate that Muddy Creek temperatures during summer increase substantially between Wolford Mountain Reservoir and its confluence with the Colorado River. This is particularly apparent below the Kremmling Wastewater Treatment Facility. The Blue River appears to normally be substantially colder during summer than the main stem and provide a cooling effect in the main stem, especially when enough flow is being released from Green Mountain Reservoir. The Blue River also appears to play an important role in moderating summer water temperatures through the study area. Hence, it is important to note that with the agreement to allow substitution of water from the Blue River with Muddy Creek, the water temperatures and the consequent influence on the Colorado River main stem may not be the same. If large quantities of water from the Blue River are swapped with Muddy Creek water, this pronounced cooling effect may be diminished.

Turbidity samples were collected from September 26 to October 2, 2012 and from October 1 to October 4, 2013. In general, turbidity increased in a downstream direction. During 2013, a storm dropped 2 to 4 inches of snow throughout the study area. Turbidity was measured in the tributaries during the snowmelt from this event to possibly identify differences in the contribution of fine sediments. The majority of sediment entering the main stem from tributaries undoubtedly occurs during intense summer thunderstorms, but snowmelt may provide some semblance of a baseline indication. Big Alkali Creek, Red Dirt Creek, and Sweetwater Creek were the most turbid. The Piney River was the least turbid.

ES.2.7 Sedimentation Above and Below Catamount

As described above, there is a general shift from a mix of igneous and sedimentary rocks to sedimentary-dominated geologic setting moving downstream. This change becomes most apparent downstream from Two Bridges to Catamount where an appreciable increase in sediment delivery occurs due to increasing numbers of gullies and washes. This increased influx of fine sediment from surrounding hillslopes, gullies, and tributaries continues all the way to Dotsero.

Upstream of Catamount, the geology within the study area is: 36% igneous, 1%, metamorphic, 41% sedimentary, and 22% other rock types. Below Catamount, the geology consists of: 15% igneous, 0% metamorphic, 57% sedimentary, and 27% other. Part of the well-known Universal Soil Loss Equation (USLE) is the K-factor or soil erodibility factor. The higher the K-factor value the higher the soil erodibility. The K-factors for soils within the study area were mapped and the results indicate more readily erodible surfaces downstream of Catamount The steepness of the surrounding hillslopes also plays a central role in delivering eroded sediment to the river. Therefore, the product of slope and USLE K-factor was mapped to represent the synergistic interaction between slope and soil erodibility. Again, areas with higher erodibility appeared to be more prevalent downstream of Catamount.

With increased sediment delivery occurring downstream of Catamount, a resulting shift in river bed slope, width, or planform might be expected. The bedslope from Pumphouse to Rancho Del Rio, from Rancho Del Rio to Burns, and from Burns to Dotsero have all been estimated at 0.0027 (Miller and Swaim, 2011); however, these slopes are estimated from topographic maps and do not reveal local trends and variations in the longitudinal profile of the river. Detailed longitudinal surveys along the length of the study area are not currently available. Another factor that could potentially change with increased sediment deposition is the frequency and size of mid-channel islands. Above Catamount there were on average 2.4 vegetated islands per mile, while below averaged 2.3. No substantial difference in island frequency is apparent; however, the islands below Catamount tended to be larger and occupy more of the channel. Results from the pebble counts data show that the river bed surface at the cross section located ~1 mi above Dotsero contained substantially more material less than 8 mm and 2 mm as compared to other cross sections. Percent embeddedness was also highest at the two cross sections downstream of Catamount. Percent fines were highest at Radium followed by the two cross sections downstream of Catamount.

The photographic evidence along with the apparent increases in: turbidity, soil erodibility, percent bed material less than 8 mm and 2 mm, percent embeddedness, and percent fines below Catamount, provide multiple lines of evidence suggesting that sediment delivery is relatively high in this part of the river corridor. This increase becomes more evident when examining benthic macroinvertebrate data as described in the following section.

ES.2.8 Macroinvertebrates

Three macroinvertebrate samples were taken at each riffle site using a 900-cm^2 Surber sampler with a 500-µm mesh size. Macroinvertebrate data were analyzed for upward or downward trends in density and richness from upstream to downstream. Overall, only the 2012 Total Richness and Ephemeroptera, Plecoptera, and Tricoptera (EPT) Richness trends were significant. Total density appeared to show a downward, although not statistically significant, trend moving downstream in 2012. Total richness increased slightly downstream in 2012 and 2013. EPT density and richness appeared to increase 0.7 mi below Two Bridges (River Mile 21.3). This increasing trend in EPT below Two Bridges runs counter to the notion that increased sediment delivery below Catamount would negatively affect macroinvertebrate density and richness. However, many of the EPT taxa collected in this study have some tolerance of fine sediment.

When considering taxa known to be sediment-tolerant or sediment-intolerant as defined by the Fine Sediment Bioassessment Index (FSBI) (Relyea *et al*., 2000), there appears to be a more discernable trend occurring. Trends in oth richness of sediment tolerant taxa and density of sediment intolerant taxa were statistically significant. Sediment-tolerant richness increased downstream and sediment-intolerant richness decreased downstream. Sediment-tolerant density also increased downstream, with a substantial increase occurring at Two Bridges. Sediment-intolerant taxa density again decreased downstream.

Macroinvertebrate taxa collected in the study area that are relatively tolerant of fine sediment include: *Baetis tricaudatus, Ephemerella* sp.*, Paraleptophlebia* sp.*, Tricorythodes explicates, Hydroptila* sp.*, Heptagenia* sp.*, Isoperla* sp.*,* and *Cheumatopsyche* sp. All of these sediment tolerant species showed an increasing trend in density moving downstream but only *Hydroptila* sp. and *Heptagenia* sp. were considered significant. Taxa that are relatively intolerant of fine sediment in the study area include: *Orthocladiinae, Chironomini, Epeorus* sp.*, Cultus* sp.*, Lepidostoma* sp.*, and Pteronarcys californica.* These taxa all showed a decrease in density downstream and four of the six trends were significant.

CDPHE WQCC uses the Multi-metric Index (MMI) to assess attainment of aquatic life use standards as required by the Colorado Water Act and defined in the 2010 *Aquatic Life Use Attainment* (CDPHE WQCC, 2010) methodology. Researchers sampled 24 total sites in 2013 and 2014; 24 on the main stem and 14 on tributaries. Streamflow variability prevented re-sampling of all sites in both years. In addition, low densities at some sites, and low numbers in certain operation taxonomic units prevented MMI calculation for some samples. The MMI was successfully calculated for 16 sites on the Colorado River and 6 tributary sites.

All sites attained state standards in 2012 and 2013, except the 2012 Blacktail Creek sample (Figure 3.104). This site produced a high score the next year, indicating either a wide natural variability to the creek, or potentially some introduced sampling error or outlier condition in the first year. Scores appeared to indicate a slight upward trend from Pumphouse to Dotsero on the main stem, although this was not statistically tested. As compared to state standards, generalized metrics for community assemblages appeared healthy in the project area.

MMI results appear to parallel the previously-reported trends in Total Richness and EPT Richness, which increased slightly in a downstream direction within the project area. Samples from perennial tributaries exhibit an apparent decreasing trend in the downstream direction, although again this was not statistically tested due to the low sample population. Perennial tributaries in the project area generally feature undeveloped or slightly-impacted headwater reaches, which then flow through areas of diversions and increased ranching including irrigated pasture and hay production, before joining the Colorado. The lower reaches of these creeks tend to have the available bottomland for agricultural use, small residential development, or access road alignment and thus the most potential for stream impacts in terms of dewatering, grazing impacts, and physical alteration. In general, MMI scores indicate the lower reaches of perennial streams are attaining CDPHE WQCC aquatic life use standards, although continued lower-frequency monitoring at a smaller subset of locations may help detect impacts of land use or changing climate/runoff regimes in the region to aquatic communities.

ES.2.9 Fishes

Between Pumphouse and Radium, the river is designated as a wild reproducing brown trout fishery. Rainbow trout are present but the population is much smaller than the brown trout. Electrofishing data from 2010-2012 indicate that brown trout biomass is approximately 5 to 14 times greater than rainbow trout (Ewert and Bakich, 2014). All fish were determined to be in good condition due partially to abundant *Pteronarcys californica* larvae as a food source (Ewert, 2013). Electrofishing data from the Colorado Parks and Wildlife (CPW) indicate that brown trout biomass decreases moving downstream. Between 2008 and 2013, the highest biomass occurred at Radium and it decreased at each site downstream.

Electrofishing surveys indicate a transition from a trout-dominated to sucker and chub-dominated water seems downstream of Catamount. Fish count data in 2009 and 2010 indicate that although trout are still established downstream of Catamount, the sucker and chub populations become more prevalent (Figure 3.107). This shift in fish assemblages is likely caused by many factors including increases in water temperature, sediment deposition, and a greater prevalence of homogeneous run and glide habitat compared to upstream of Catamount.

ES.2.10 Flushing Flows

The importance of moderate to high streamflows in maintaining aquatic and riparian ecosystems is widely recognized (Poff *et al*., 1997; Bunn and Arthington, 2002; Annear *et al*., 2004; Poff and Zimmerman, 2010). Moderate to high flows in Rocky Mountain snowmelt rivers provide several types of amenities, physical processes, and ecological functions.

A flushing flow analysis was performed on the main stem Colorado River to provide a preliminary estimate of flows needed to mobilize the median grain size bed material and surficial deposits of fine sediment at cross sections along the Colorado River through the study area. Sites were chosen along the Colorado River to be representative of a larger portion of the river, yet had to be to allow for data collection across the entire channel. Due to the size and limited wadeability of the Colorado River through the study area, only five sites were chosen as representative and accessible. A systematic point grid frame method was used in combination with a gravelometer to collect substrate data at each site along transects spanning the bankfull channel (Bunte and Abt, 2001). The systematic point grid frame method was used to obtain over

300 pebble count observations with the gravelometer. Transects were placed in riffles as these areas are commonly used to assess the condition of aquatic ecosystems within gravel-bed streams. Substrate samples were taken pre- and post-runoff to quantify changes in bed material composition as a result of the magnitude and duration characteristics of the 2013 snowmelt hydrograph. Resulting grain-size distributions taken pre-runoff were truncated at 2 mm to estimate the d_{50} used in the flushing flow analysis. The substrate data collected before runoff was deemed a more accurate representation of what would possibly be flushed during runoff.

The point grid frame method was also used in conjunction with a bucket viewer to collect presence of fines, algae, and coarse substrate data. Embeddedness data were collected at each site by measuring the average depth of the largest substrate above and below the layer of fine material surrounding the rock. Fifteen rocks within the wetted boundary were measured at each site. Both embeddedness and presence of fines data were also collected pre- and post-runoff.

The peak flows in 2013 did not mobilize coarse sediment at any of the study sites. Marginal removal of surface veneers of fines from the channel center may have occurred at two sites but did not occur at the other three study locations. Preliminary estimates of flushing flows necessary for coarse substrate mobilization at a few accessible riffles generally exceed 12,000 cfs. Preliminary analyses also suggest that removal of surficial veneers of fine sediment could potentially be achievable at flows in the vicinity of 4,000 to 8,000 cfs, especially in the upstream reaches of the study area.

ES.3 Projects and Strategies for Conservation

ES.3.1 Ecosystem-scale Projects

ES.3.1.1 Environmental Flow Management in the Upper Colorado River

Aquatic life communities and terrestrial riparian communities in the Upper Colorado River corridor have developed life-history strategies built around the natural flow regime of a snow-fed, mountain river system. Alterations of the timing and magnitude of key hydrologic events (especially peak runoff and flow recession) by water-management activities outside the project area produce important changes to the river corridor. Unmitigated sedimentation degrades aquatic habitat conditions in the lower reaches, and high summertime temperature regimes potentially affect cold-water stream communities. The state’s Water Court decreed minimum in-stream flow (ISF) rights for the project reach in 2013, providing some amount of protection to the Upper Colorado ecosystem against management-driven extreme low-flow events in summer and fall. While minimum flow protection supplies an important component of environmental flows in the Upper Colorado, habitat maintenance flows are an equally important component.

Available fishery and macroinvertebrate data indicate aquatic life community health changes in a downstream direction, with a decrease in sediment-intolerant taxa and an increase in sediment-tolerant taxa. Analyses and empirical evidence provided by the CRIA identifies fine sedimentation and temperature as two primary influences on aquatic conditions. The river is unable to frequently provide habitat maintenance flows that flush accumulated fine sediment downstream due to man-made changes in the flow regime, and reservoir management may exacerbate summertime temperature concerns. Coordinated diversion and reservoir release actions by upstream water resource managers hold the potential to alleviate these ecosystem stressors in the project area. However, numerous existing and potential water-management agreements create a difficult political and regulatory arena in which to effect these vital restoration actions. Future storage and water-management activities in the Colorado Basin currently identified in the State Water Plan hold potential to further exacerbate the altered flow regime issues within the project area. For example, increased diversions from the Fraser River as part of the Moffat Firming Project and potential changes in release schedules tied to a proposed Wolcott Reservoir could both have direct and negative implications for flushing flows in the Upper Colorado area.

The CRIA provides preliminary flushing flow (habitat maintenance flows) estimates for the project reach from Pumphouse to Dotsero using five cross sections. Establishing additional cross sections, especially in the region from Catamount down, will refine these estimates. Additional substrate sampling before and after different spring runoff volumes can provide empirical evidence to support these estimates and reduce potential error. Flushing flow estimates may serve as the basis for flow regime targets for regional water managers, providing the scientific foundation for negotiation of coordinated reservoir actions upstream. A rational future goal would be to include a periodic flushing flow regime in statewide water-management agreements between Colorado River stakeholders to properly sustain ecosystem processes in the river reaches between Kremmling and Glenwood Canyon. The Upper Colorado W&S Stakeholder Group maintains a Channel Maintenance Work Group that is currently working towards consensus on this important issue. It is recommended that ERWC establish and promote a partnership with this Work Group for future monitoring and policy implementation activities surrounding flushing flows in the project area. Table ES.1 outlines goals, tasks, and initiation time frames for flushing flow activities; and Table ES.2 lists recommended flushing flow monitoring and additional sites.

Table ES.1 – Flushing flow activities.

Goal	Task	Time Frame to Initiate
Provide empirical evidence of flushing flows.	• Re-sample substrate data after 2014 runoff and additional flow years for evidence of substrate mobilization.	• Immediate; post-runoff 2014 (2014 is currently a high-runoff year)
Close estimation error on flushing flow estimates throughout project reach.	• Establish additional cross sections, especially between Catamount and Sweetwater Creek.	• Low flow • Late summer/fall 2014 – 2015
Institutionalize flushing flows within the policy framework for river management.	• Using best available scientific evidence, convene appropriate stakeholders (water rights holders, State Engineer, transmountain diversion (TMD) operators, reservoir operators, etc.) for collaborative negotiation of flow regime targets. • Write flushing flow schedules into operational policies and compacts that determine Upper Colorado flow regimes. Language used in the 2014 *Grand County Mitigation and Enhancement Coordination Plan* (Grand County, 2014) can serve as a template.	• After appropriate evidence and analysis is complete • 2015+

Table ES.2 – Recommended flushing flow monitoring and additional sites.

Cross Sections and Substrate Monitoring Sites		Task/Status
Current sites:	Pumphouse	Re-sample substrate in 2014
	Radium	Re-sample substrate in 2014
	Above Catamount	Re-sample substrate in 2014
	Above Sweetwater	Re-sample substrate in 2014
	Above Dotsero	Re-sample substrate in 2014
Additional recommended sites (approximate locations):	State Bridge area	Establish cross section, sample substrate, and model flows
	Derby Creek area	Establish cross section, sample substrate, and model flows
	Red Dirt Creek area	Establish cross section, sample substrate, and model flows

ES.3.1.2 Temperature Management

CPW, BLM, and the W&S Stakeholder Group all conduct stream temperature monitoring on the Upper Colorado. Analysis in the CRIA of publicly-available data from the GCWIN identified exceedances of CDPHE WQCC temperature standards for the river above Dotsero in 2012 and 2013, and near Red Dirt Creek in 2013. This preliminary analysis suggests that temperature issues for the lower project reach may be a consistent issue and warrant continued monitoring and investigation. The W&S Stakeholder Group and Trout Unlimited (TU) identified these issues in 2013 as well, pursuing voluntary stakeholder-initiated mitigation activities with water managers to alleviate late-summer temperature increases. Additional temperature monitoring over a range of water years at existing or additional sites will provide a fuller picture of the geographical and temporal nature of temperature issues in the project area. Continued exceedances may indicate a designation of 303(d) impairment for the reach is appropriate; however, such a designation warrants careful consideration, as it may either help or hinder negotiation of management alternatives among stakeholders and resource managers.

Future flow depletions and/or climate change will potentially exacerbate summer temperature extremes in the Upper Colorado River corridor. Since elevated temperatures appear to be controlled by interactions with major tributaries and reservoirs in the upstream watershed, it is recommended that future water-management decisions upstream of the study area be considered in terms of potential system-level temperature effects. It is strongly recommended that the influence of water management and reservoir operations on downstream temperatures be explicitly included in management agreements between Colorado River stakeholders to conserve critical ecosystem processes in the river reaches between Kremmling and Glenwood Canyon. The Upper Colorado W&S Stakeholder Group maintains a Monitoring Work Group that is currently working towards consensus on managing this important issue. ERWC is encouraged to establish and promote a closer working partnership with this group for future monitoring and policy implementation activities surrounding temperature issues in the project area.

ES.3.2 Regional-scale Projects

ES.3.2.1 <u>Invasive Species</u>

Tamarisk occurs along the river corridor in sparse amounts, making it an ideal candidate for eradication before further establishment. Concerted efforts to cut and spray tamarisk communities from Bond to Dotsero will hinder the ability of communities to disperse further upstream or entrench at existing locations. As this area is likely approaching the natural climate boundary for most tamarisk species, the probability of success is positively weighted. Invasive species is a programmatic mandate for BLM resource managers as well as county governments in Colorado; thus, a streamlined planning and approval process would be anticipated for these activities on BLM-managed land within the river corridor. An agency partnership with the ERWC on this effort will both strengthen stakeholder relations and serve as a nexus for short-term community volunteer engagement. Russian olive also occurs downstream of Bond, however, the degree of community establishment is much greater than tamarisk and will likely prove harder to manage. Russian olive is notoriously difficult to remove, often involving mechanical extraction of the entire root system with large equipment. Russian olive in areas with multiple or high conservation values may still be worthy to consider for control or removal. Current contact information for invasive plant management is reported in Table ES.3.

Table ES.3 – Area contacts for invasive plant management.

Agency	Contact Information
BLM	Project area: State Bridge – Dotsero Hydrologist/Geologist: Pauline Adams Colorado River Valley Field Office Telephone: (970) 876-9071 E-mail: padams@blm.gov
Eagle County	Scott Griffin Eagle County Noxious Weed Control Telephone: (970) 328-3553 Fax: (970) 328-8788

ES.3.2.2 Native Fish Conservation and Reclamation Strategy

Colorado River cutthroat trout (Blue Lineage) and as-yet-to-be-named Green Lineage cutthroat trout exist in a small number of perennial tributaries to the main stem Colorado River in the project area. The Blue Lineage cutthroat is a species of special concern in the state and a BLM, State of Colorado, and U. S. Forest Service (USFS) Region 2 sensitive species. Green Lineage cutthroats are currently treated as federally threatened, although recent genetic research in the state has initiated a review of species status and management. Regardless of current uncertainties surrounding Green Lineage fish, populations as a whole occupy a fraction of historical range and face the same difficult pressures as Blue Lineage fish. The last century has brought large reductions in overall habitat range and loss of genetics through hybridization with non-native trout species. Non-natives introduced for sport aggressively out-compete cutthroats for habitat in the limited number of suitable Colorado streams, threatening viability statewide and throughout the central Rocky Mountains.

Out of hundreds of miles of perennial streams in the project area, including tributaries to the Piney River, only six streams are currently known to support native cutthroat (White River National Forest (WRNF), 2014). Other tributaries may still hold populations of indeterminate lineage and purity. Taken together, these subwatersheds of the Upper Colorado represent a potentially viable sanctuary region for cutthroat conservation and preservation; a region of headwater streams with some agricultural pressure; but partly free of heavy development, habitat loss, and legacy impacts from forestry, mining, and urbanization that degrade other watersheds in the Colorado River basin. These fisheries represent a unique, under-appreciated, and under-valued asset of the Upper Colorado region. A locally-pushed, unified strategy for their protection and enhancement could help ensure a sustainable and resilient stronghold for these populations in the face of statewide human and natural pressures that increasingly threaten their long-term survival prospects.

In 2006, the state wildlife agencies of Colorado, Utah, and Wyoming adopted a joint *Conservation Strategy for Colorado River Cutthroat Trout* (CRCT) to address threats to the species and preemptively avoid a potential Endangered Species Act listing (CRCT Coordination Team, 2006). The CRIA project area nests within the Colorado Headwaters Geographic Management Unit for that document. One significant tributary hosts a conservation population of Green Lineage fish and has already received limited attention by WRNF and

EWRC for habitat improvement projects. Conservation populations are "*naturally reproducing and recruiting populations of native cutthroat trout that managed to preserve the historical genome and/or unique genetic, ecological, and/or behavioral characteristics*;" in general, they are more than 90% genetically pure (CRCT Coordination Team, 2006).

Populations of Green lineage in nearest-neighbor stream systems in Upper Colorado perennial tributaries could potentially qualify as 'metapopulations' under the interstate/interagency management strategy, although more data may be necessary to fully understand regional population genetics. Metapopulations are "*geographically distinct yet genetically interconnected. If individual localized populations go extinct, they can be refounded by surrounding populations*" (CRCT Coordination Team, 2006). A unified strategy for protection, habitat improvement, and stream range reclamation in the Upper Colorado region could proactively protect broodstocks, small populations, and spawning fish, creating a sustainable genetic sanctuary for cutthroat in the Pumphouse-Dotsero region.

This report does not recommend a single project, but rather, suggests investing in the development of a unified conservation strategy among local area partners including ERWC, CPW, WRNF, Colorado River Valley Field Office (CRVFO) / Kremmling Field Office (KFO) BLM, local hunting/fishing outfitters, and other potential partnerships such as Colorado Headwaters Chapter of Trout Unlimited (CO TU), Colorado Mountain Club (CMC), Walking Mountains, etc. At its core, this unified conservation strategy could be a down-scaled version of the interstate/interagency framework laid out in the 2006 Conservation Strategy. It would nest within the greater multi-agency/multi-state effort, but be guided by local-to-regional organizational partnerships (Table ES.4). Strategy implementation could utilize a suite of stream and reach-specific tools including habitat protection and enhancement (both riparian and in stream); non-native species removal; physical migration barriers and other engineered solutions; ISF and water rights acquisition; and where both appropriate and having a high probability of success, reclamation (re-introduction). Implementation strategies would vary reach to reach based on feasibility, probability of success, and land ownership situations.

Table ES.4 – Native fish conservation goals and tasks.

Goals	Tasks	Time Frame
Gage interest and coalition building.	• **Concept development.** Stakeholder engagement (ERWC, CPW, WRNF, BLM, other nongovernmental organizations (NGOs), and appropriate private parties).	2014
Identify available conservation options.	• **Feasibility assessment.** Fully review available fishery data, identify inter-agency management goals, objectives, and responsibilities. Determine property ownership and access status, initiate National Environmental Policy Act (NEPA), and other agency-required processes.	Fall 2014 – 2015
Begin active strategy implementation and fieldwork.	• **Strategy implementation.** Utilize suite of available tools to actively protect and enhance cutthroat in Upper Colorado region.	2015 – 2025

ES.3.3 Local-scale Projects

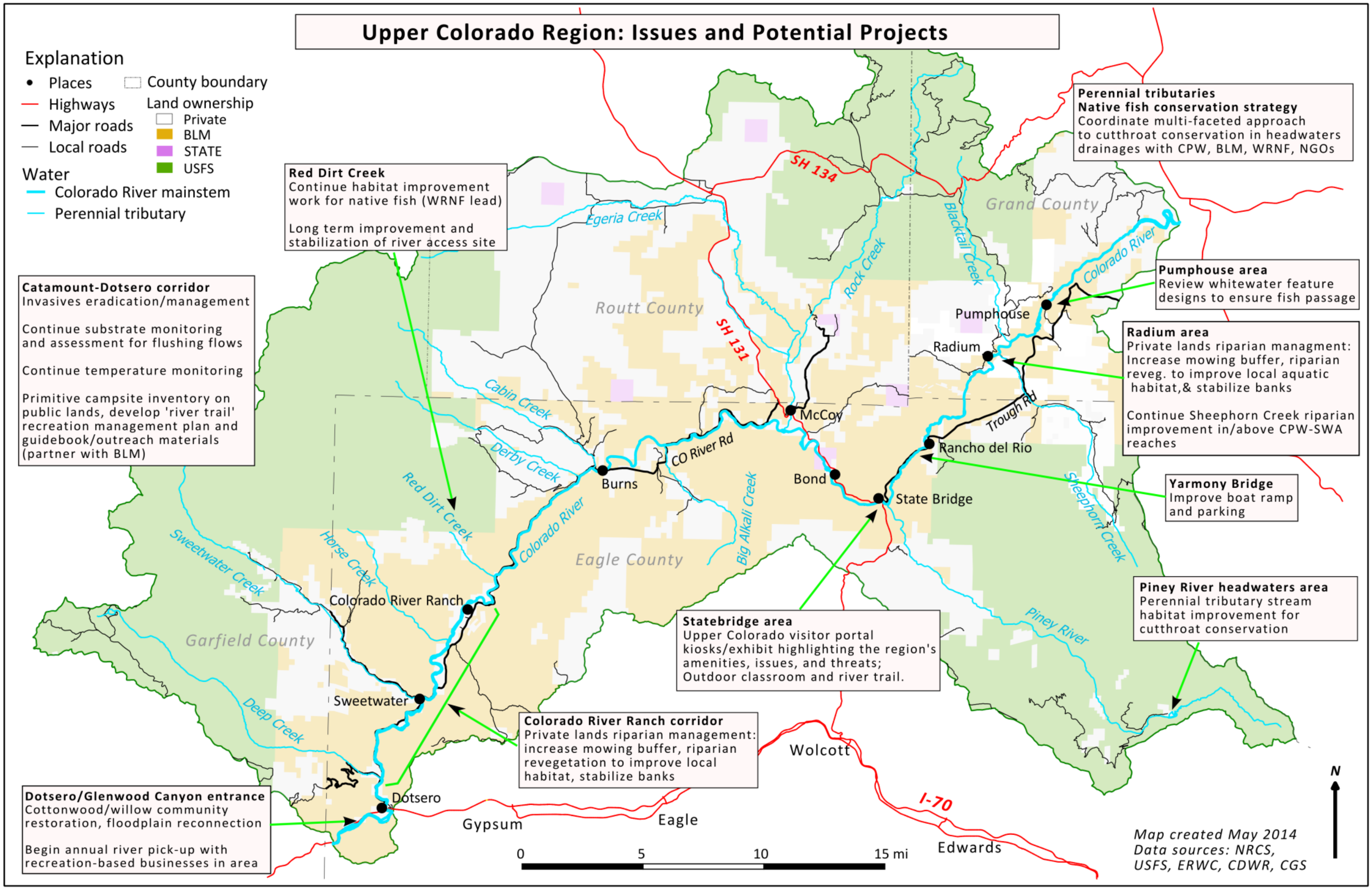
ES.3.3.1 <u>Riparian Buffer and Plantings</u>

Functional riparian buffers generally persist in the project area, except where interrupted by localized land-management activities such as agricultural and residential mowing, or removed by significant physical alteration such as railroad construction directly bordering the river. For the main stem Colorado River, work conducted for the CRIA indicates that hydrologic alteration and localized sedimentation driven by water-management activities outside the project area are the primary controllers of aquatic ecosystem conditions. In general, actions targeting riparian improvement are unlikely to provide significant changes or improvements to main stem water-quality condition and aquatic communities. Where riparian improvement activities coincide with additional conservation values or special areas of concern, revegetation projects may still prove worthwhile due to the other resource values they support. Examples include river parcels with identified conservation easements, or segments with identified habitats for species of concern such as river otter. In general, short-scale reaches with outstanding wildlife, recreational, or other conservation values may be well-served by vegetation-oriented projects. In certain cases, landowners engaged in riparian restoration on Sage grouse habitat may receive certain technical assistance, planning, and other benefits from the Natural Resources Conservation Service (NRCS). Sage grouse habitat mapped by the NRCS tends to concentrate in northern Eagle County, on the south side of the river above Burns in the Big Alkali Creek watershed, and to a limited degree in the upper Cabin Creek watershed. Conservation-minded riparian management practices in these areas may have synergistic benefits for both native fish in perennial streams and landowner credits for grouse habitat preservation.

Tributaries. In select perennial tributaries with existing valuable native fish populations, additional riparian improvement projects can provide measureable benefits to aquatic habitat in the project area. One example is Red Dirt Creek, where existing vegetation and road-corridor work by the ERWC, WRNF, and CPW has sought to improve conditions for the conservation population of cutthroat, and potentially decrease sediment load to the Colorado River. Potential locations for reach-scale riparian improvement projects include the Colorado River Ranch, Red Dirt Creek, high-visibility recreational visitor ‘portals’ like the boat ramps and picnic areas at Lyons Gulch, Cottonwood, and Catamount. Sheephorn Creek has already been the focus of previous restoration; in 2001 NRCS initiated a bank-stability project on Piney Peak Ranch, in the lower reaches which border the Radium State Wildlife Area (SWA). As these downstream reaches are CPW-administered, publicly-accessible fishing segments, additional attention to stream stability, temperatures, and sediment delivery from upstream land use may be a worthwhile endeavor to ensure a sustainable and productive sport fishery in this high-use area.

Private lands. Private lands with degraded riparian conditions on the main stem tend to concentrate in the Bond-McCoy and Red Dirt Creek-Dotsero reaches (Figure ES.1), although the aerial extent of mowing and hayfield encroachment, and grazing impacts comprises only 4.1% of the 62-mi project area. A limited education/outreach campaign with landowners may generate voluntary efforts to refrain from mowing or otherwise developing riparian zones further. Emphasis for property owners could be placed on the improved bank stability and sediment retention characteristics of native vegetation over shallow turf grasses, in order to increase stakeholder buy-in to riparian projects on private lands. Geographic emphasis can be placed on corridors that are anticipated to receive more public use in the near future, such as the area near the Colorado River Ranch and downstream to other large parcels like the Roundup River Ranch (Figure ES.2). New and improved public river access at locations like Red Dirt Creek and Horse Creek are anticipated to increase recreational float boating and fishing use in these areas. Improving riparian conditions can provide examples of model land stewardship, as well as provide localized improvements to streamside habitat such as increased bank complexity, woody debris, and thermal refugia for aquatic life. Before implementing riparian improvement strategies in these areas, additional landowner education and outreach is necessary to generate support and local buy-in/ownership of conservation issues by residents, and to avoid the perception by landowners that unnecessary conservation projects are thrust upon them by top-down management planning.

Figure ES.1 – In the corridor from Red Dirt Creek to Dotsero, many private lands maintain little or no riparian buffer, potentially exacerbating bank erosion and limiting local-scale habitat for animal communities dependent on the riparian zone. An outreach campaign and guidance/support on riparian stewardship for riverside landowners can help improve this issue in the reach, which is experiencing increased recreational use from float boaters and fishermen due to access improvements by Eagle County.


Upper Colorado Region: Issues and Potential Projects

Red Dirt Creek
Continue habitat improvement work for native fish (WRNF lead)

Long term improvement and stabilization of river access site

Catamount-Dotsero corridor
Invasives eradication/management

Continue substrate monitoring and assessment for flushing flows

Continue temperature monitoring

Primitive campsite inventory on public lands, develop 'river trail' recreation management plan and guidebook/outreach materials (partner with BLM)

Perennial tributaries
Native fish conservation strategy
Coordinate multi-faceted approach to cutthroat conservation in headwaters drainages with CPW, BLM, WRNF, NGOs

Pumphouse area
Review whitewater feature designs to ensure fish passage

Radium area
Private lands riparian managment: Increase mowing buffer, riparian reveg. to improve local aquatic habitat,& stabilize banks

Continue Sheephorn Creek riparian improvement in/above CPW-SWA reaches

Yarmony Bridge
Improve boat ramp and parking

Piney River headwaters area
Perennial tributary stream habitat improvement for cutthroat conservation

Statebridge area
Upper Colorado visitor portal kiosks/exhibit highlighting the region's amenities, issues, and threats; Outdoor classroom and river trail.

Colorado River Ranch corridor
Private lands riparian management: increase mowing buffer, riparian revegetation to improve local habitat, stabilize banks

Dotsero/Glenwood Canyon entrance
Cottonwood/willow community restoration, floodplain reconnection

Begin annual river pick-up with recreation-based businesses in area

Map created May 2014
Data sources: NRCS, USFS, ERWC, CDWR, CGS

Figure ES.2 – Upper Colorado region issues and potential projects.

Agency lands. BLM staff at the CRVFO has identified the Colorado River at the entrance to Glenwood Canyon as a location of interest for larger-scale riparian restoration, including reconnection of the river to floodplain areas and re-establishing of cottonwood-willow communities (Table ES.5). Increased water-based recreational use between the Dotsero put-in and Bair Ranch rest area by tubers and standup paddleboarders has produced a large jump in visitor use and social impacts to the river corridor in the last 5+ years. This area is also potentially degraded from past land use management activities, legacy impacts from highway construction, and hydrologic impacts of Shoshone Dam downstream including delta formation and sedimentation in the reservoir backwaters. Bank and floodplain re-contouring and other localized physical improvements, followed by revegetation to reestablish healthy and functional riparian communities such as willow-cottonwood to this high-visibility portal to Glenwood Canyon and the Upper Colorado area surrounding Dotsero. Table ES.6 outlines goals, tasks, and initiation time frames for riparian improvement. Current contact information for riparian projects is reported in Table ES.7.

Table ES.5 – Local riparian improvement opportunities.

Site	Project
Colorado River Ranch-Dotsero corridor	Riparian improvement, private lands
Radium area	Riparian improvement, private lands
Glenwood Canyon entrance	Floodplain reconnection, revegetation, and willow-cottonwood restoration

Table ES.6 – Riparian improvement goals and tasks.

Goal	Task	Time Frame to Initiate
Generate landowner buy-in to riparian stewardship and improvement.	• Focused landowner outreach and education campaign to avoid the perception of an outsider-imposed conservation mandate. • Determine interest level, cooperative partners, and available locations	2014 – 2015
Identify priority improvement areas within Red Dirt Creek-Dotsero corridor.	• Prioritize areas by landowner access, riparian condition, and revegetation feasibility. • Produce a planning or guidance document.	2014 – 2015
Partner with residents, Eagle County, and relevant agencies to implement riparian improvement.	• Help landowners design and implement BMPs for riparian buffering and mowing/grazing restrictions on streambanks. • Utilize volunteer base and partnerships to re-vegetate impacted areas.	2015+

Table ES.7 – Area contacts for riparian projects.

Agency	Contact Information
BLM	Hydrologist/Geologist: Pauline Adams Colorado River Valley Field Office Telephone: (970) 876-9071 E-mail: padams@blm.gov
Eagle County Conservation District	District Manager: Audra Meyers PO Box 360 Eagle, CO 81631 Telephone: (970) 230-0844
Colorado NRCS	District Conservationist: Derek Wiley Glenwood Springs Field Office (Eagle County) 258 Center Drive Glenwood Springs, CO 81601-2539 Telephone: (970) 945-5494 Fax: (970) 945-0837

ES.3.3.2 Visitor Portal Enhancement

Physical improvement or maintenance of high-use visitor portals addresses recreational values in the project area (Table ES.8). These can include improving boat ramp conditions for sustainable long-term use; or other engineering projects around these areas involving re-grading, drainage work, and revegetation and visitor use pattern management.

Table ES.8 – Visitor portal improvement projects.

Location	Work Needed	Purpose	Operator
Red Dirt Creek	Continued stabilization of boating access point and vehicle access road.	Long-term physical site stability	Eagle County Open Space
Yarmony Bridge	Used as unofficial put-in below Rancho del Rio, eroding ramp and parking issues.	High visibility/recreation value and visitor portal	None currently
Others as needed	Update inventory on existing status, user numbers, and work needed at multi-agency boat ramps and riverside recreational amenities.	Various	BLM, Eagle County, CPW

ES.3.3.3 Education and Outreach Projects

State Bridge river access: Outdoor classroom and interpretive station. In addition to research and projects, ERWC is mandated to advocate for the health of the Eagle and Upper Colorado Rivers via public education and outreach. The State Bridge area is a key access to the Upper Colorado River corridor for thousands of local and out-of-area visitors yearly, arriving both by I-70/Wolcott, the Steamboat area to the north, and Grand County via the Trough Road. Eagle County invested significant resources in improved river access here in 2012, and the State Bridge music center and BLM campground continue to serve as a social focal point for thousands of recreational users including float boaters, fishermen, and others. This portal is a high-visibility, high-use, and high-quality location for public engagement by ERWC and organizational partners like Walking Mountains Science Center, Eagle County, and BLM. A small river interpretive station at the access site can provide visitors a welcoming overview of the Upper Colorado region, including conservation issues and threats, recreation amenities, and wildlife resources. In addition to these river access site items, coupling additional amenities such as a short interpretive trail/walking classroom towards the Piney River confluence (below the existing road cut) and a small outdoor classroom or primitive amphitheater seating setup, could provide the physical setting for reoccurring outreach/education activities by ERWC and partners like Walking Mountains Science Center.

Dotsero-Glenwood area river cleanup. In recent years, the advent of several commercial tubing businesses in the Vail and Glenwood area and the large increase in Stand Up Paddleboarding (SUPing) on state rivers have both significantly increased recreational river use on the reach from Dotsero landing to Bair Ranch. The river is generally calm, deeper, and devoid of major rapids through this area, making it ideal for these uses. With increased social use comes increased resource pressure, as well as a desire for a clean natural setting for optimum visitor experiences. Large metal debris from legacy land uses, as well as occasional litter from recreational users, currently detract from scenic values on this reach and could be addressed with a minimum amount of work. A partnership between ERWC and area businesses that utilize this stretch for a yearly, bi-yearly, or as-needed cleanup effort would ensure the resource retains the high-quality experience that visitors to the area expect, and that underpins the region’s tourism and recreation-based economy.

ES.4 Conclusions

When considering the results from the inventory and assessment of the Eagle County portion of the Colorado River corridor, there appear to be certain factors that control the ecological condition of the river corridor. Generally speaking, land use within the river corridor has changed modestly since the first arrival of European settlers. Homes have been built and irrigated hay fields have been established along areas with wider floodplains, but the lack of mineral and oil or gas resources have kept hydrologic and water-quality impacts from local land use change to a minimum. Future land use change is likely to remain minimal due to the arid and steep setting of the river corridor. However, rehabilitation of the riparian area along these private lands could provide localized ecological benefit to the river corridor.

The railroad and road are the two biggest encroachments upon the river corridor. Paralleling the river throughout the entire study area, the railroad and road have impacted the river corridor by: reducing riparian habitat, disrupting connectivity between surrounding terrestrial habitats and the river for wildlife, acting as a pathway for invasive species, reducing wood inputs to the river, and replacing natural banks with riprap that remain sparsely vegetated. However, the removal of either the road and/or railroad from the river corridor is impractical and socially unacceptable. Despite this, sections of the river corridor still harbor one of the most intact riparian areas on the Colorado River within the state including rare plant assemblages.

Future threats to the riparian area include greater establishment of invasive species, future hypothetical high-speed rail plans which may further encroach upon the river, and decreased frequency and duration of flows inundating the riparian area to maintain ecological health.

Overall, the most significant current threats to the ecological condition of the Colorado River are elevated water temperatures above the known thermal tolerance of trout, and interactions between fine sediment loading and the available environmental maintenance flows. All of these issues can be attributed to water quantity and flow regime. Beyond the water rights held by the Shoshone Water Plant and Cameo Call group downstream, the magnitude, frequency, and duration of environmental flows are controlled completely by the upstream watershed. Given uncertainty in future water demands and climate, ensuring the provision of future flows necessary to keep water temperatures below critical levels, flush deposited fine sediments, and mobilize the substrate for rejuvenation of habitats in the river bed becomes the utmost priority. Water-management decisions in the upstream watershed may directly affect the Eagle County portion of the Colorado River and should be monitored closely. Preliminary estimates of flushing flows necessary for coarse substrate mobilization at a few accessible riffles generally exceed 12,000 cfs. Preliminary analyses also suggest that removal of surficial veneers of fine sediment could potentially be achievable at flows in the vicinity of 4,000 to 8,000 cfs, especially in the upstream reaches of the study area. Continued monitoring of the capacity of the current flow regime to flush the system is recommended to allow water managers to make informed decisions in the future. Finally, it is important to manage this portion of the Colorado River as an inseparable unit of the entire upstream watershed system that ultimately determines its fate.

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Symbols

a, b	constants
A	cross-section area
d_{50}	median diameter of bed material
d_i	diameter of the i^{th} percentile grain size (16, 50, 64, 84 mm, etc.) of the distribution
G	specific gravity of sediment
∞	infinity
n	Manning roughness coefficient
N	number of samples
Q	volumetric flow rate
$Q_{1.5}$	peak discharge with a return period of 1.5 years in the annual maximum series
Q_2	peak discharge with a return period of 2 years in the annual maximum series
Q_C	critical discharge
R	hydraulic radius
S	slope
S_f	friction slope
V	velocity; cross-section average velocity
w	effective channel width
β_0	intercept
β_1	coefficient variable
γ	specific weight of the water/sediment mixture
γ_s	specific weight of sediment
μ	mean of input distribution
σ	standard deviation of input distribution
τ	shear stress
τ_*	dimensionless shear stress
τ_{*50}	dimensionless shear stress using d_{50} in sediment entrainment analysis
τ_{*C}	critical dimensionless shear stress (Shields parameter)
τ_C	critical shear stress (shear stress at incipient motion)
ϕ	constant

Units of Measure

AF	acre-feet
AF/year	acre-feet per year
cfs	cubic feet per second
cm^2	square centimeter(s)
°F	degree(s) Fahrenheit
ft	foot or feet
g/L	gram(s) per liter
m^2	square meter(s)
mg/L	milligram(s) per liter

mg/L-N	milligram(s) per liter as nitrogen
mi	mile(s)
mi^2	square mile(s)
µm	micrometer(s)
%	percent
µS/cm	microSiemen(s) per centimeter
mm	millimeter(s)
mV	milliVolt(s)
MYA	million years ago
NTU	Nephelometric Turbidity Units
ppt	parts per trillion
SI	International System of Units

Abbreviations

ACEC	Areas of Critical Environmental Concern
BBC	BBC Research & Consulting
BLM	Bureau of Land Management
BMPs	best management practices
BOR	Bureau of Reclamation
C-BT	Colorado-Big Thompson
CDOW	Colorado Division of Wildlife
CDPHE	Colorado Department Public Health and Environment
CDSS	Colorado Decision Support System
CMC	Colorado Mountain Club
CNHP	Colorado Natural Heritage Program
CO TU	Colorado Headwaters Chapter of Trout Unlimited
CPW	Colorado Parks and Wildlife
CRCT	Colorado River Cutthroat Trout
CRIA	Colorado River in Eagle County Inventory and Assessment
CROA	Colorado River Outfitters Association
CRVFO	Colorado River Valley Field Office
CRWCD	Colorado River Water Conservation District
CS-II	Cold Stream Tier II
CSU	Colorado State University
CWCB	Colorado Water Conservation Board
D/S	downstream
D&RG	Denver & Rio Grande Railroad
D&SLR	Denver & Salt Lake Railroad
DM	Daily Maximum
DWR	Division of Water Resources
EIS	environmental impact statement
EPT	Ephemeroptera, Plecoptera, and Tricoptera
ERWC	Eagle River Watershed Council
FSBI	Fine Sediment Bioassessment Index
GCWIN	Grand County Water Information Network
GIS	Geographic Information Systems

GPS	Global Positioning System
I-70	Interstate 70
ID	identification
IHA	Indicators of Hydrologic Alteration
ISF	in-stream flow
KFO	Kremmling Field Office
MMI	Multi-metric Index
MWAT	Maximum Weekly Average Temperature
#	number
N/A	not available
NCWCD	Northern Colorado Water Conservancy District
NEPA	National Environmental Policy Act
NGOs	nongovernmental organizations
NPS	National Park Service
NRCS	Natural Resources Conservation Service
ORVs	outstandingly remarkable values
PCA	Potential Conservation Area
PFC	Proper Functioning Condition
POW	Prisoner of War
®	registered trademark
SD	standard deviation
SNOTEL	SNOw TELemetry
SUPing	Stand Up Paddleboarding
SWA	State Wildlife Area
SWE	Snow Water Equivalent
TEMS	Transportation Economics & Management Systems, Inc.
™	trademark
TMD	transmountain diversion
TU	Trout Unlimited
TVS	Table Value Standard
TWIP	The Water Information Program
U/S	upstream
UDWR	Utah Division of Wildlife Resources
USFS	U. S. Forest Service
USFW	U. S. Fish and Wildlife
USGS	U. S. Geological Survey
USLE	Universal Soil Loss Equation
VRMC	Visual Resource Management Class
WQCC	Water Quality Control Commission
WRNF	White River National Forest
WSA	Wilderness Study Area
WSR	Wild and Scenic River
W&S	Wild and Scenic
WWII	World War II
XS	cross section(s)

Chapter 1

Introduction

The Colorado River corridor through Eagle County is a unique ecosystem that offers a multitude of valuable resources, services, and amenities. Owing to a largely confined valley surrounded by a relatively arid and mineral-poor landscape, local human influences in the Eagle County portion of the upper Colorado are relatively modest despite direct encroachment by road and railroad corridors. Yet its remote and picturesque setting belies mounting pressures from upstream; namely, the fundamental societal challenge of meeting increasing demands for water supplies while simultaneously providing flows necessary to sustain aquatic and riparian ecosystems. Finding this balance rests squarely upon future water-management decisions throughout the Upper Colorado River basin.

This report describes the results of the *Colorado River in Eagle County Inventory and Assessment* (CRIA), a joint effort of Colorado State University (CSU) and the Eagle River Watershed Council (ERWC), to assess the current state of the Colorado River corridor within Eagle County. The overarching goals of the project were to: 1) conduct a systematic inventory of channel, riparian, and upland characteristics in the main stem river corridor and 2) use data collected and analyzed during the inventory to assess pertinent parameters and characteristics that affect the ecological integrity, recreational amenities, and aesthetic values of the Eagle County portion of the river. The specific objectives of the inventory and assessment were to:

- Perform an analysis of existing monitoring data and information to assess the status of river corridor. Existing water quality data may be used to "bracket" sources of nonpoint source pollution and to identify the spatial distribution of water quality influences and biological stressors.
- Conduct synoptic field surveys of riparian condition, chemical, physical, and biological water quality, and geomorphic attributes to supplement existing information. The spatial domain of this survey was defined as the Colorado River main stem from Pumphouse to Dotsero.
- Identify and describe candidate rehabilitation projects (structural and non-structural) and link to current issues and likely outcomes based on:
    - field reconnaissance,
    - meetings with watershed stakeholders,
    - meetings with local, state, and federal scientists,

    - Geographic Information System (GIS) inventory and analysis (e.g., riparian conditions, land cover, geomorphic processes, etc.), and
    - scientific assessment.

The following chapters address these objectives and present various results of the inventory and assessment. Based on the results, a list of potential projects and management activities that would help improve the state of the river is presented and discussed.

Chapter 2

Watershed Overview, History, and Policy

2.1 Watershed Overview

The study area for this project is defined as the 60-mi main stem corridor of the Colorado River from Pumphouse boat launch downstream to the confluence with the Eagle River. Nevertheless, the Colorado River basin upstream of the study area has a direct impact on the hydrology and the resulting ecological condition of the Eagle County portion of the river. Therefore, the Colorado River and its major tributaries upstream of the study area will be briefly reviewed first.

The Upper Colorado River watershed upstream from the confluence with the Eagle River encompasses parts of Eagle, Grand, Summit, and Routt Counties in north-central Colorado. The watershed drains approximately 3,420 mi^2 of mountainous terrain. Elevations within the watershed range from 14,275 ft at Torreys Peak down to 6,783 ft at the confluence with the Eagle River (Figure 2.1). Much of the higher elevation terrain consists of evergreen forest, while the lower lying valleys are typically non-irrigated rangeland or irrigated hay fields. Due to the large range in elevations, temperature and precipitation vary greatly with higher elevations experiencing lower temperatures and increased precipitation.

As the Colorado River flows downstream from its headwaters, several major tributaries including Willow Creek, Fraser River, Williams Fork, Muddy Creek, and the Blue River join before reaching the study section. Up to 75% of annual flow for these rivers and streams comes from snowmelt usually beginning in March and April and peaking in June. Streamflow for the rest of the year consists of runoff from summer convective thunderstorms and baseflows. Some of the water within the Upper Colorado River watershed is captured by inter-basin reservoirs and moved out of the basin from the West Slope to the East Slope to provide water for a growing population along the Colorado Front Range.

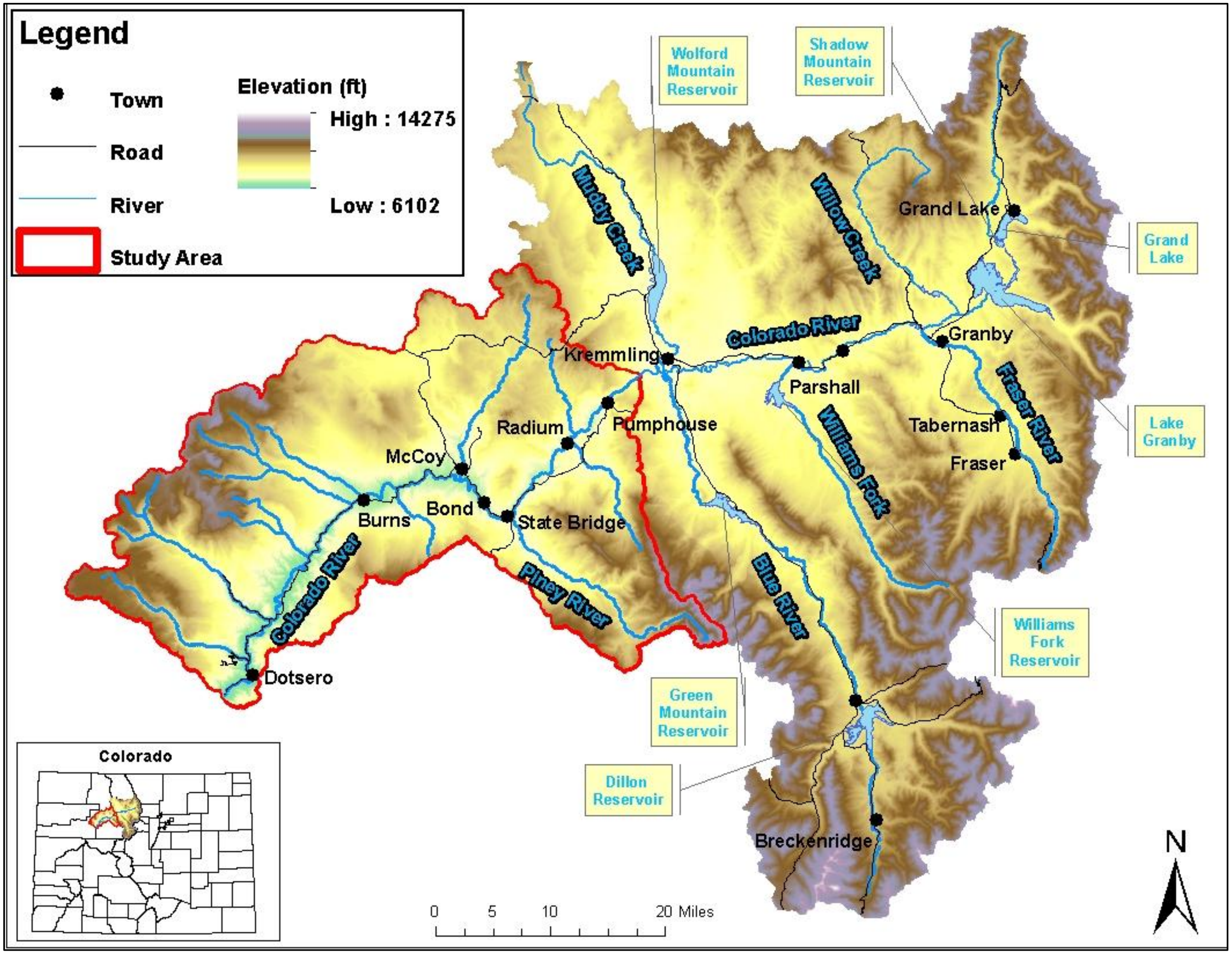


Figure 2.1 – Upper Colorado River watershed upstream of Dotsero.

2.1.1 Colorado River (headwaters to pumphouse)

The headwaters of the Colorado River begin at La Poudre Pass Lake (10,174 ft) located within Rocky Mountain National Park (Figure 2.2). From here the Colorado River begins its course down through Rocky Mountain National Park and drains into Shadow Mountain Lake, which is connected through a dam to Lake Granby. Upon exiting through Granby Dam, the Colorado River merges with Willow Creek prior to its confluence with the Fraser River near the town of Granby. After passing through Windy Gap Reservoir, the Colorado River merges with the Williams Fork and travels through mostly hay fields before passing by the town of Kremmling. Muddy Creek and the Blue River are the last two major tributaries entering the Colorado River before it enters Gore Canyon.

Figure 2.2 – The Colorado River starts at La Poudre Pass Lake in Rocky Mountain National Park (http://www.fotopedia.com/wiki/La_Poudre_Pass_Lake#!/items/flickr-4309872641).

The watershed upstream of Pumphouse drains 2,390 mi^2. Elevation ranges from 14,275 ft down to 7,898 ft. Land cover is dominated by evergreen forest at higher elevations, and shrub/scrub in the lower elevations (Figure 2.3). A brief overview of the major tributaries in the upstream watershed can be found in Appendix A.

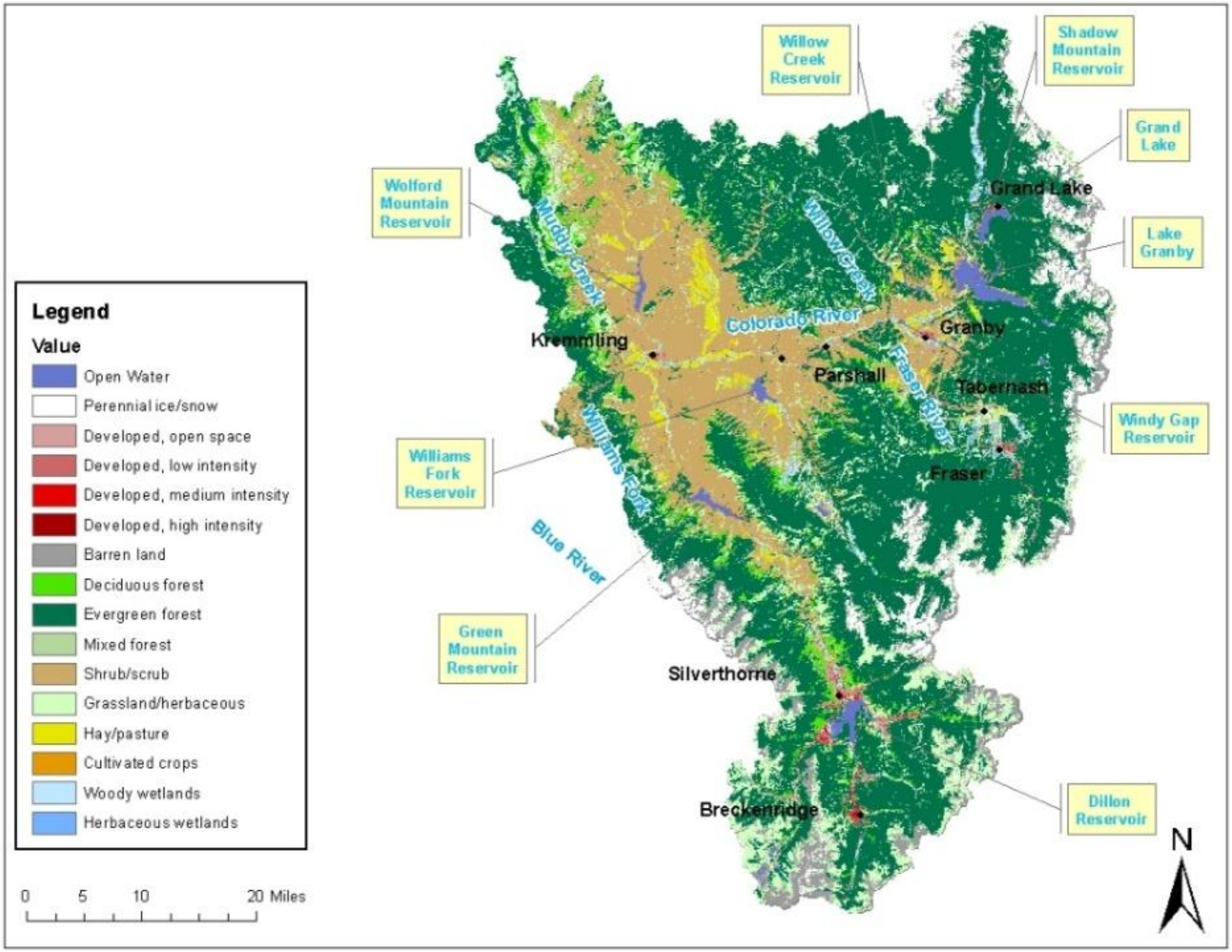


Figure 2.3 – Land cover within the Colorado River watershed above Pumphouse.

2.1.2 Colorado River Pumphouse to Dotsero

The study area for this project encompasses the 60-mi main stem corridor of the Colorado River from Pumphouse boat launch downstream to the confluence with the Eagle River (Figure 2.4). In general, the river is mostly confined by canyon and steep-sided topography. Pumphouse is located at the bottom of Gore Canyon where the Colorado River runs steeply out from the narrow canyon onto flatter, less confined topography. From here, the river travels through Lower Gore Canyon before Blacktail Creek enters from the north. The river continues downstream where Sheephorn Creek merges from the south before reaching Radium. Below Radium, Red Gorge Canyon offers a steeper decent before mostly flatter water presides until State Bridge. Just upstream of State Bridge, the largest tributary in the study area, the Piney River, enters the Colorado River. Downstream to Rock Creek the river alternates between steep-walled canyon and less confined valley. Areas with wider floodplains in this reach of the river are mainly used for growing hay. Catamount boat launch is located at the junction of Big Alkali Creek and the Colorado River. From Catamount downstream the geologic setting begins to become more sedimentary-dominated and the river valley alternates between relatively steep canyon-like sections and flatter yet still confined areas. Land cover within the watershed downstream from Pumphouse is 36% evergreen forest, 28% shrub/scrub, 14% grasslands/herbaceous, and 14% deciduous forest (Figure 2.5). A brief description of nine perennial tributaries is provided below. A more in-depth analysis of tributary water quality and influence on the main stem are discussed in Chapter 4. Although Big Alkali Creek may be perennial, the creek was observed having minimal flow, nearly dry, and biologically depauperate during three site visits conducted during this study. Given the insignificant influence of Big Alkali Creek on the river main stem due to its relatively small contributing area and channel size, it is not included in this discussion.

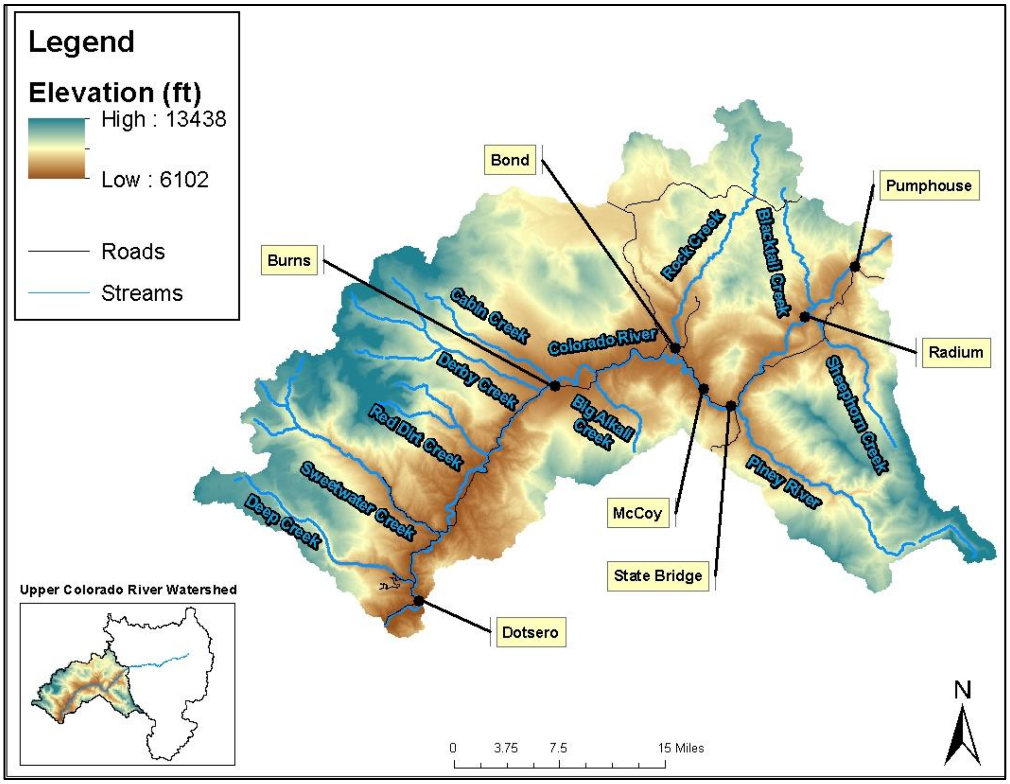


Figure 2.4 – Colorado River watershed elevation within the study area.

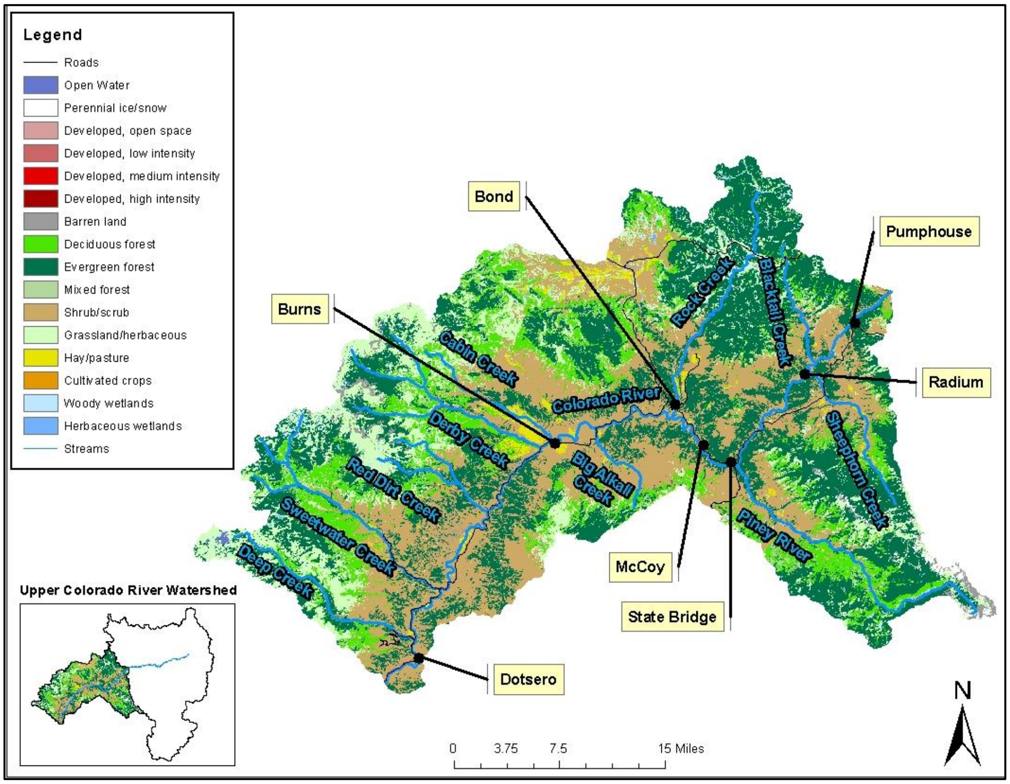


Figure 2.5 – Colorado River watershed land cover within the study area.

2.1.3 Blacktail Creek

Blacktail Creek watershed (Figure 2.6) drains a 28 mi^2 area of mountainous terrain ranging from 10,535 to 6,893 ft (Figure 2.7). The mean basin elevation is 9,110 ft. The largest percent land covers within the watershed are 65% evergreen forest, 12% shrub/scrub, and 10% grassland/herbaceous (Figure 2.8). Mean annual precipitation for the watershed is 25 inches. Buffalo Park SNOw TELemetry (SNOTEL) site (9,240 ft) is located just directly north of the watershed and has a median peak Snow Water Equivalent (SWE) of 10.4 inches (1995-2010) (Figure 2.9).

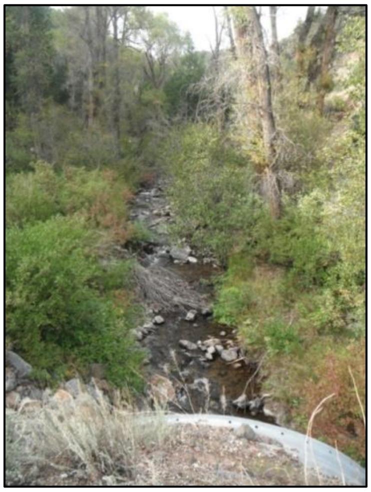


Figure 2.6 – Blacktail Creek approximately 1 mi upstream from the confluence with the Colorado River.

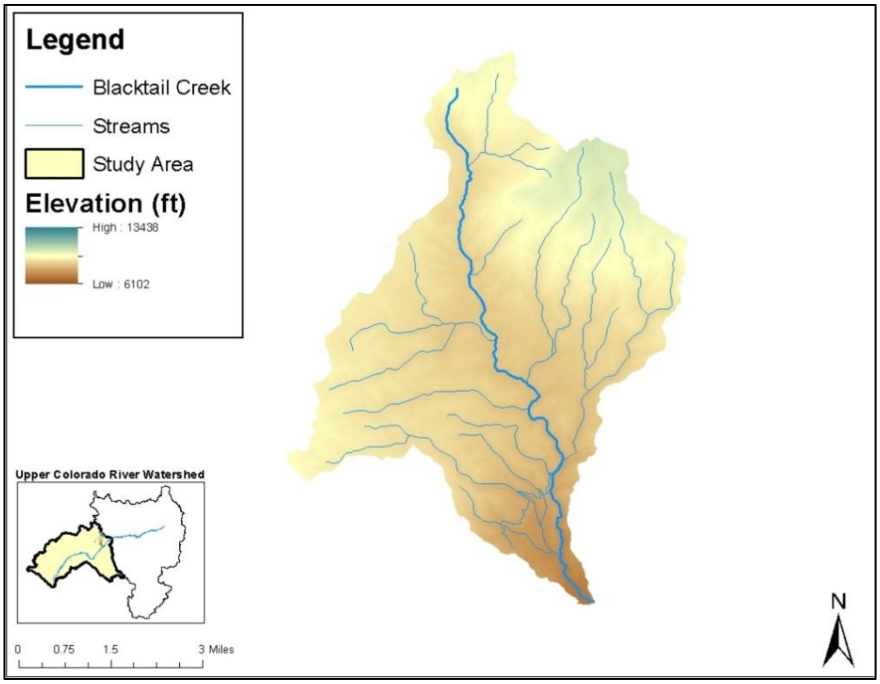


Figure 2.7 – Blacktail Creek watershed elevations.

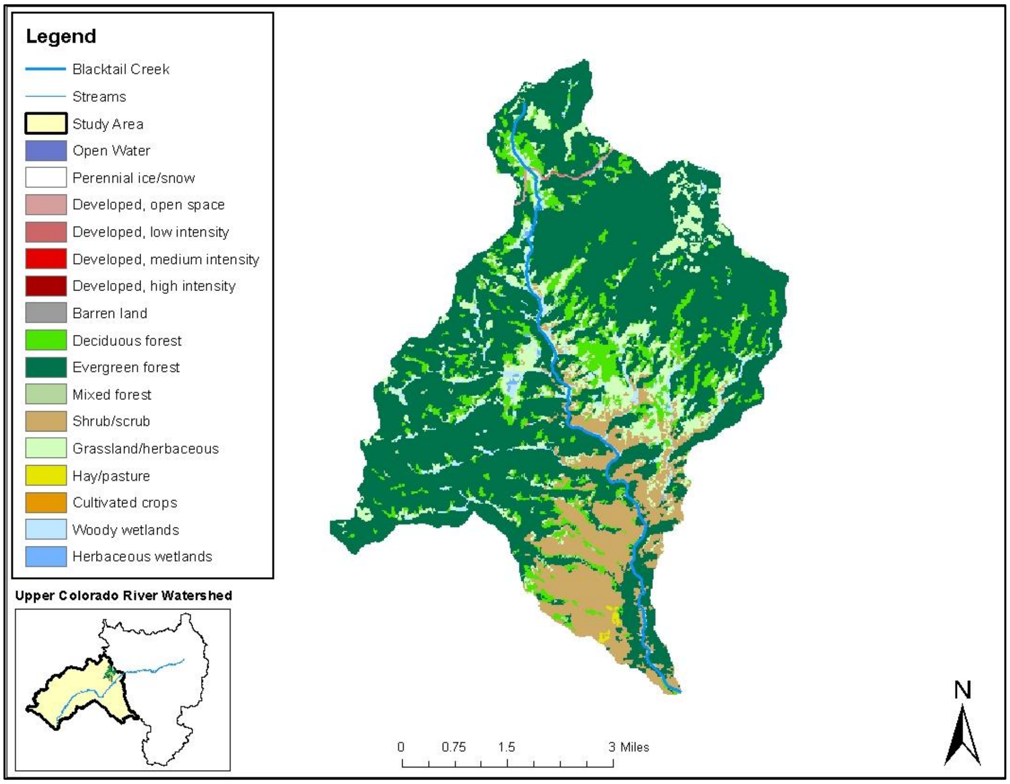


Figure 2.8 – Blacktail Creek watershed land cover.

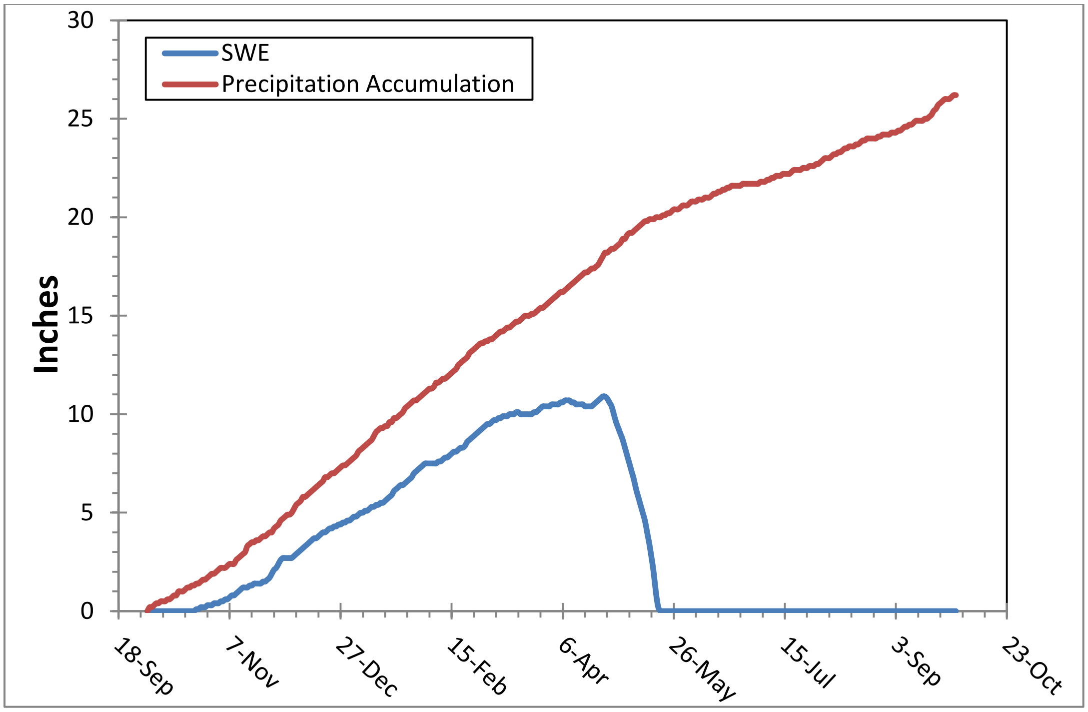


Figure 2.9 – Median SWE and average precipitation accumulation (1995-2010) for Buffalo Park SNOTEL site.

2.1.4 Sheephorn Creek

Sheephorn Creek watershed (Figure 2.10) drains a 57 mi^2 area of mountainous terrain ranging from 11,633 to 6,850 ft with a mean basin elevation of 9,040 ft (Figure 2.11). Evergreen forest covers just over half of the land with shrub/scrub and deciduous forest covering 25% and 12%, respectively (Figure 2.12). Mean annual precipitation for the watershed is 22 inches.

Figure 2.10 – Sheephorn Creek approximately 1 mi upstream from the confluence with the Colorado River.

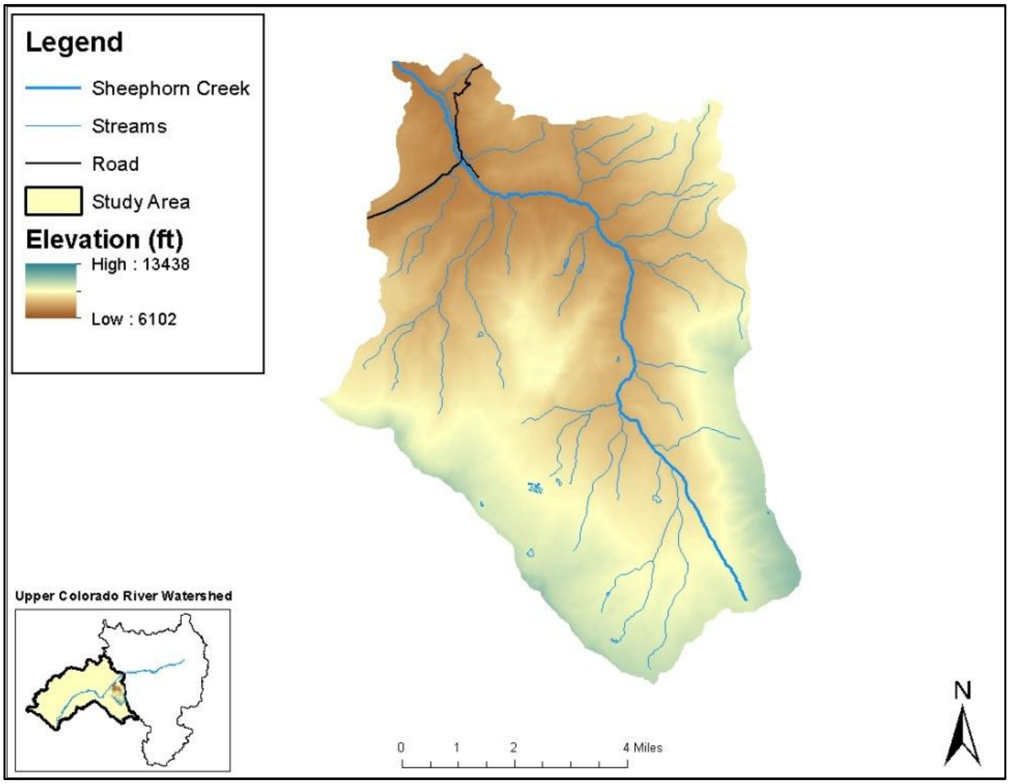


Figure 2.11 – Sheephorn Creek watershed elevations.

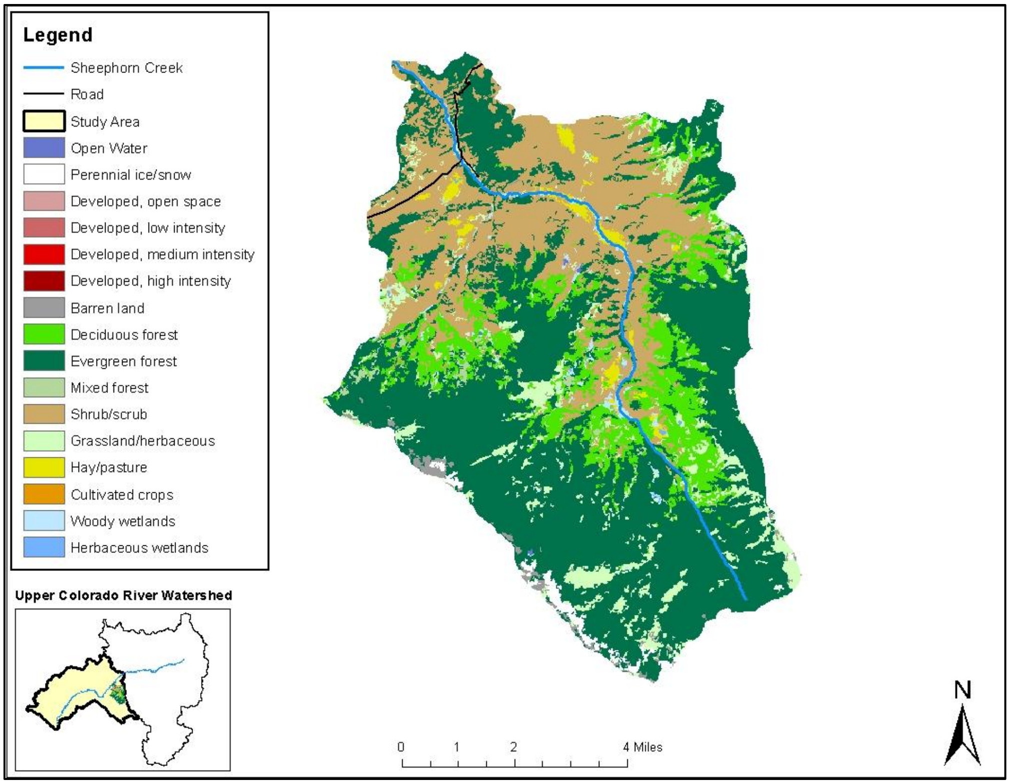


Figure 2.12 – Sheephorn Creek watershed land cover.

2.1.5 Piney River

The Piney River (Figure 2.13) is the largest tributary to the Colorado River in the study area. The watershed drains 118 mi^2 of mountainous terrain ranging from 13,438 to 6,749 ft (Figure 2.14). The mean basin elevation is 9,490 ft. The largest percent land covers within the watershed are 41% evergreen forest, 22% deciduous forest, and 14% shrub/scrub (Figure 2.15). Mean annual precipitation for the watershed is 24 inches.

Figure 2.13 – The Piney River approximately 1 mi upstream from the confluence with the Colorado River.

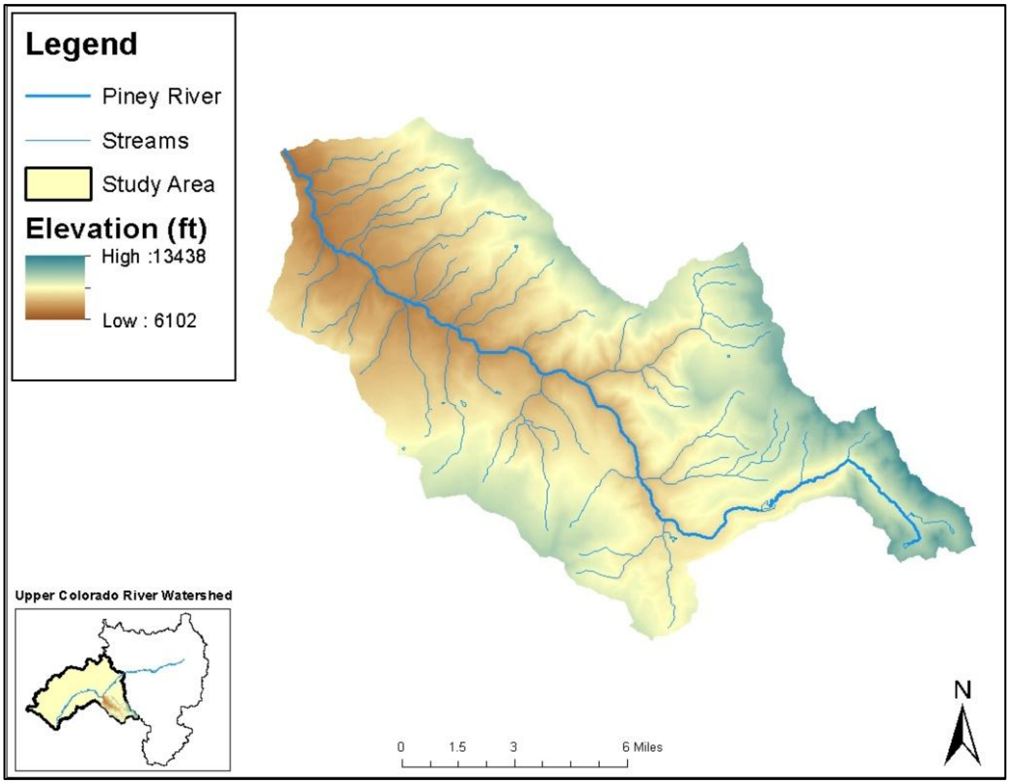


Figure 2.14 – Piney River watershed elevations.

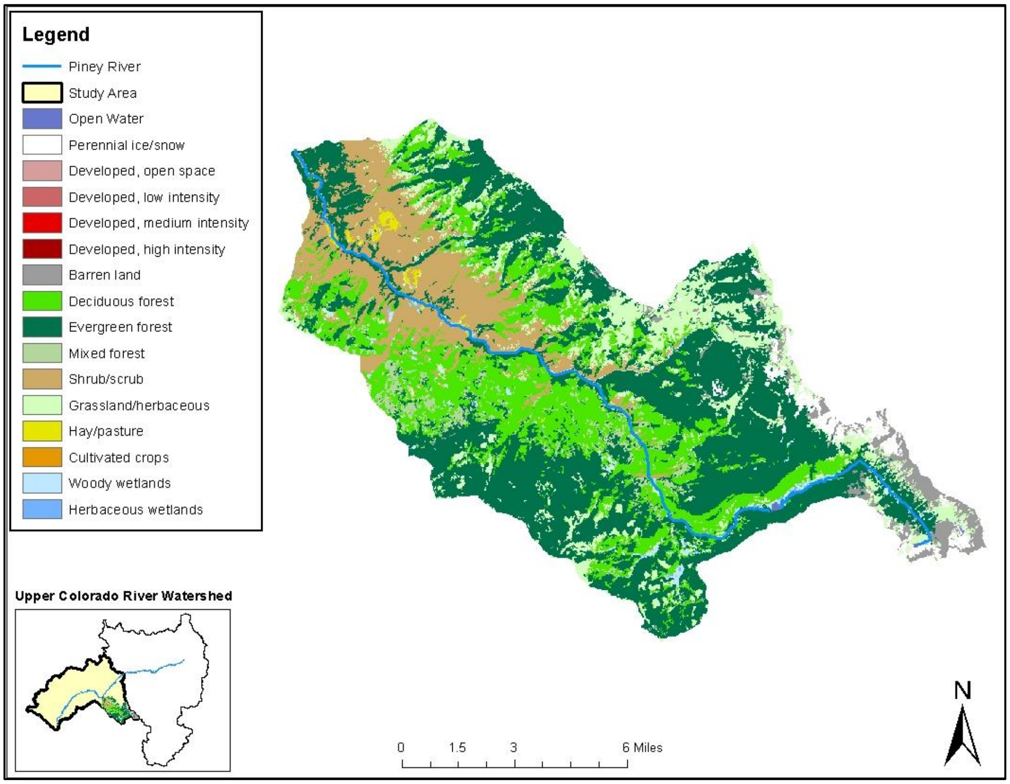


Figure 2.15 – Piney River watershed land cover.

2.1.6 Rock Creek

Rock Creek (Figure 2.16) has the largest watershed area of all the tributaries examined in this study at 201 mi^2. Elevation ranges from 11,283 to 6,627 ft with a mean basin elevation of 8,940 ft (Figure 2.17). The largest percent land covers are 43% evergreen forest, 21% shrub/scrub, and 14% grassland/herbaceous (Figure 2.18). Mean annual precipitation for the watershed is 26 inches.

Figure 2.16 – Beaver dam located on Rock Creek directly upstream from the confluence with the Colorado River.

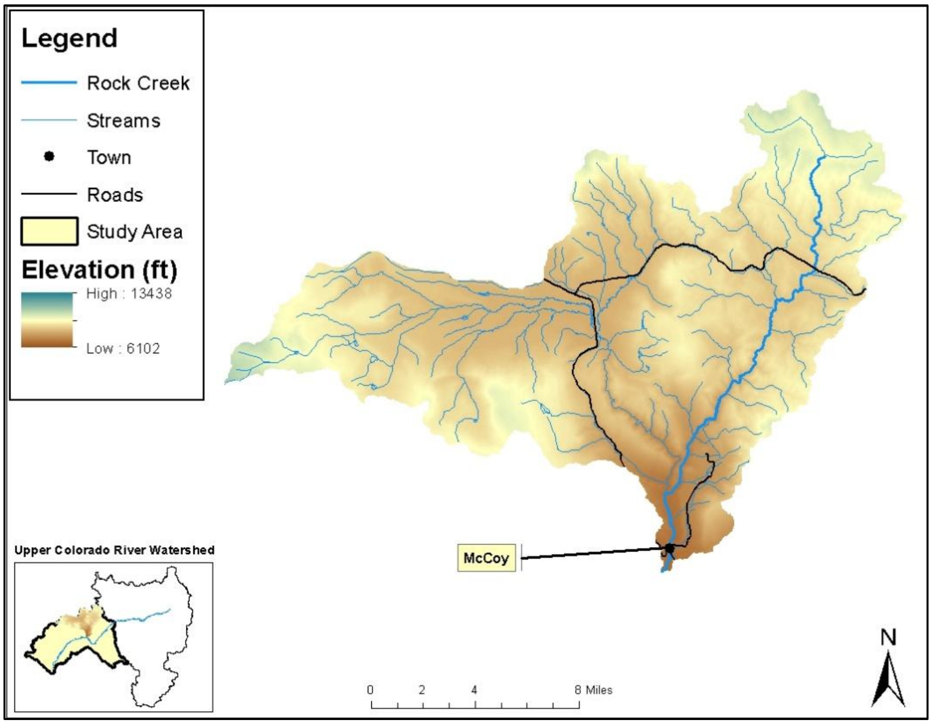


Figure 2.17 – Rock Creek watershed elevations.

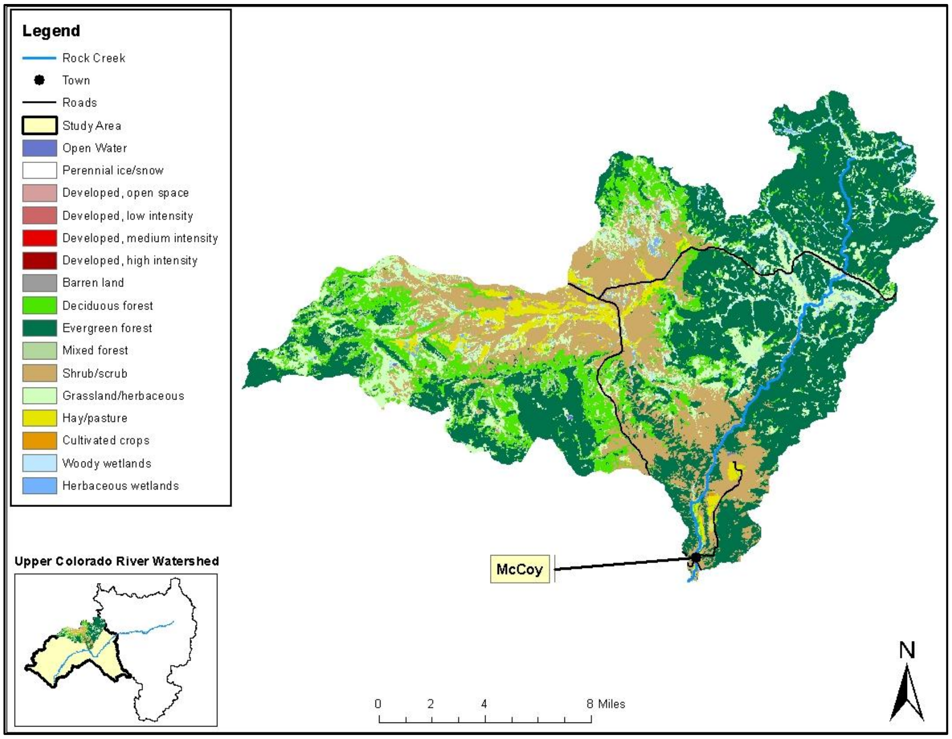


Figure 2.18 – Rock Creek watershed land cover.

2.1.7 Cabin Creek

Cabin Creek watershed (Figure 2.19) drains a 67 mi^2 area of mountainous terrain ranging from 12,221 to 6,746 ft (Figure 2.20). The mean basin elevation is 8,800 ft. Shrub/scrub cover the largest portion of land at 32%. Grassland/herbaceous and deciduous forest are the next largest at 21% and 20%, respectively (Figure 2.21). Mean annual precipitation for the watershed is 27 inches.

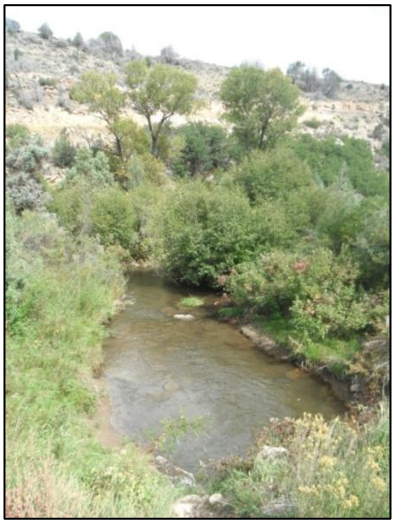


Figure 2.19 – Cabin Creek approximately 1 mi upstream from the confluence with the Colorado River.

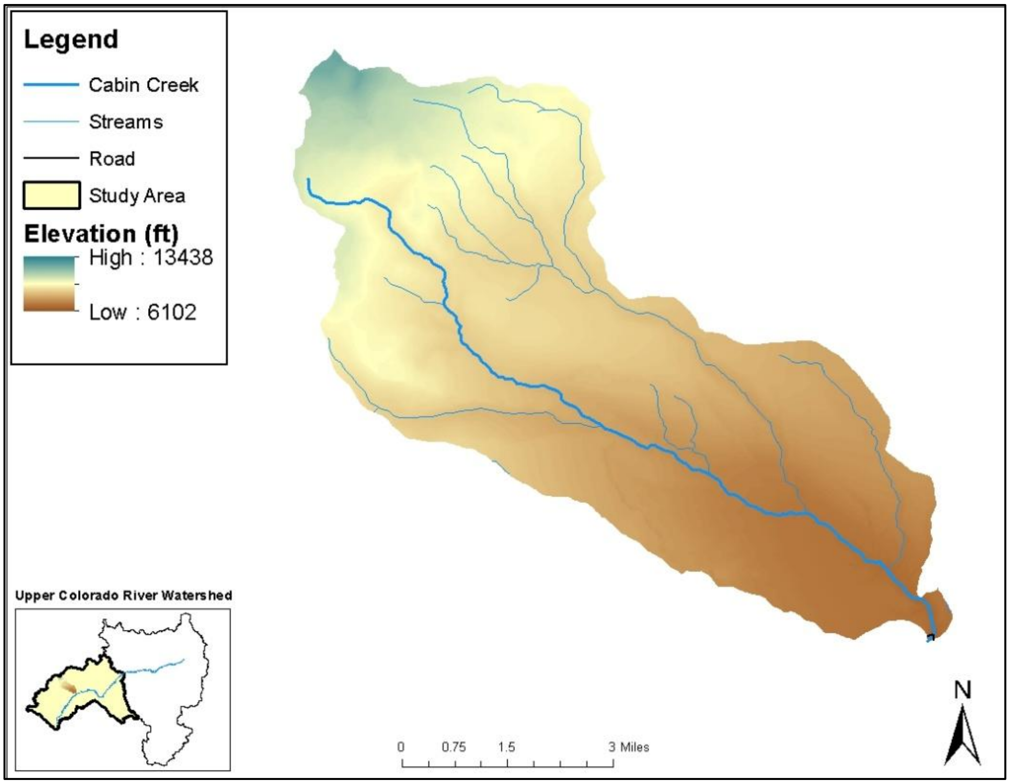


Figure 2.20 – Cabin Creek watershed elevations.

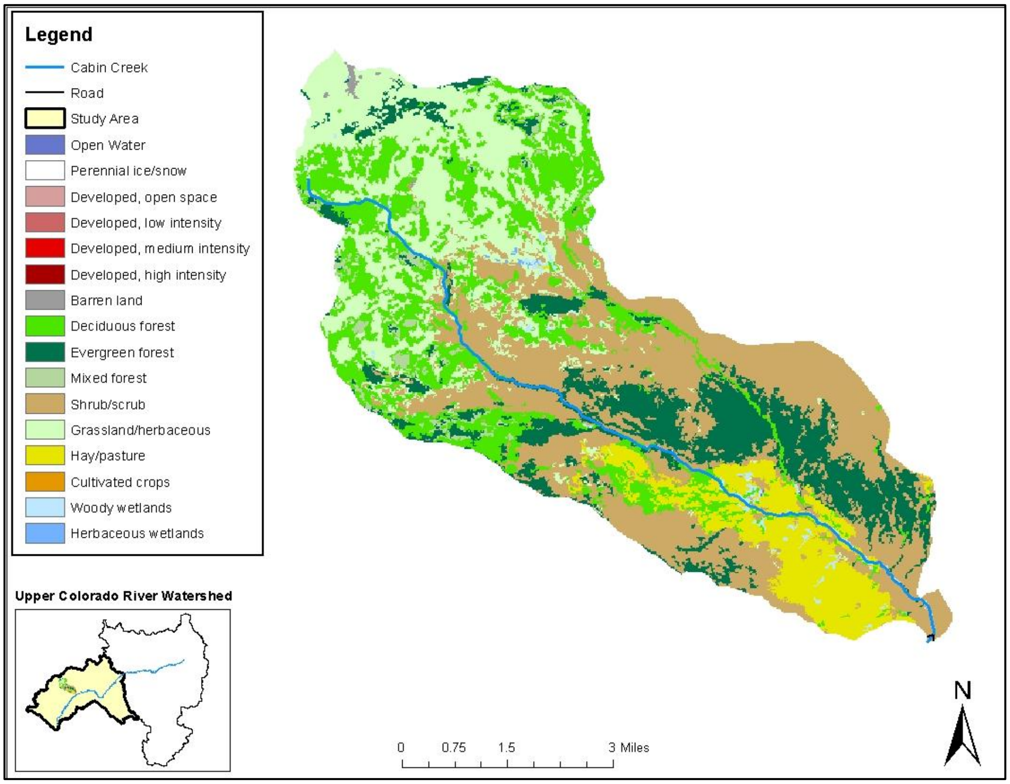


Figure 2.21 – Cabin Creek watershed land cover.

2.1.8 Derby Creek

Derby Creek watershed (Figure 2.22) drains 72 mi^2 of mountainous terrain ranging from 12,352 to 6,470 ft (Figure 2.23). The mean basin elevation is 9,970 ft. The largest percent land covers within the watershed are 33% grassland/herbaceous, 30% evergreen forest, and 21% deciduous forest (Figure 2.24). Mean annual precipitation for the watershed is 37 inches.

Figure 2.22 – Derby Creek directly upstream from the confluence with the Colorado River.

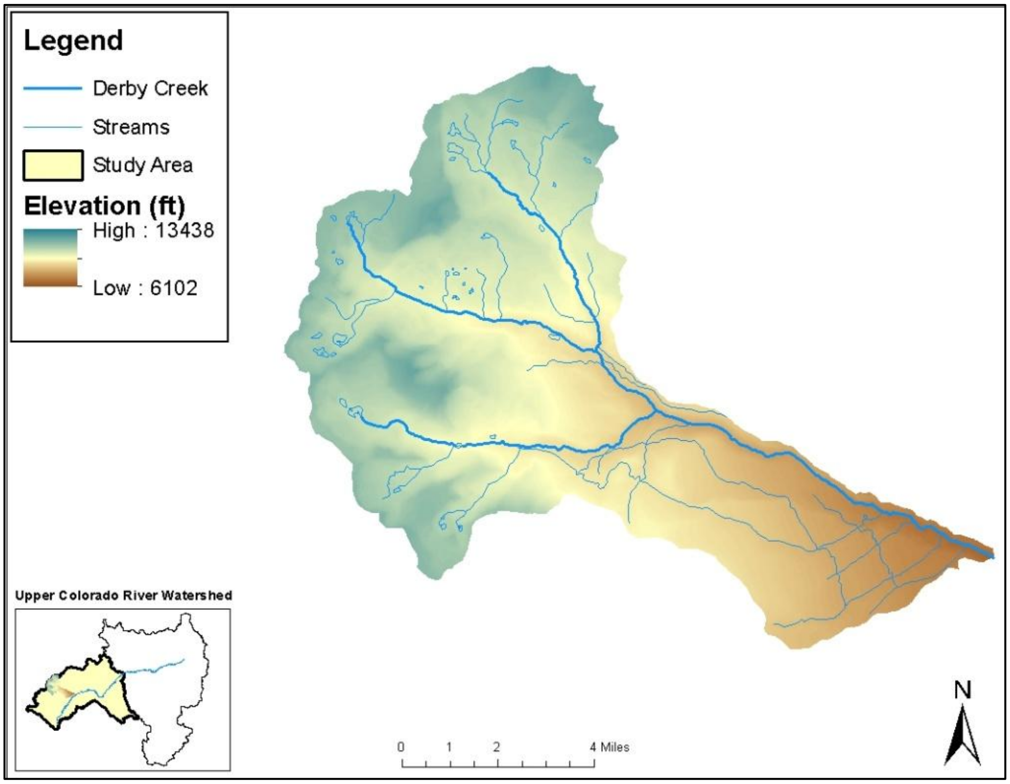


Figure 2.23 – Derby Creek watershed elevations.

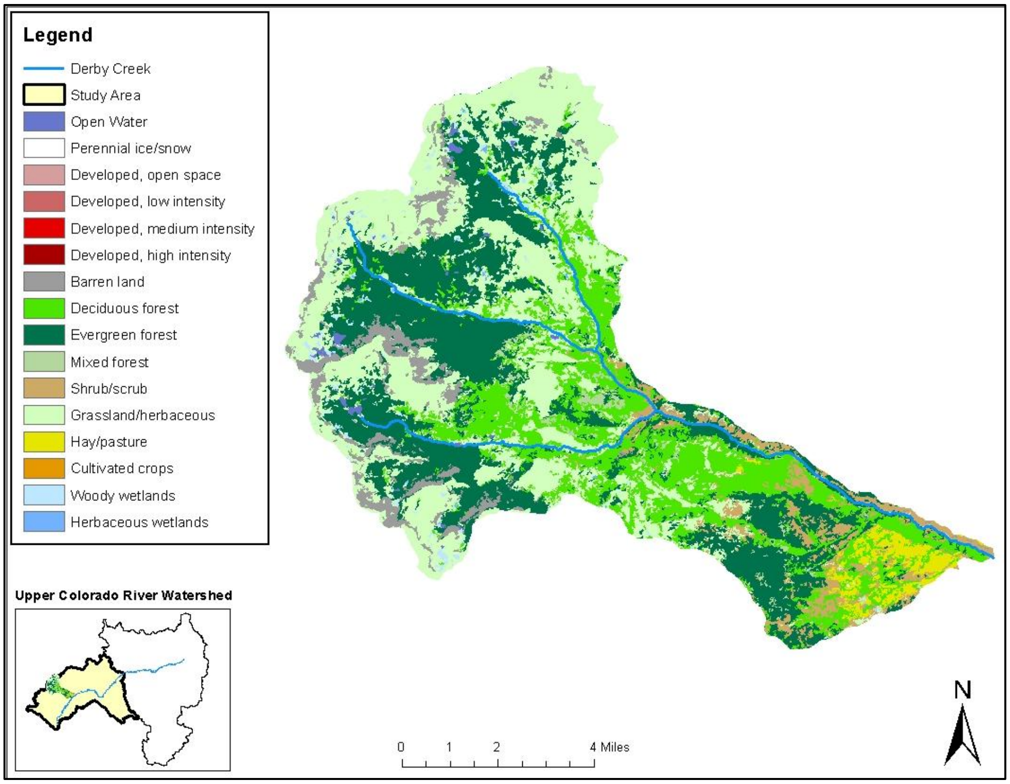


Figure 2.24 – Derby Creek watershed land cover.

2.1.9 Red Dirt Creek

Red Dirt Creek watershed (Figure 2.25) drains a 22 mi^2 area of mountainous terrain ranging from 11,703 to 6,375 ft with a mean basin elevation of 9,040 ft (Figure 2.26). Evergreen forest covers approximately 33% of the land, while grassland/herbaceous and shrub/scrub cover 26% and 21%, respectively (Figure 2.27). Mean annual precipitation for the watershed is 29 inches.

Figure 2.25 – Red Dirt Creek approximately 1 mi upstream from the confluence with the Colorado River.

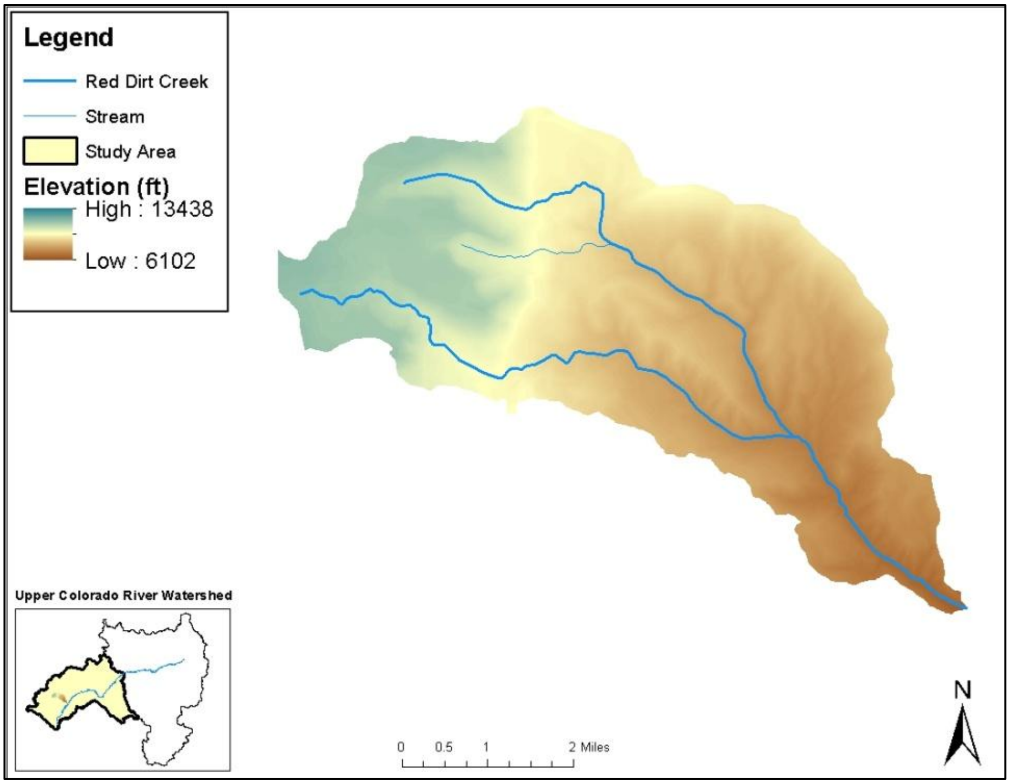


Figure 2.26 – Red Dirt Creek watershed elevations.

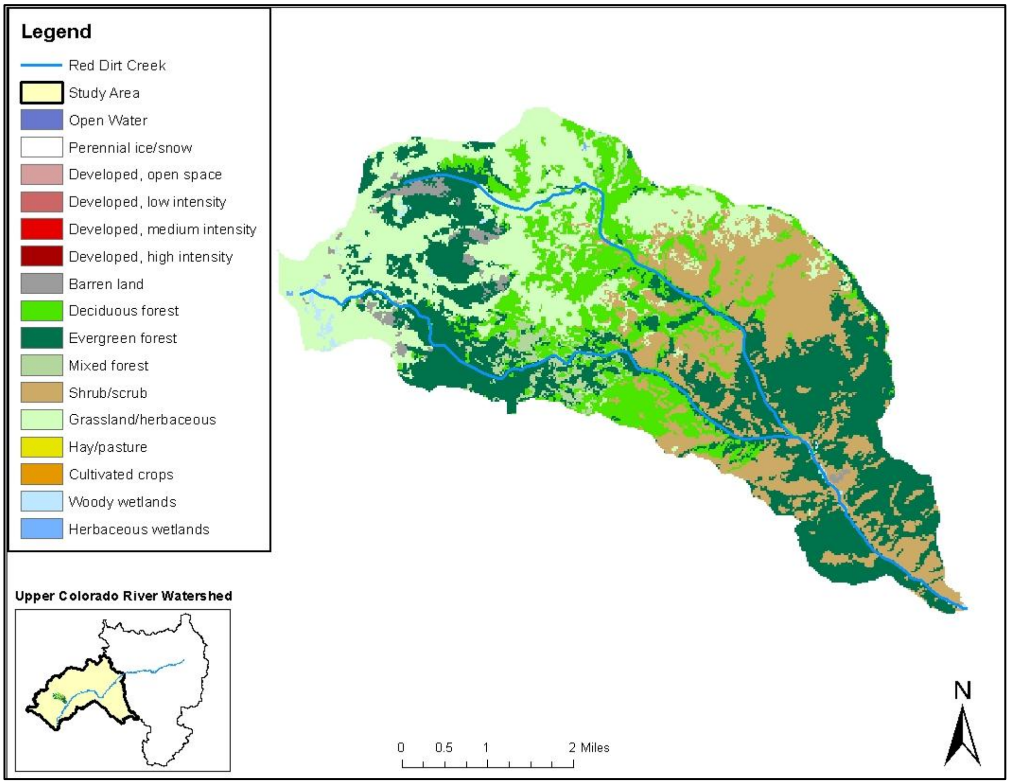


Figure 2.27 – Red Dirt Creek land cover.

2.1.10 Sweetwater Creek

Sweetwater Creek watershed (Figure 2.28) drains 105 mi^2 of mountainous terrain ranging from 11,978 to 6,227 ft (Figure 2.29). The mean basin elevation is 9,450 ft. The land cover is more forested with 29% evergreen forest, 22% deciduous forest, and 21% shrub/scrub (Figure 2.30). Mean annual precipitation for the watershed is 32 inches.

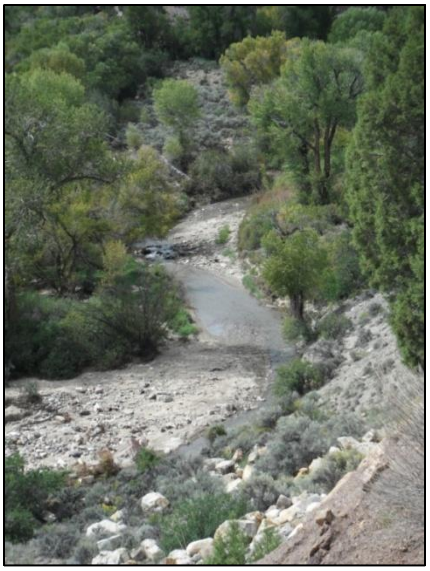


Figure 2.28 – Sweetwater Creek approximately 1 mi upstream from the confluence with the Colorado River.

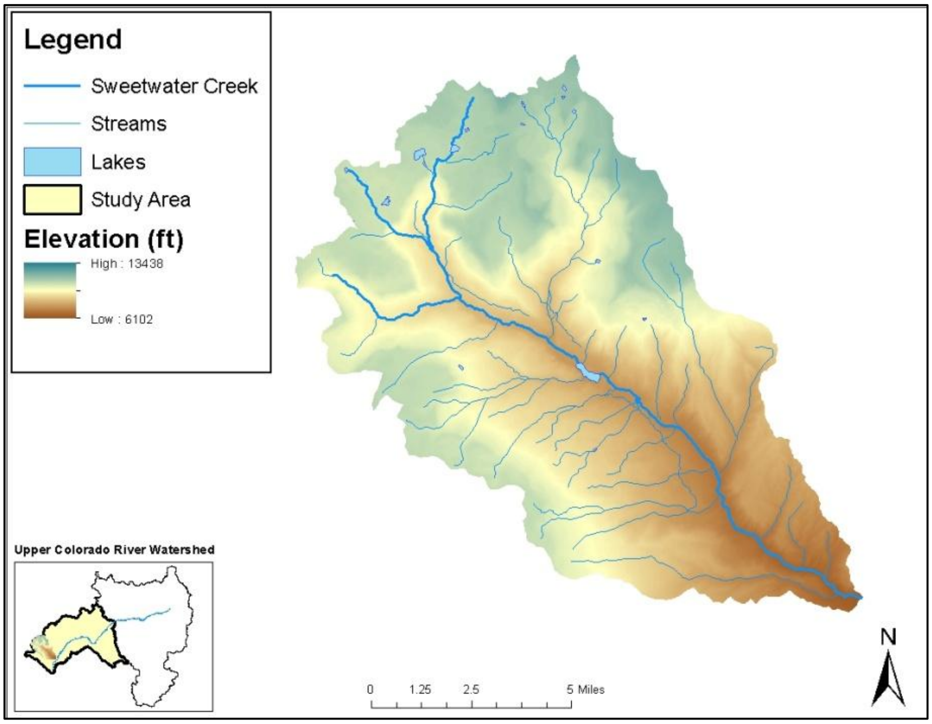


Figure 2.29 – Sweetwater Creek watershed elevations.

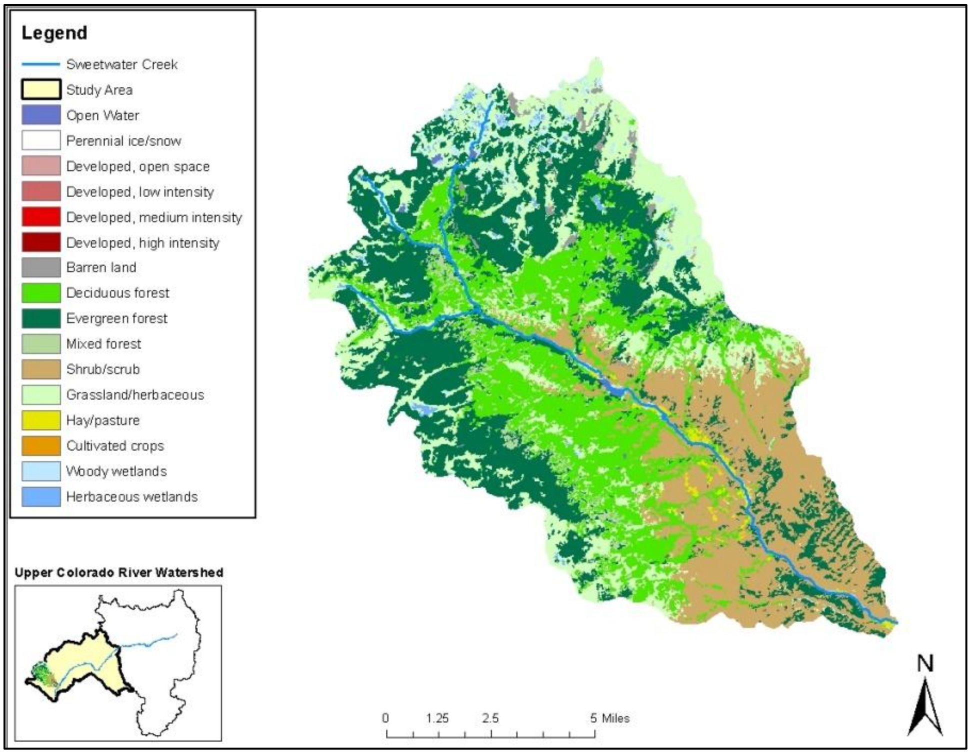


Figure 2.30 – Sweetwater Creek watershed land cover.

2.1.11 *Deep Creek*

Deep Creek watershed (Figure 2.31) drains a 49 mi^2 area of mountainous terrain ranging from 11,296 to 6,175 ft with a mean basin elevation of 9,680 ft (Figure 2.32). The largest percent land covers within the watershed are 43% grassland/herbaceous, 29% evergreen forest, and 12% shrub/scrub (Figure 2.33). Mean annual precipitation for the watershed is 34 inches.

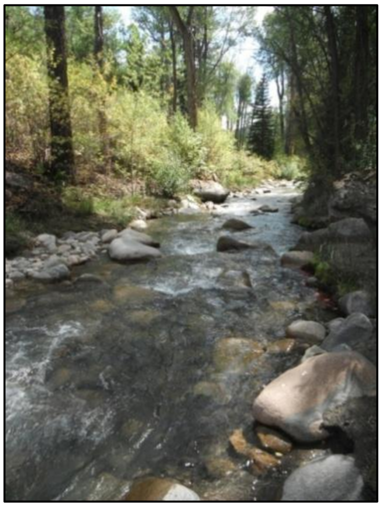


Figure 2.31 – Deep Creek approximately 1 mi upstream from the confluence with the Colorado River.

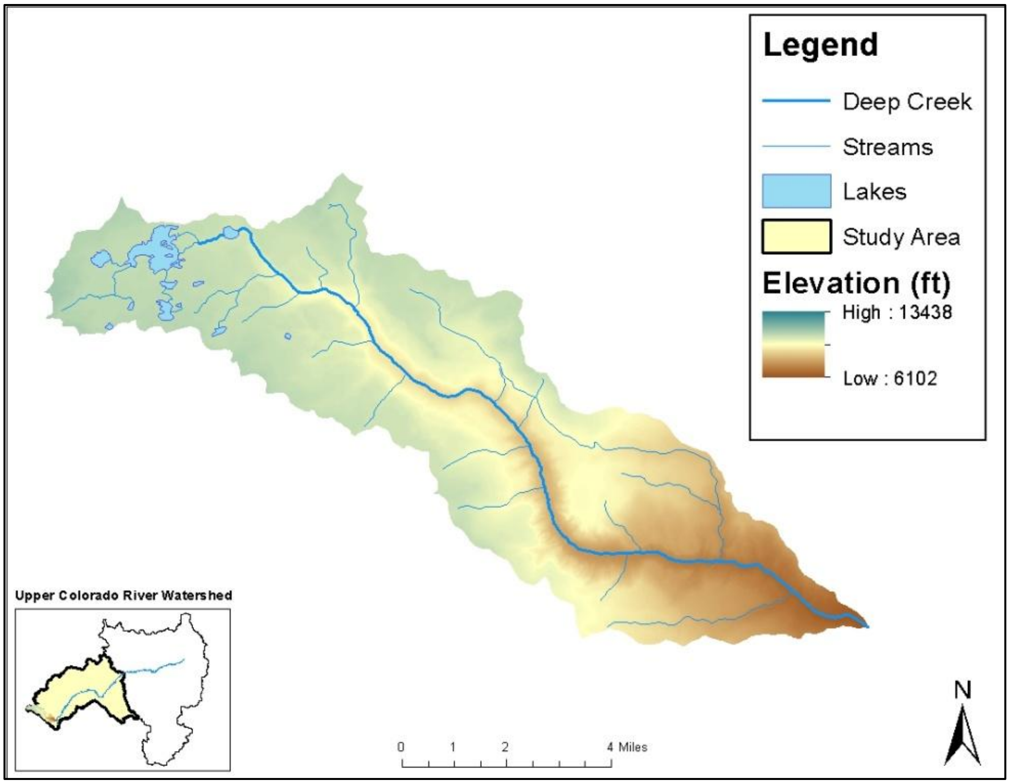


Figure 2.32 – Deep Creek watershed elevations.

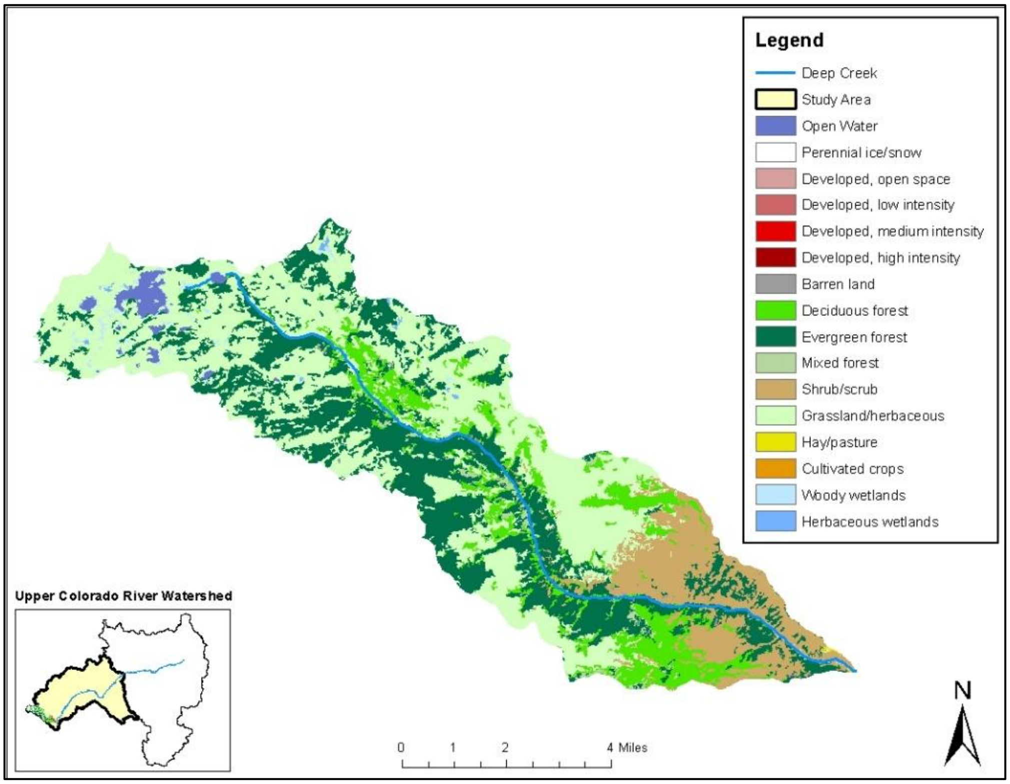


Figure 2.33 – Deep Creek watershed land cover.

2.2 Geology

The geologic setting of the upper Colorado River corridor is a fundamental control on the river's course, slope, and channel characteristics. Erosion of the surrounding hillslopes also directly influences ecologically relevant physical factors such as bed material composition. Changes in the geologic context below Catamount have observable impacts on the river. An overview of the geologic setting follows.

During Precambrian time (over 600 million years ago (MYA)), shale sediments were deposited, folded, and metamorphosed into schists. These became intruded by mostly granites, raised into mountains, and then eroded down to plains (Lovering, 1929). Precambrian rocks to the northeast of the McCoy area then began to erode providing sediment to the Cambrian Sea which eventually settled out to form Cambrian sediment (~540 MYA). The Mississippian Sea (~359 MYA) saw the settling of Leadville limestone before early Pennsylvanian time (~323 MYA) saw erosion and active channel cutting (Donner, 1949). The Pennsylvanian sea spread further than the previous seas and the area that is now between McCoy and Dotsero was located in what is known as the Central Colorado Trough. The trough is surrounded by the Ancestral Front Range Uplift and the Uncompahgre Uplift land masses (Figure 2.34). Fluctuating sea levels submerged the McCoy area underwater at varying times through history. As a result, the rocks of the area are made up of alternating layers of marine and non-marine sediments (Itano, 2002).

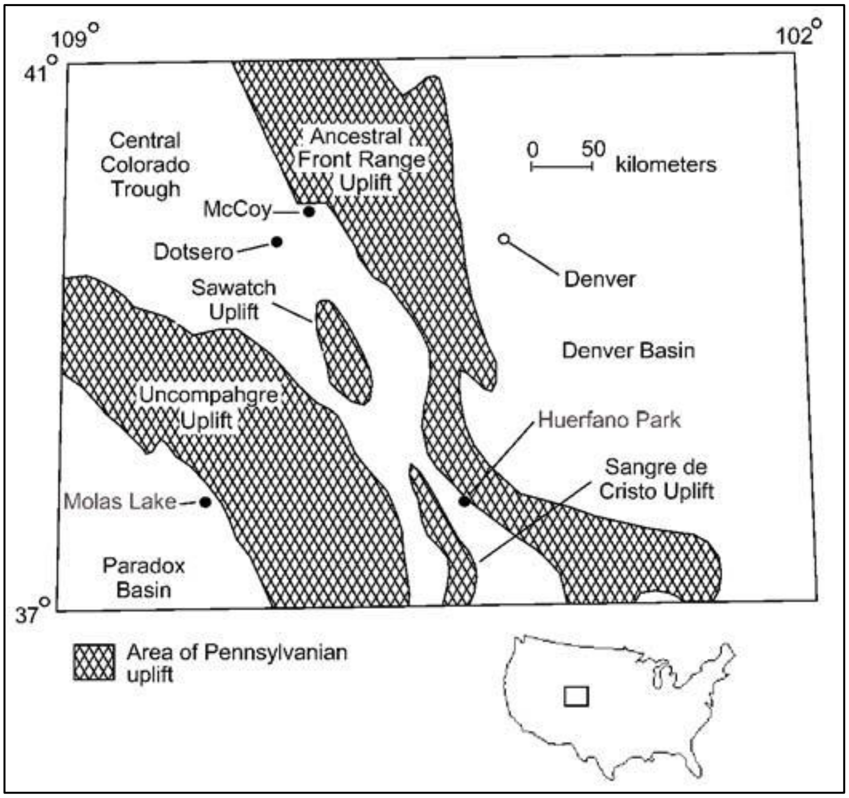


Figure 2.34 – Paleogeography of Colorado during the middle Pennsylvanian period showing the location of McCoy and Dotsero in the Central Colorado Trough (Itano, 2002).

As time passed into the Permian (~299 MYA), fining of the conglomerates and sandstones in the area indicate that the Front Range Highland was eroding and stream slopes were decreasing. However, as time passed into the Triassic (~252 MYA), sedimentation and erosion appeared to slow. By the Jurassic (~201 MYA), the Front Range Uplift was probably reduced to low hills leading to complete submergence by mid-Cretaceous time (~100 MYA). Dakota sandstones were widely deposited during this time. It was not until after Pierre time (~80 MYA) that the Front Range Highland began to rise again forming the landscape we see today (Donner, 1949).

During the Miocene (~23 MYA), volcanic activity produced basaltic and andesitic lavas. Uplifting as a result of the lava flows occurred along the Front Range Highland, but sagged in the State Bridge and Piney River area. Pediments, gently sloping bedrock material, were formed in the late Pliocene (~3.6 MYA) early Pleistocene time (~0.126 MYA) and can be seen in the upper rock terrace near Bond today. These are the probable locations of the river level at that time. A general uplift in the region was also occurring during the early Pleistocene and the Colorado River probably cut its channel down within 25 to 30 ft of its present elevation. Eventually the mountains to the northeast of the area became glaciated. When these glaciers retreated, the streams probably became oversupplied with glacial debris and began to aggrade. Coarse gravel was deposited first followed by finer material as the glaciers retreated. These gravel and silt terraces can be seen 150 to 200 ft above the present river level, indicating that as the glaciers disappeared the streams cut back down through the deposits to their current day elevation (Donner, 1949).

Major geologic formations within the study area include the Minturn, Maroon, Belden, and Eagle Valley. Sandstone-dominated, the Minturn formation is present in many areas along the river. The Maroon formation appears mostly downstream of State Bridge and consists mainly of siltstone. The Belden and Eagle Valley formations are made up of shale and siltstone, and dominate the landscape downstream of Derby Creek. Most of the canyon sections consist of igneous granite, basalt, and schist. Ancient lava flows around State Bridge consist of basalt and associated tuff, breccia, and conglomerate.

2.3 Wildlife

The Colorado River corridor provides critical habitat for various aquatic and terrestrial species including some state designated species of concern. Species previously documented within the study area are listed in Table 2.1. Of note is the observation of state threatened river otter (*Lontra canadensis)* upstream of Rodeo Rapids between Cabin Creek and Derby Creek. A general overview of aquatic species of concern follows.

Table 2.1 – Some of the terrestrial and aquatic wildlife present within the study area.

TERRESTRIAL SPECIES		
Name	**Status**	**Notes**
american peregrine falcon (*Falco peregrinus anatum*)	State Special Concern	Potential Conservation Area (PCA) that supports the falcon is Deep Creek.
american river otter (*Lontra canadensis*)	State Threatened	Observed otter upstream of Rodeo Rapids between Cabin Creek and Derby Creek.
badger (*Taxidea taxus*)	None	
bald eagle (*Haliaeetus leucocephalus*)	State Special Concern	Nesting and over-wintering habitat. Observed Bald Eagles throughout the study area.
beaver (*Castor canadensis*)	None	Observed beaver lodges in multiple areas throughout the study area.
bighorn sheep (*Ovis canadensis*)	None	Observed Bighorn sheep in Gore Canyon.
black bear (*Ursus americanus*)	None	Observed Black Bear with cub between Radium and Rancho Del Rio.
coyote (*Canis latrans*)	None	
elk (*Cervus elaphus*)	None	Winter range and calving.
golden eagle (*Aquila chrysaetos*)	None	Observed Golden Eagle nears Burns, Colorado.
mountain lion (*Felis concolor*)	None	
mule deer (*Odocoileus hemionus*)	None	Migration corridor and winter range.
muskrat (*Ondatra zibethicus*)	None	
turkey (*Meleagris galloavo*)	None	
AQUATIC SPECIES		
Name	**Status**	**Notes**
bluehead sucker (*Catostomus discobolus*)	State Special Concern	Native species. Competition from non-native white sucker is causing concern.
brook trout (*Salvelinus fontinalis*)	Cold Water Game Fish	Non-native.
brown trout (*Salmo trutta*)	Cold Water Game Fish	Non-native wild reproducing.
Colorado River cutthroat (*Oncorhynchus clarki pleuriticus*)	State Special Concern	Native species.
Snake River cutthroat (*Oncorhynchus clarki behnkei*)	Cold Water Game Fish	Non-native species.
flannelmouth sucker (*Catostomus latipinnis*)	State Special Concern	Native species. Lyons Gulch is a major spawning area. Competition from non-native white sucker is causing concern.
lake trout (*Salvelinus namaycush*)	Cold Water Game Fish	Non-native.
longnose sucker (*Catostomus catostomus*)		Non-native.
mottled sculpin (*Cottus bairdi*)		Native species.
mountain whitefish (*Prosopium williamsoni*)		Native species.
rainbow trout (*Oncorhynchus mykiss*)	Cold Water Game Fish	Non-native stocked.
rainbow-Cutthroat hybrid (*Oncorhynchus clarkii X mykiss*)		Non-native.
roundtail chub (*Gila robusta*)	Federal Candidate Species	Native species. Competition from non-native white sucker is causing concern.
salmonfly (*Pteronarcys californica*)		Prevalent in the upper reaches especially Gore Canyon.
speckled dace (*Rhinichthys osculus*)		Native species.
white sucker (*Catostomus commersoni*)		Non-native.

A natural transition appears to occur between cold-water Tier I and Tier II fish species below Catamount. Upstream of Catamount, brown trout, rainbow trout, and mountain whitefish dominate the fish assemblage; whereas, trout tend to coexist with more prevalent sucker and chub species downstream. Seven native fish species exist in the river and four of these are designated species of concern within Colorado (Figure 2.35). The historic range of the Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*), the only native trout in the study area, included the Colorado River and many of its tributaries in Eagle County. Today, competition with many non-native species and hybridization with non-native rainbow trout (*Oncorhynchus mykiss*) have decreased their range dramatically. Genetically pure or conservation populations of native trout exist in the headwaters of Deep Creek and Red Dirt Creek.

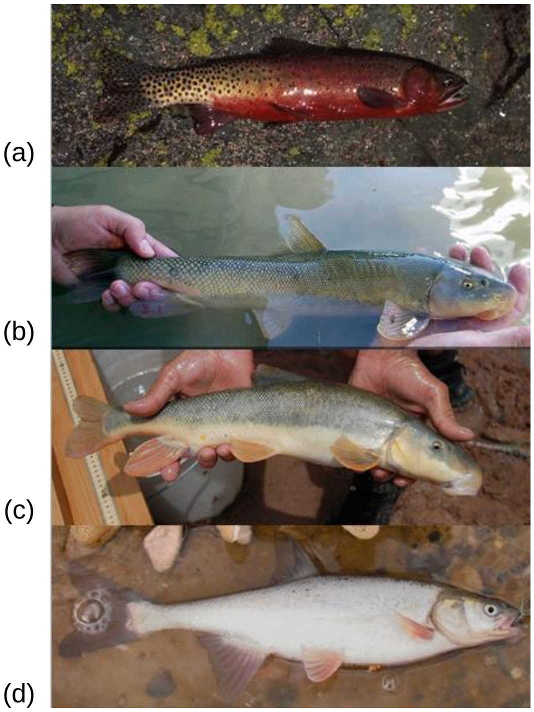


Figure 2.35 – Native fish species of concern in the study area: (a) Colorado River cutthroat trout, (b) bluehead sucker, (c) flannelmouth sucker, and (d) roundtail chub.

Resulting population declines from competition and hybridization with non-native suckers have made the native bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*), and roundtail chub (*Gila robusta*) designated species of concern within the state of Colorado. The roundtail chub is also listed as a candidate for federal protection under the Endangered Species Act. The non-native white sucker (*Catostomus commersoni*) is being partially blamed for population declines (Utah Division of Wildlife Resources (UDWR), 2006). In 2006, a range-wide agreement was made by six state wildlife agencies to help study and conserve the three species. Locally, the Colorado Parks and Wildlife (CPW) has stated that riffle habitat near Lyons Gulch provides an important spawning area for the flannelmouth sucker (CPW, 2013).

Macroinvertebrates also play a critical role in the Colorado River ecosystem, and perhaps none more so than the salmonfly (*Pteronarcys californica*). The salmonfly is one of the largest stonefly species measuring over 2 inches in length (Figure 2.36). Due to its size, it is a vital energy source for trout, birds, bats, and spiders. It has also been identified as an excellent organism to examine in bioassessments of ecological integrity. In 2011, the estimated density of salmonfly larva at Pumphouse was 363/m^2 (Nehring *et al*., 2011).

Figure 2.36 – Salmonfly (*Pteronarcys californica*) (a) adult and (b) larva are an important energy source for trout, birds, bats, and spiders.

2.4 Vegetation

Over 250 mi of the Colorado River are within the state of Colorado. Virtually all of the riparian area has been altered by human influences but the reach from Radium to Red Dirt Creek has been identified as a potential conservation area by the Colorado Natural Heritage Program (CNHP). It is described as having one of the largest intact riparian habitats along the Colorado River despite railroad and road corridors paralleling the river through most of the study area (Table 2.2). Definitions of global and state rankings are provided in Table 2.3. Several distinct riparian communities have been noted to exist only along this reach and the site supports a good (B-ranked) and a fair (C-ranked) occurrence of plant communities which is imperiled on a global scale: narrowleaf cottonwood / Rocky Mountain juniper (*Populus angustifolia / Juniperus scopulorm*) woodland, silver buffaloberry (*Shepherdia argentea*) (G3G4/S1), and Rocky Mountain juniper / red-osier dogwood (*Juniperus scopulorum / Cornus sericea*) (G4/S2) (Bell, 2003).

Table 2.2 – Riparian plant communities present between Radium and Red Dirt Creek (adapted from Bell (2003)).

Element State ID	State Scientific Name	State Common Name	Global Rank	State Rank	Driving Site Rank
24657	*Juniperus scopulorum* / *Cornus sericea* woodland	riparian woodland	G4	S2	No
24773	*Alnus incana* / *Cornus sericea* shrubland	thinleaf alder-ded-osier dogwood riparian shrubland	G3G4	S3	No
22992	*Cornus sericea* shrubland	foothills riparian shrubland	G4Q	S3	No
18795	*Carex utriculata* herbaceous vegetation	beaked sedge montane wet meadows	G5	S4	No
24963	*Populus angustifolia – Juniperus scopulorum* woodland	montane riparian forest	G2G3	S2S3	No
24659	*Salix exigua* / barren shrubland	coyote willow / bare ground	G5	S5	No
24645	*Alnus incana* / mesic forbs shrubland	thinleaf alder / mesic forb riparian shrubland	G3	S3	No
17439	*Shepherdia argentea* shrubland	foothills riparian shrubland	G3G4	S1	No
24657	*Juniperus scopulorum* / *Cornus sericea* woodland	riparian woodland	G4	S2	No
24686	*Betula occidentalis* / *Maianthemum stellatum* shrubland	foothills riparian shrubland	G4?	S2	No
23569	*Nuttallia multicaulis*	many-stem stickleaf	G3	S3	No
19662	*Penstemon harringtonii*	harrington beardtongue	G3	S3	No
24496	*Populus angustifolia* / *Salix ligulifolia – Shepherdia argentea woodland*	narrowleaf cottonwood riparian forests	G3	S3	No

Table 2.3 – Definitions of Natural Heritage Imperilment Ranks (http://www.avlt.org/docs/PCA_Reports/Colorado_Natural_Heritage_Program_Ranking_System.pdf).

G/S1:	Critically imperiled globally/state because of rarity (5 or fewer occurrences in the world/state; or 1,000 or fewer individuals), or because some factor of its biology makes it especially vulnerable to extinction.
G/S2:	Imperiled globally/state because of rarity (6 to 20 occurrences, or 1,000 to 3,000 individuals), or because other factors demonstrably make it very vulnerable to extinction throughout its range.
G/S3:	Vulnerable through its range or found locally in a restricted range (21 to 100 occurrences, or 3,000 to 10,000 individuals).
G/S4:	Apparently secure globally/state, though it may be quite rare in parts of its range, especially at the periphery. Usually more than 100 occurrences and 10,000 individuals.
G/S5:	Demonstrably secure globally/state, though it may be quite rare in parts of its range, especially at the periphery.

Another potential conservation area identified by the CNHP is located along the Colorado River between Derby Junction and Jack Flats where two large groundwater seeps emerge from the canyon walls. Two parallel seeps trickle down the canyon wall and support a rare river birch (*Betula occidentalis*) dominated plant community (G3/S2). A drier patch of land dominated by big sagebrush (*Artemisia tridentate var. tridentata*) and Great Basin wildrye (*Leymus cinereus*) occurs between the two seeps (G2/S1). The site has been given a B2: Very

High Biodiversity Significance rating due to the occurrence of these globally imperiled plant communities (Table 2.4) (Fayette, 2000).

Table 2.4 – Table of globally imperiled plant communities located along two seeps above the Colorado River between Derby Junction and Jack Flats (adapted from Fayette (2000)).

Element State ID	State Scientific Name	State Common Name	Global Rank	State Rank	Driving Site Rank
24637	*Betula occidentalis* / Mesic graminoids shrubland	lower montane riparian shrublands	G3	S2	No
24677	*Artemisia tridentata*. *tridentata* / *Leymus cinereus* shrubland	sagebrush bottomland shrublands	G2	S1	Yes

Elsewhere within the study area, steep upland slopes along the river corridor support Douglas fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) on north-facing slopes while south-facing slopes consist of juniper and sagebrush. Riparian vegetation seems to change depending on the floodplain width. Narrower confined floodplains tend be dominated by alder (*Alnus incana*), red-osier dogwood, river birch, and junipers. Wider valley bottoms may contain narrowleaf willow (*Salix exigua*), narrowleaf cottonwood, and sedges (*Carex* sp.) (Bell, 2003). Both narrowleaf cottonwood and willows seemed to be healthy and well-established with multiple age classes present. Only a handful of older plains cottonwoods (*Populus deltoides*) were observed along the river. Unlike narrowleaf cottonwoods which can propagate from roots, the plains cottonwood usually only grows from seed on newly-formed bars. Plains cottonwood recruitment also requires a specific timing and duration floodplain inundation (Mahoney and Rood, 1998). The absence of young plains cottonwoods reflects in part the post-development hydrologic alteration that has occurred on the Colorado River. General distribution maps of willows, cottonwoods, sedges, and upland grasses were created using GIS data from the CPW to visually determine potential differences in distribution along the main stem river corridor (Figure 2.37, Figure 2.38, Figure 2.39, and Figure 2.40, respectively). Willow and cottonwoods appear more widely distributed in the downstream half of the of the study area along the main stem. However, sedges and other mesic grasses seem more widely distributed in the upper half of the study area. There seems to be no apparent difference in upland grass distribution.

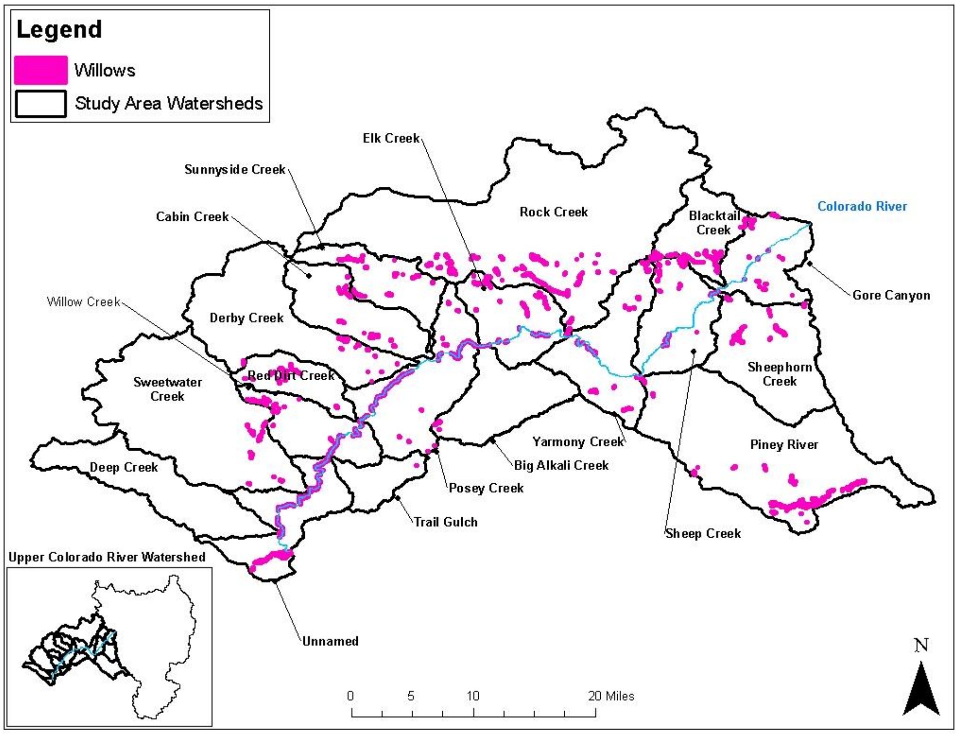


Figure 2.37 – Willow distribution along riparian corridors within the study area (CPW, 2012).

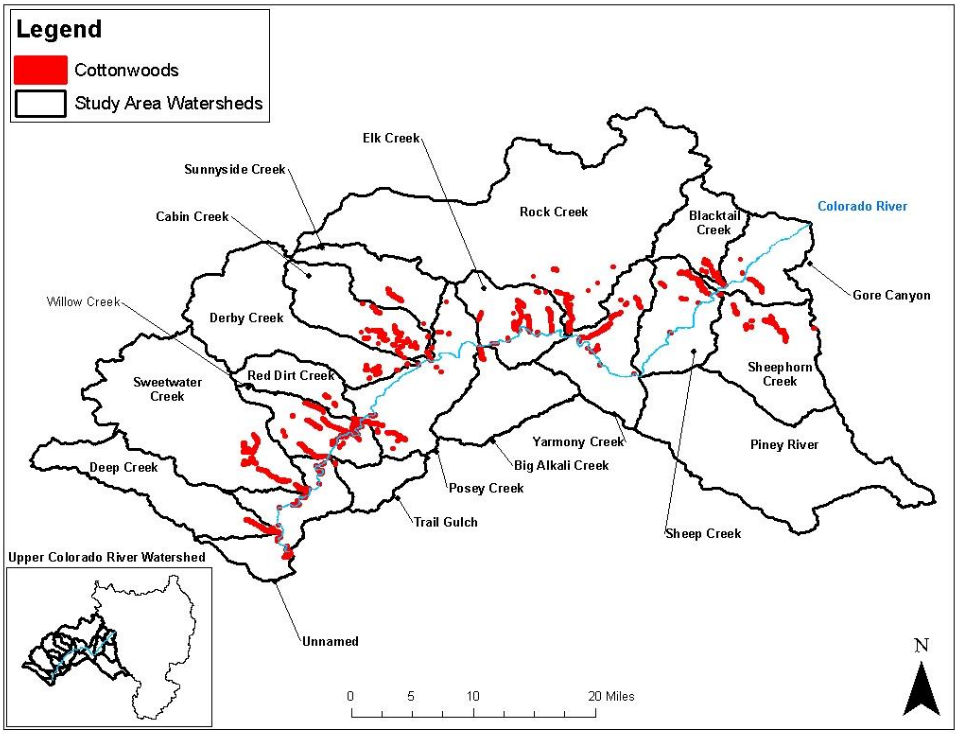


Figure 2.38 – Cottonwood distribution along riparian corridors within the study area (CPW, 2012).

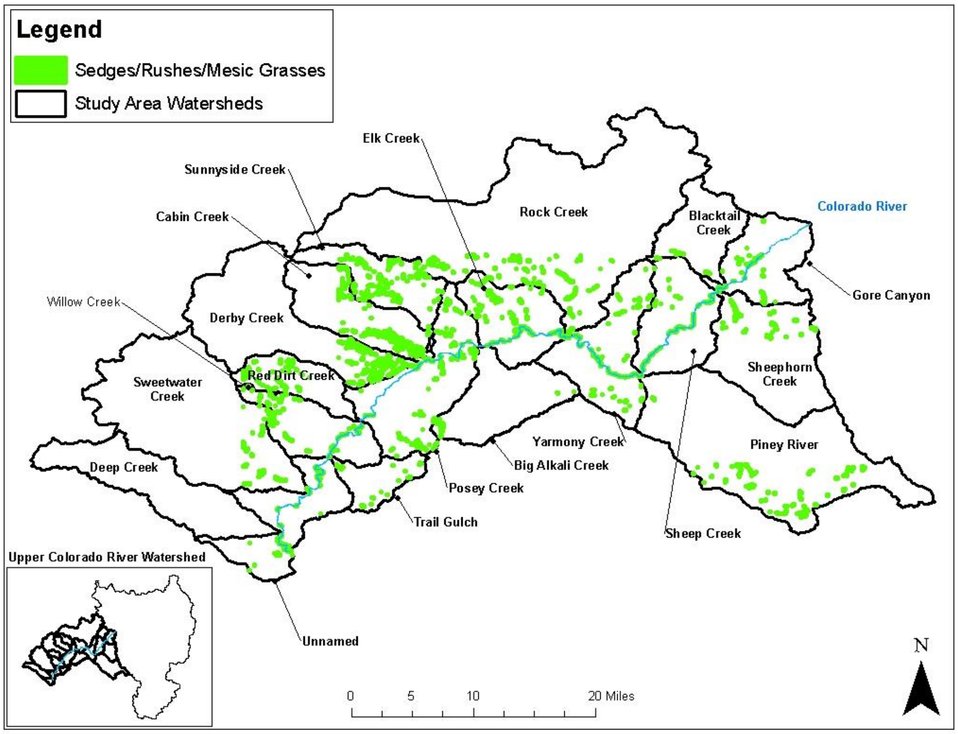


Figure 2.39 – Sedge, rush, and mesic grass distribution along riparian corridors within the study area (CPW, 2012).

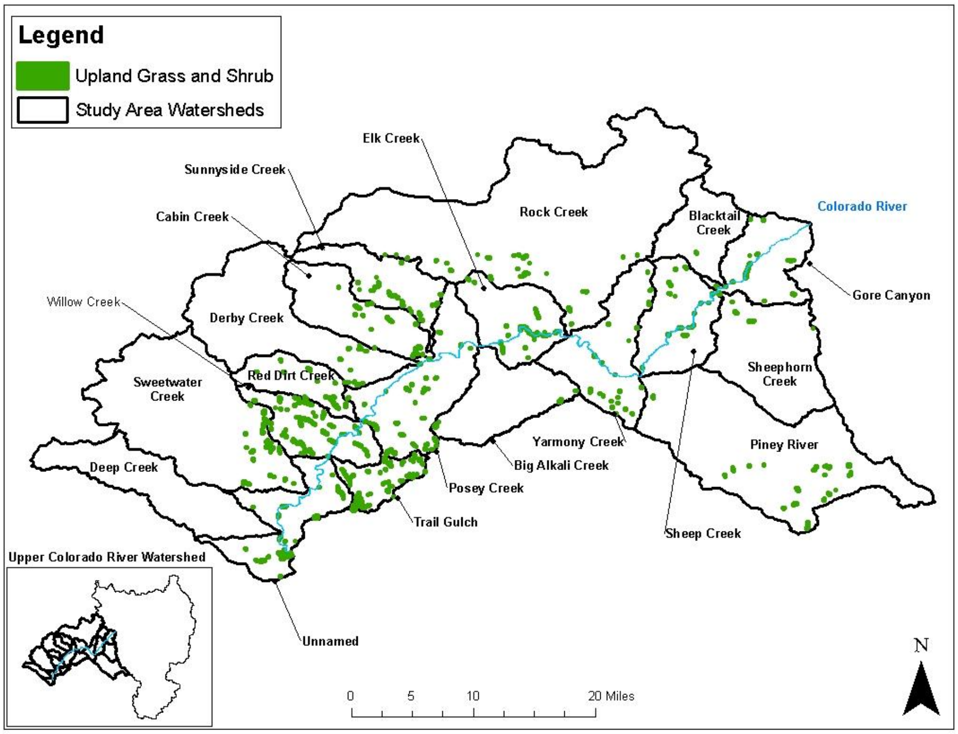


Figure 2.40 – Upland grass and shrub distribution along riparian corridors within the study area (CPW, 2012).

During field surveys performed during this study, Russian olive (*Elaeagnus angustifolia*) was first spotted ~1.5 mi downstream of Bond and was widely distributed all the way to Dotsero (Figure 2.41). Russian olive presence seemed to increase on private lands where disturbances such as mowing had occurred along the banks. Tamarisk (*Tamarix* sp.) was also present with most individuals appearing on the same side of the river as the railroad, possibly indicating how they initially arrived. Tamarisk was much less widespread and usually found infrequently as individual plants. Both species only occurred downstream of Bond where a train depot is located. The feasibility of eradicating Russian olive and tamarisk from the study area is discussed in Chapter 4.

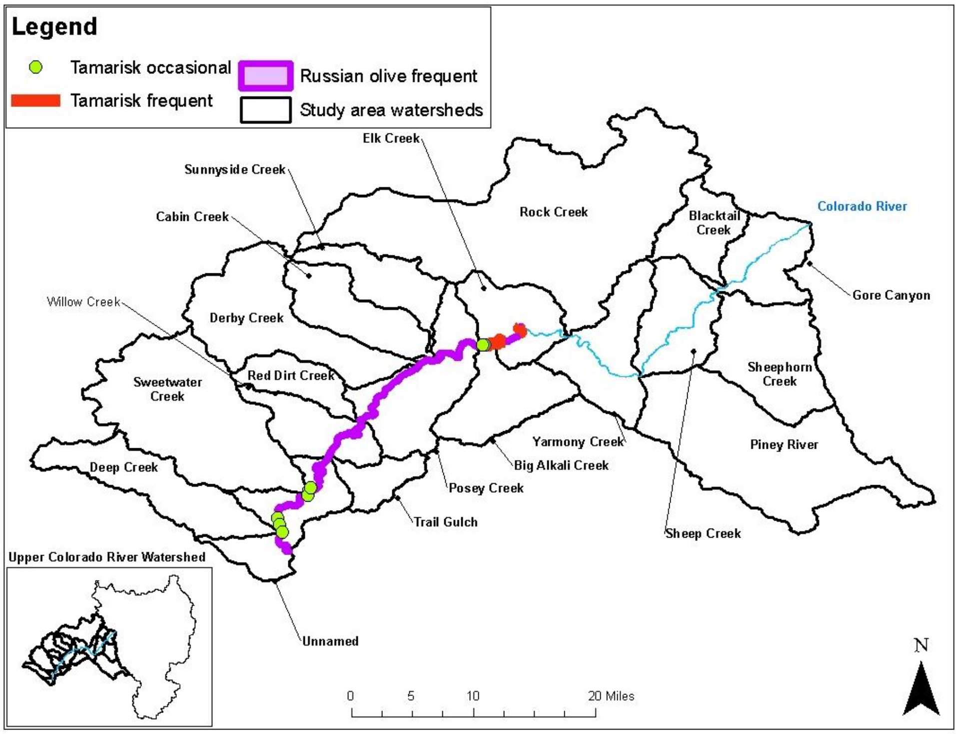


Figure 2.41 – Tamarisk and Russian olive distribution along the Colorado River main stem.

2.5 Literature Review

Previous reports about the Upper Colorado River have covered a wide range of issues including water-quantity, water-quality, ecology, and aquatic resources. Only a few of these directly involve the Colorado River within Eagle County; however, changes in the upstream watershed directly impact the reaches within this study. Hence, a brief overview of the most relevant reports follows.

2.5.1 Wild and Scenic River Suitability Report (Tetra Tech, Inc., 2010)

The Bureau of Land Management (BLM) and White River National Forest (WRNF) Service have jointly assessed the suitability of designating segments of the Colorado River and some of its tributaries as a Wild and Scenic River (WSR). Six reaches of the Colorado River including two through Eagle County contain outstandingly remarkable values (ORVs). In-stream flow protection and cooperative flow management would come with this federal designation. Some of the ORVs for the Colorado River through Eagle County are as follows:

- Scenic
    - Gore Canyon
    - Little Gore Canyon
    - Red Gorge
- Recreational
    - Fishing
    - Rafting
    - Scenic driving
- Geological
- Wildlife
    - Bald eagle nesting and winter habitat
    - River otter habitat
- Historic
    - Early hydroelectric projects
    - World War II (WWII) German Prisoner of War (POW) camp
    - Moffat Road
    - Copper mining
    - Brass Balls mine/Cable Rapids Cabin
    - State Bridge
- Botanical
    - Riparian plant communities
- Paleontological
    - Fossils

2.5.2 Upper Colorado River Wild and Scenic Stakeholder Group Management Plan (Wild & Scenic Stakeholder Group, 2011)

A diverse group of stakeholders was formed to develop a management plan to help protect the ORVs found on the Colorado River from Gore Canyon downstream to Glenwood Canyon. The stakeholder group management plan is being proposed as a potential alternative to federally designating the area as a WSR. The goal of the plan is to balance permanent protection of the ORVs while allowing flexibility for water users. Parts of the plan would include in-stream flows, ensuring water delivery to downstream senior water-right holders, and delivery of endangered fish flows to the 15-mi reach near Grand Junction. The plan aims to protect all ORVs through focusing on recreational fishing and floating flows.

2.5.3 In-stream Flow Report for the Colorado River from Kremmling, Colorado downstream to Dotsero, Colorado (Miller and Swaim, 2011)

The focus of this report was to assess how fish habitat in the Colorado River between Kremmling and Dotsero responded to different flows. The results would be used to help with management decisions and determine how changes in the watershed may impact fish habitat. For the project, the major fish species of interest were rainbow trout, brown trout, mountain whitefish, and flannelmouth sucker. A River2D analysis (2-d hydraulic modeling of habitat suitability) of the study section was conducted to determine 1) the current state of the physical habitat available for the identified species and 2) the expected changes to physical habitat as a result of natural and man-made hydrologic changes. The three study sites were located at Pumphouse, Rancho del Rio, and Lyons Gulch. Results show that habitat for most species and lifestages was most abundant at flows between 500 and 1,500 cfs. Habitat was also shown to decrease rapidly at flows below 500 cfs. Based on available hydrology and habitat-discharge functions recommendations were given for baseflows to be higher than 500 cfs and for peak flows to exceed 2,000 cfs upstream and 4,000 cfs downstream to maintain habitat. Peak flows approximately twice those values and with a recurrence interval of one to two times every 10 years are required to maintain habitat and riparian function.

2.5.4 In-stream Flow Rulings (CWCB, 2011)

In-stream flow rulings for the Colorado River between Kremmling and Dotsero have been passed as part of an alternative management plan to the potential federally designated WSR. Two studies were conducted in order to determine 1) the existence of a natural environment, and 2) the minimum amount of water necessary to preserve the natural environment to a reasonable degree. Recommendations for in-stream flows were provided by the Colorado Water Conservation Board (CWCB) and Colorado Division of Wildlife (CDOW) and the final decreed in-stream flow values are as follows:

- Confluence Blue River to confluence Piney River
    - 600 cfs (5/15-7/31)
    - 750 cfs (8/1-9/15)
    - 500 cfs (9/16-5/14)
- Confluence Piney River to confluence Cabin Creek
    - 650 cfs (5/15-7/31)
    - 800 cfs (8/1-9/15)
    - 525 cfs (9/16-5/14)
- Confluence Cabin Creek to confluence Eagle River
    - 900 cfs (5/15-6/15)
    - 800 cfs (6/16-9/15)
    - 650 cfs (9/16-5/14)

2.5.5 *Colorado River Aquatic Resources Investigations Federal Aid Project F-237R-18 (Nehring et al., 2011)*

A study was performed to assess macroinvertebrate and mottled sculpin populations on the Upper Colorado River. Previous sampling had occurred in 1980-1981 with the same sites being resampled in 2010-2011. Pumphouse boat launch was one of the sites sampled in 2010-2011. A large portion of the study was dedicated to the stonefly (*Pteronarcys californica*) which is considered both an important food source for the surrounding ecosystem and an indicator species of possible negative impacts that may be occurring within the river. Results show that these stoneflies among other important macroinvertebrate species have significantly declined in areas below Windy Gap Reservoir. Samples were not taken at Pumphouse in 1980-1981 so direct comparison of populations could not be conducted. However, resulting abundance estimates from the 2010-2011 sampling at Pumphouse were significantly higher than any other sites upstream to Windy Gap Reservoir.

2.5.6 *Upper Colorado River Water Quality Management Plan (Northwest Colorado Council of Governments, 2012)*

This report focuses mainly on the Colorado River within Grand County. An assessment was conducted of water-quality issues on the main stem Colorado River and all major rivers that feed into it. Increased sedimentation below State Bridge was mentioned to be possibly caused by stream bank erosion. Rock Creek was also investigated for possible water quality effects from upstream timber harvesting in Routt County. Results indicated good water quality as evidenced by low dissolved solids and nutrient concentrations.

2.5.7 *Grand County Stream Management Plan – Temperature Data Review (Tetra Tech, Inc. (2010) and others)*

Water temperature data were analyzed for the period 2006-2009 for the Upper Colorado River and its tributaries in Grand County to determine if temperatures exceeded Maximum Weekly Average Temperature (MWAT) or Daily Maximum (DM) standards set forth by the Colorado Department Public Health and Environment (CDPHE). For 2006-2008, gages downstream of Windy Gap often exceeded MWAT standards. Most of the sites were below DM standards except for Ranch Creek. Temperature-discharge relationships were also analyzed at certain gaging stations. Further observations are presented below.

- River temperatures in the Fraser River cool at the confluence with the Colorado River upstream of Windy Gap.
- The Colorado River warms as it travels through Windy Gap. A warming trend continues through the entire reach from Windy Gap to Hot Sulphur Springs.
- From Hot Sulphur Springs to Williams Fork, changes in river temperatures vary. Of the five dates plotted, 2 days show a decrease, 2 days show an increase, and 1 day (August 1) shows only a slight decrease.
- Flows released from Williams Fork Reservoir tend to cool water temperatures below the confluence.
- From KB Ditch to Kremmling river temperatures remain relatively unchanged.

2.5.8 Windy Gap Firming Project EIS (Bureau of Reclamation (BOR), 2011)

Denver Water is proposing to expand Gross Reservoir to meet future water demands along the Front Range. Water would be diverted in average to wet years from the Fraser River, Williams Fork, and South Boulder Creek. The expansion would allow for an additional 72,000 acre-feet (AF) of storage. Some possible impacts stated in the environmental impact statement (EIS) are as follows:

- Streamflow
    - Fraser River and Williams Fork would see decreased peak flows in average and wet years. This also impacts tributaries to the Fraser River.
    - Blue River would have decreased summer flows and slightly increase winter flows during average and wet years.
    - Colorado River flows would decrease during runoff during average and wet years.
- Sedimentation
    - Sediment-transport capacity is expected to decrease in all affected rivers.
    - Only a small amount of localized sedimentation is expected.
- Aquatic biology
    - There would be no changes to water quality or channel geomorphology in the Fraser, Williams Fork, Blue, and Colorado Rivers that would affect fish and other aquatic biological resources.

2.5.9 Colorado River Cooperative Agreement (CRCA, 2013)

An agreement has been made between West Slope cities and counties, Denver Water, and other involved parties on how future water projects will be governed within the Colorado River basin. Major points of the agreement are as follows:

- Additional water for towns, districts, and ski areas in Grand and Summit Counties to serve the needs of residents and to improve the health of rivers and streams.
- An agreement to operate key Denver Water facilities, such as Dillon Reservoir in Summit County, and Williams Fork Reservoir and the Moffat Collection System in Grand County, in a way that better addresses the needs and concerns of neighboring communities and enhances the river environment.
- Greater certainty for Denver Water to develop future water resources for its customers by resolving long-standing disputes over its service territory, its ability to use West Slope water, its ability to develop future water supplies in the Colorado River basin, and other legal issues.
- Additional water and enhanced system reliability for customers of Denver Water, representing nearly 25% of the state’s population, by moving forward the Moffat Collection System Project.
- Agreement by all partners to not oppose Denver’s storage of its Blue River and Moffat Project water on the Front Range.
- Reinforcement of the priority and increased conservation and reuse within Denver Water’s service area.

2.5.10 10825 Water Supply Study – Phase 1 (GEI Consultants Inc. and Grand River Consulting Corporation, 2004)

East Slope and West Slope entities will provide a permanent supply of 10,825 AF/year of water to help with the recovery of four endangered fishes. The four fish species (Colorado pikeminnow (*Ptyochocheilus lucius*), razorback sucker (*Xyrauchen texanus*), humpback chub (*Gila cypha*), and bonytail chub (*Gila elegans*)) are currently present in the Colorado River near Grand Junction. The water will be used during the late summer months to help with low-flow conditions. Due to the downstream location of the endangered fishes, some of the water being delivered will also help with elevated water temperatures within the study area being caused by low-flow conditions. Ten alternatives to provide the water have been proposed and will be further investigated:

1) Orchard Mesa Irrigation improvements;
2) Sulphur Gulch Reservoir;
3) Buzzard Creek Reservoir;
4) Wolford Mountain Reservoir improvements;
5) Roan Creek Reservoir;
6) Wolcott Reservoir;
7) 15-mi Reach Pumpback;
8) Yank Creek Reservoir;
9) Ruedi Reservoir (2012 Backfill) impacts; and
10) Synchronized use of multiple facilities.

2.5.11 Ecological and Physical Processes During Spring Peak Flow and Summer Baseflows in the 15-mi Reach of the Colorado River (Rees et al., 2008)

Reductions in peak flows have negatively impacted endangered fish species present in a 15-mi reach on the Colorado River near Grand Junction. This study focuses on determining if the current peak flow regime is in fact limiting to the native fishes and the surrounding aquatic ecosystem. The investigation examined physical and biological processes. Results indicated that a variety of factors may influence primary and secondary productivity within the 15-mi reach including: turbidity, frequency and intensity of storm events, deposition of sediments, runoff characteristics, sediment scouring, and flow stability.

2.5.12 Climate Change in Colorado (Ray et al., 2008)

This report synthesizes the potential impacts of climate change on Colorado's water supply. Temperatures have increased about 2°F over the past 30 years in Colorado. Warming is expected to continue reaching a 4°F increase by 2050. Winters are expected to have less extreme cold months, but more extreme warm months. No consistent long-term trend in annual precipitation can be detected. However, more precipitation is expected to fall as rain instead of snow. The peak flow on many rivers has already shown a shift to 2 weeks earlier that may also reduce late summer flows. A decline in snowmelt runoff is also expected. Water managers may need to develop adaptation strategies in response to potential climate change.

2.5.13 Colorado River Water Availability Study (AECOM, 2012)

The study combined data and models developed by CWCB and Division of Water Resources (DWR) to examine the Colorado River water supply within Colorado. Three different water supply conditions were used in the analysis:

1) Historical Hydrology – uses hydrology data from 1950-2005 to estimate water supply.
2) Extended Historical Hydrology – uses tree-ring records for the past 1,200 years.
3) Climate-adjusted Hydrology – assesses the magnitude of future water supply considering the potential effects of climate change.

Climate projections for 2040 and 2070 were used to determine resulting trends in temperature, precipitation, streamflow, reservoir storage, and consumptive use. Average monthly and annual temperatures are expected to rise. Precipitation is shown to increase in the winter months and decrease in the summer months. Temperature increases will make more precipitation fall as rain instead of snow. A decrease in annual stream flow is expected in both the 2040 and 2070 scenarios, while consumptive use is expected to rise.

2.5.14 Colorado River Water Bank Feasibility Study (MWH, 2012)

The Colorado River Compact of 1922 states that the Upper Division (Colorado, New Mexico, Utah, and Wyoming) must curtail water use if they cause flows at Lee Ferry, Arizona, to drop below 75,000,000 AF during any consecutive 10-year period. Recent drought has caused conservation agencies to conduct a feasibility study of water banking within Colorado in order to avoid curtailment. Water banking works by having willing agricultural participants temporarily fallow or deficit irrigate lands using pre-1922 water rights in return for financial compensation. Different scenarios were run to try and quantify the amount of available water supply for banking. Results show that deficit irrigation is feasible for grass pasture and alfalfa in order to save ~950,000 AF/year. Overall, feasibility will hinge on certain legal and water-right administration questions.

2.5.15 Agreement on Wolford Mountain Reservoir and Green Mountain Reservoir Exchange (BOR, 2007)

This report is an environmental assessment of a proposed agreement between the BOR, the Colorado River Water Conservation District (CRWCD), and Northern Colorado Water Conservancy District (NCWCD). The agreement states that in order to mitigate any existing shortages due to operating limits at Green Mountain Reservoir, water can be substituted from Wolford Mountain Reservoir. The investigation included a no-action alternative, banking exchange, and a borrowing exchange. The effects on aquatic resources under the proposed plans are posited as follows:

- Blue River
    - The proposed alternatives could have an adverse impact to aquatic resources.
    - Spawning fish in fall and spring could be affected.
- Muddy Creek
    - The banking exchange could cause short-term negative impacts on aquatic resources, but in the long-term could be negligible.

    - Borrowing exchanges have the potential to cause minor negative impacts on aquatic resources.
- Macroinvertebrates
    - No impacts are expected specific to macroinvertebrates due to any decreases in flow in the Blue River and Muddy Creek are protected by in-stream flow regulations.

2.5.16 Wolcott Reservoir Feasibility Assessment – Phase I (GEI Consultants, Inc. and Grand River Consulting Corporation, 2004)

The feasibility of building a reservoir on land owned by Denver Water is being assessed. Three reservoir scenarios have been identified and in each scenario it would be operated by East Slope and West Slope entities. The water being stored would not be diverted to the eastern slope but used on a substitution or exchange basis. Water would be diverted from both the Eagle River and Alkali Creek where the dam would be located. Water would be taken during runoff and released into the Eagle River primarily during low flows. Reservoir releases would be used primarily for the following purposes:

- Maintenance of habitat for threatened and endangered fishes in the lower Colorado River.
- Water supply for Eagle River and other West Slope water users.
- Exchange or substitution to existing transmountain diversion facilities.
- Enhancement of environmental conditions of the Eagle and Colorado Rivers.

A proposed alternative to pumping water from the Eagle River into the reservoir would be to run a gravity-fed tunnel from the Piney River which is the largest tributary to the Colorado River between Kremmling and Dotsero.

2.6 History

The following subsections present an overview of selected historical aspects of the Colorado River watershed between Pumphouse and Dotsero that have influenced the trajectory of the river corridor to its present state.

2.6.1 Human Settlement

Limited data suggest that the earliest habitation of the area may have occurred 10,000 years ago by Paleoindian big-game hunters of the Folsom Complex (Metcalf and Black, 1991). More recently, archeological finds at the Yarmony Site (located between State Bridge and Radium) suggest that human occupation in the area began about 7,000 years ago. The site was shown to be used repeatedly by prehistoric Native Americans possibly coming from the nearby Ute Trail (Metcalf and Black, 1991). This same trail allowed for early European settlers to enter the area in the late 1800s (Hayden, 1881). Another trail following the Colorado River eventually became a wagon road known as the Colorow Route and follows sections of what is currently the Colorado River Trough Road.

Homesteading became more active with the first noted homestead being built by the Joseph McPhee family in 1880. A year later, Ute Indians were removed to reservations and the land was opened up for larger scale Euro-American settlement. Despite being forced from the land, some Ute Indians remained in the McCoy area until 1903. A ferry was built in the area to provide access to the north side of the Colorado River for those heading along a trail (present-day Highway 131) to Wolcott and Steamboat Springs. In 1890, the first state granted steel bridge was completed across the river giving State Bridge its name. The bridge was built to facilitate travel across the river and State Bridge became a stagecoach stopping station.

As settlers moved into the area they brought herds of cattle and began to ranch the area. To support cattle year round they began to divert water from the river to irrigate surrounding hay fields. One of the remaining artifacts of the era is the McCoy waterwheel (Figure 2.42). Constructed in 1922 by local ranchers, it is believed to be the largest remaining waterwheel in Colorado. Waterwheels were the primary way ranchers could easily irrigate their fields by delivering water from the wheel buckets to ditches that ran into the hay fields. This technology was eventually replaced by the electric pump.

Figure 2.42 – The largest waterwheel in Colorado was built in 1922 just south of McCoy.

Although mining fever had hit the surrounding region by the late 1800s, the pursuit for riches within the study area was more subdued. Gold was sought in the area in 1888 in placer deposits and hard rock exposures (Metcalf and Black, 1991). One of the more viable mining opportunities within the area at the time was copper mining near McCoy. By 1890, nine claims had been opened by W. H. J. Miller to tap into a large copper vein assaying 15% copper (McCabe, 1899). No further copper mining has occurred within the study area since the 1920s (Tetra Tech, Inc., 2010). From Pumphouse to State Bridge one uranium mine has been identified, but no production records are available. Below State Bridge another uranium site with moderate potential exists just outside of the river corridor. Other materials mined in the study area include an old gold mine with low to moderate potential, and two sand-and-gravel operations of moderate to high potential (Tetra Tech, Inc., 2010). No known investigations into possible mining legacy effects within the study area have been conducted. However, presently there appear to be no water quality impacts connected with mining sites such as acid mine drainage and elevated heavy metals concentrations.

2.6.2 Transportation

Construction of the Moffat Road began in 1903 by the Denver & Salt Lake Railroad (D&SLR) to connect Denver to Salt Lake City. Part of the line ran from Kremmling to Bond. The railroad tracks reached the State Bridge area in 1905 where a station and stockyard were built to load cattle onto the trains. In 1932, the Denver & Rio Grande Railroad (D&RG) bought out D&SLR and began to construct the Dotsero Cutoff to connect Moffat Road to the Rio Grande rails in Dotsero. Construction was completed in 1934 and to this day the track is heavily used by Union Pacific and Burlington-Santa Fe train lines (Figure 2.43).

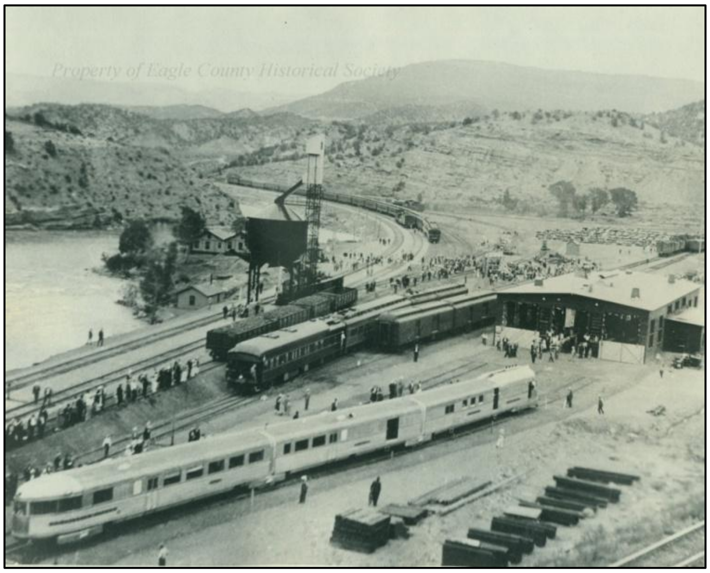


Figure 2.43 – View of the Dotsero Cutoff dedication in Bond on June 16, 1934 (http://evldlh.wordpress.com/2011/05/16/whatever-happened-to%E2%80%A6the-bond-coach-school/#more-282).

Due to the river's narrow confined valley, the railroad generally runs directly adjacent to the river. Riprapped channel banks along the elevated tracks are common throughout the valley (Figure 2.44). In addition to the railroad, the Colorado River Trough Road (County Road 1) also encroaches upon the river as it follows the confined valley. It is not uncommon for the railroad and road to completely border the river on both sides.

Figure 2.44 – The railroad tracks follow right alongside the river in many areas of the confined valley.

A state-wide transportation study explored the feasibility of high-speed rail opportunities (Transportation Economics & Management Systems, Inc. (TEMS), 2010). One hypothetical plan is to add a high-speed diesel train service from Steamboat Springs to Aspen. The rail would join into the existing track at Bond and travel 38 mi south to Dotsero. If the high-speed rail were to be used, most of the existing track would have to be modified. Approximately 8 mi would run on existing track with the other 30 mi requiring upgrades including embankments, tunnels, and bridges. Although this is a hypothetical plan, upgrading the existing track could possibly further encroach upon the river and its riparian corridor.

2.6.3 Tourism and Recreation

The mining boom in the late 1800s in Colorado brought an influx of people to the area. It did not take long for them to find the abundant elk and fish along the Colorado River and surrounding lands. In 1901, then Vice President Teddy Roosevelt stayed at a cabin in State Bridge while on a hunting trip in the Flat Tops Wilderness (State Bridge, 2011). Hunting and fishing have continued through the years and to this day provide a viable economy. In 2008, hunting and fishing in Eagle County accounted for over $67 million in revenue. Grand County was slightly lower at over $49 million (BBC Research & Consulting (BBC), 2008). Other recreational pursuits such as float boating and kayaking have become popular, especially between Pumphouse and State Bridge, which provides whitewater, fishing, and float trips. In 2012, revenue from rafting on the Upper Colorado River was the third highest for any river in Colorado at over $12 million (Colorado River Outfitters Association (CROA), 2012).

Many people have visited the Eagle County portion of the Colorado River since the late 1800s, but the steep topography, arid climate, and limited mining opportunities have minimized the number of settlers and impacts on the land as compared to elsewhere in the state. As in most mountainous areas, steep topography of the hillslopes pushes development towards the flat valley bottoms of the river corridor. The arid climate also means that hay pastures must be irrigated and located alongside the river. The resulting encroachment on the river can negatively impact the riparian area and river itself. Despite the encroachment, much of the river corridor was too steep and confined to develop for agricultural use. Aside from the railroad and road corridors that now parallel the river's course, the contemporary river corridor in Eagle County still offers the opportunity to experience a landscape that appears much as it did well over a century ago.

Chapter 3

Analysis of Watershed Characteristics

An analysis of the Colorado River watershed was conducted to assess the current condition of the river corridor through Eagle County. Land use characteristics, water rights, and details of the vast water diversion and storage infrastructure upstream of the study area were evaluated. The effects of these water-management activities were assessed by analyzing changes in the hydrologic regime. Water quality was examined through direct sampling of water quality, macroinvertebrates, and fishes. Finally the geomorphic characteristics, physical habitat, and riparian condition of the main stem river corridor were assessed. The following sections present the results of these analyses.

3.1 Land Use

Land use change within the study area has remained relatively modest due to steep topography and aridity. Ranches and irrigated pasture have encroached upon the river floodplain in the wider valley bottoms; however, 65% of the river runs through public land managed by the BLM (Figure 3.1). Future opportunities for development along river corridor appear minimal and are primarily focused on opening up recreational opportunities. Recently, three new boat launch sites have been built at Two Bridges, Dotsero, and on the Colorado River Ranch property to allow better access for visitors to explore the scenery, wildlife, and recreational opportunities the area provides.

A recent proposal from Grand County to build a whitewater park upstream of Pumphouse is being reviewed by the BLM (Figure 3.2) and other resource agencies. An objective of the design of the park would be to allow fish passage at all flows. Expected benefits include a longer season for recreational river activities and improved recreational experiences for visitors. The proposal is in the public scoping for the environmental assessment stage at the time of this writing. The environmental assessment will necessarily evaluate the potential for impacts to fish passage and any habitat loss that may affect fish and macroinvertebrates, including sensitive taxa such as the salmonfly. If approved, construction is scheduled to begin in October 2014. The proposed timing of the construction is not ideal from an ecological perspective, as it occurs during brown trout spawning. .

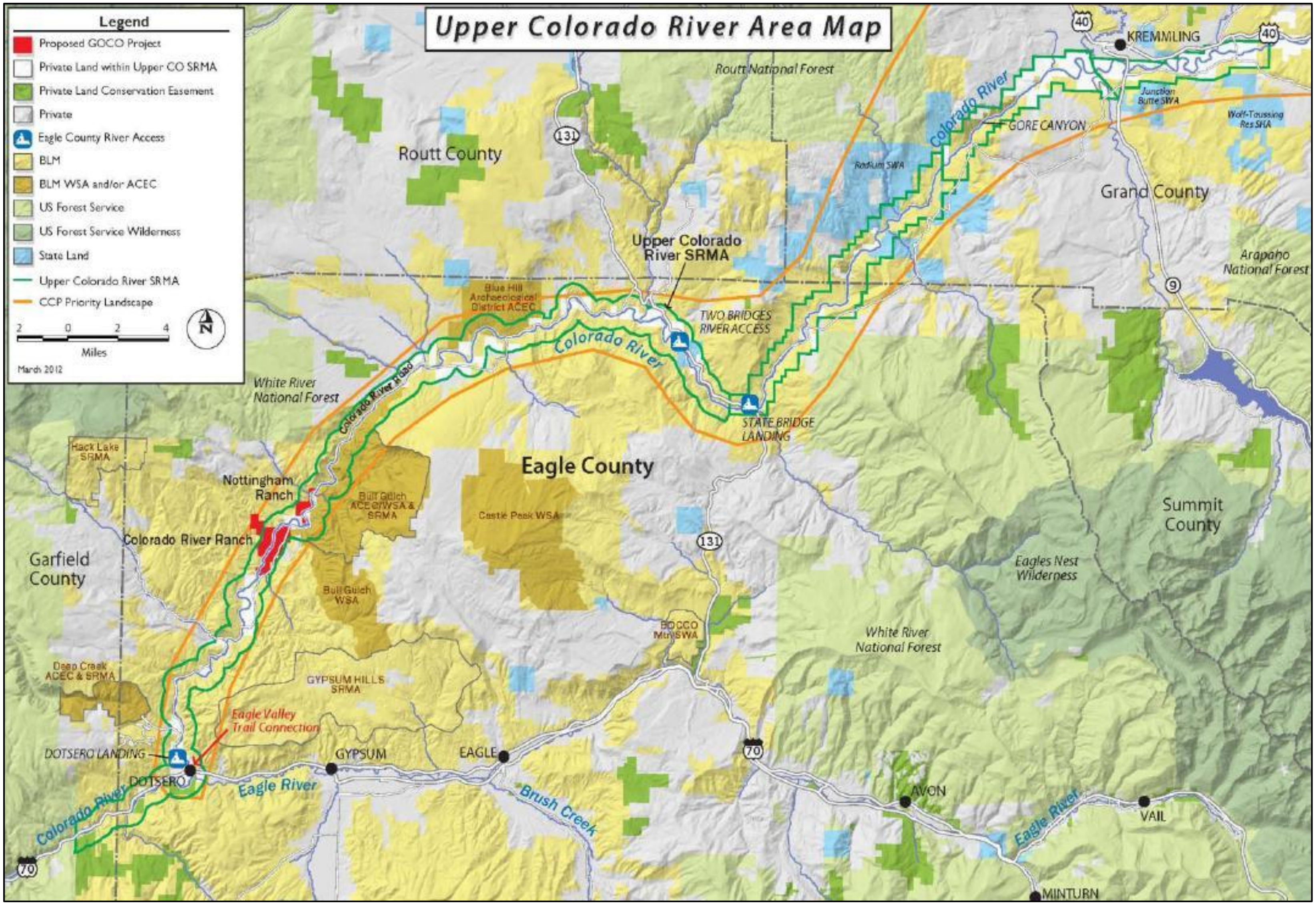


Figure 3.1 – Land ownership and status map for the study area (BLM, 2013a) (http://www.blm.gov/pgdata/etc/medialib/blm/co/resources/resource_advisory/northwest_rac/minutes.Par.56348.File.dat/Eagle%20County%20UCR%20Project.pdf).

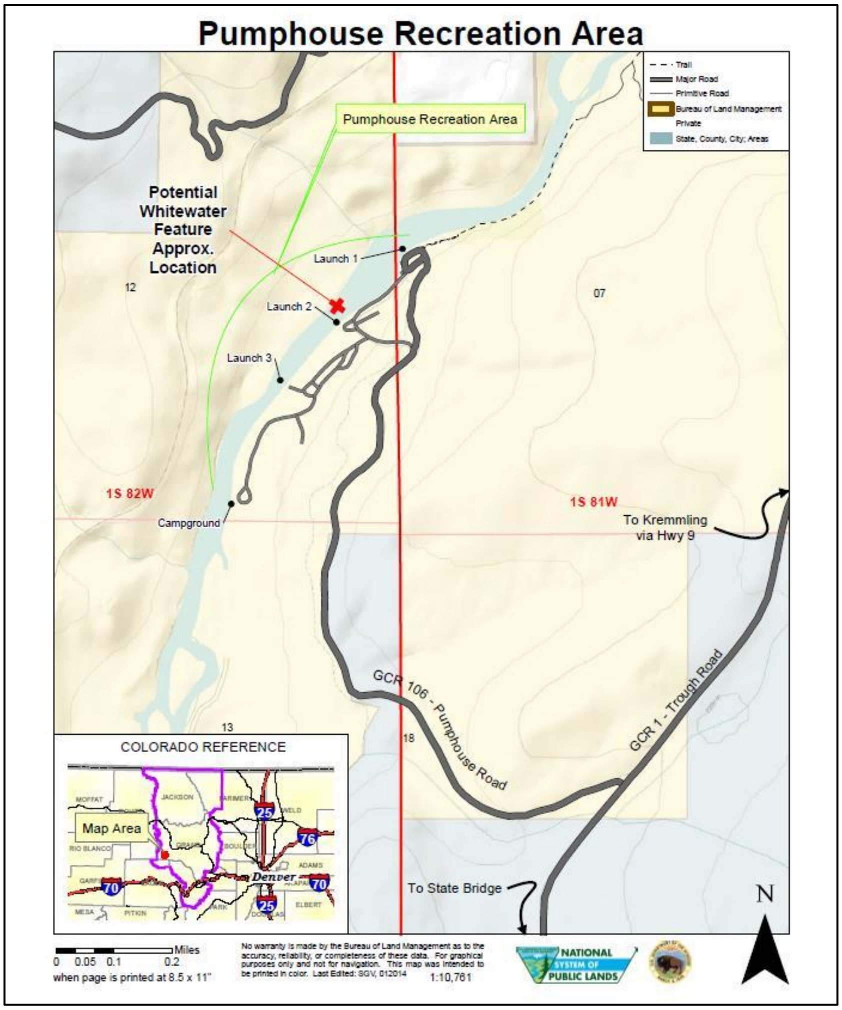


Figure 3.2 – Location of proposed whitewater park (BLM, 2013b).

Public lands within the study area have been assigned various classifications intended to protect and conserve the different resource values they provide. One Wilderness Study Area (WSA), Bull Gulch, is located near Red Dirt Creek. WSAs are defined as BLM-owned lands in a roadless area with wilderness characteristics. WSAs are managed to protect their wilderness values until Congress votes to designate them as an actual Wilderness Area. Bull Gulch WSA is classified as a Visual Resource Management Class (VRMC) I and II for its scenic qualities including the diverse topography, geologic forms, and sharp contrasting colors (BLM, 2007).

Two Areas of Critical Environmental Concern (ACEC), Blue Hill and Deep Creek, are also located within the study Area (Figure 3.3). The ACEC is a conservation ecology program managed by the BLM which establishes protection for important riparian corridors, threatened and endangered species habitat, cultural and archeological resources, and scenic landscapes. Blue Hill is northwest of Burns and is designated a sensitive area for cultural and Native American resources that could allow for a better understanding of the area's prehistory and history (BLM, 2007). The Deep Creek area was designated as a VRMC I and II for its outstanding landforms, vegetation, and water features. It is also determined to meet geologic values for its high concentration of cave and karst topography (BLM, 2007). Proposed ACECs include the Dotsero Crater and McCoy Fan Debris fans. The Dotsero Crater is the youngest known volcanic event in Colorado at ~4,700 years old. The McCoy fan debris fans are exposed material from the Minturn formation, which through fluvial fanicprocesses has deposited an abundance of invertebrate, vertebrate, and plant fossils.

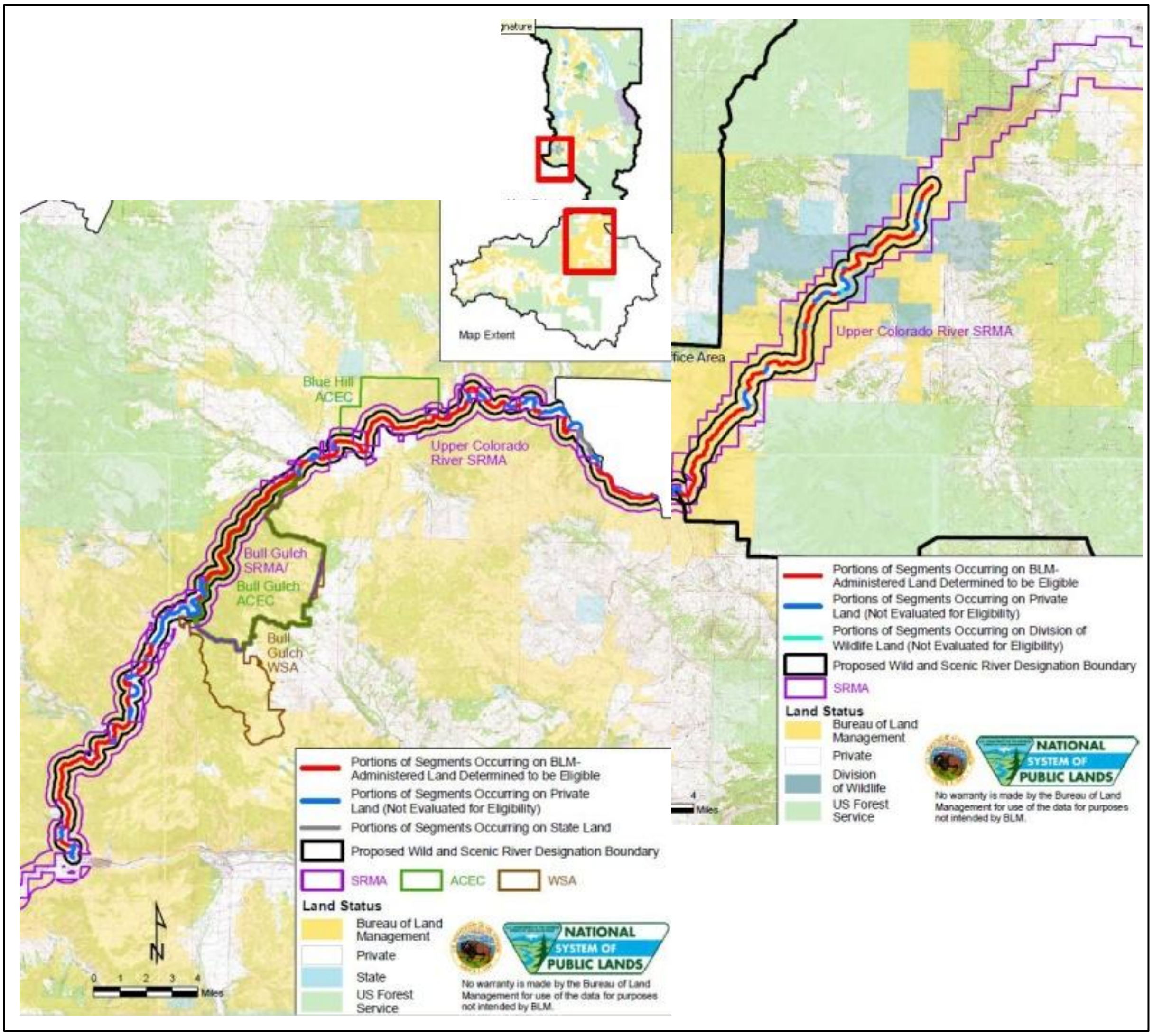


Figure 3.3 – Portions of river segments occurring on BLM and private lands (Tetra Tech, Inc., 2010).

Both the Routt Forest and WRNF are located along the western higher elevations of the study area. Most perennial tributaries to the north of the Colorado River begin within these lands. Also incorporated into the WRNF is the Flat Tops Wilderness Area which Deep, Sweetwater, Red Dirt, Derby, and Cabin Creeks all start. Wilderness areas are managed by the four following federal government agencies: 1) the National Park Service (NPS), 2) the U. S. Forest Service (USFS), 3) the U. S. Fish and Wildlife (USFW), and 4) the BLM. They do not allow motorized recreation, logging, mining, road building, or other forms of development.

The Radium State Wildlife Area is managed by the CPW mainly for deer and elk winter range habitat but offers camping, fishing, and hunting opportunities. Wildlife for hunting include: deer, elk, rabbit, dusky grouse, dove, waterfowl, black bear, and mountain lion.

Currently there are no oil and gas leases within the study area (BLM, 2013a). Most of the area has no known or low potential for gas occurrence except for one medium potential section around Cabin Creek and Big Alkali Creek watersheds (Figure 3.5). Although potential future oil or gas exploration seems unlikely within the study area, examination of any new leases would be necessary to ensure there are no negative ecological impacts to wildlife, vegetative species of concern, and or possible water quality impacts to nearby streams.

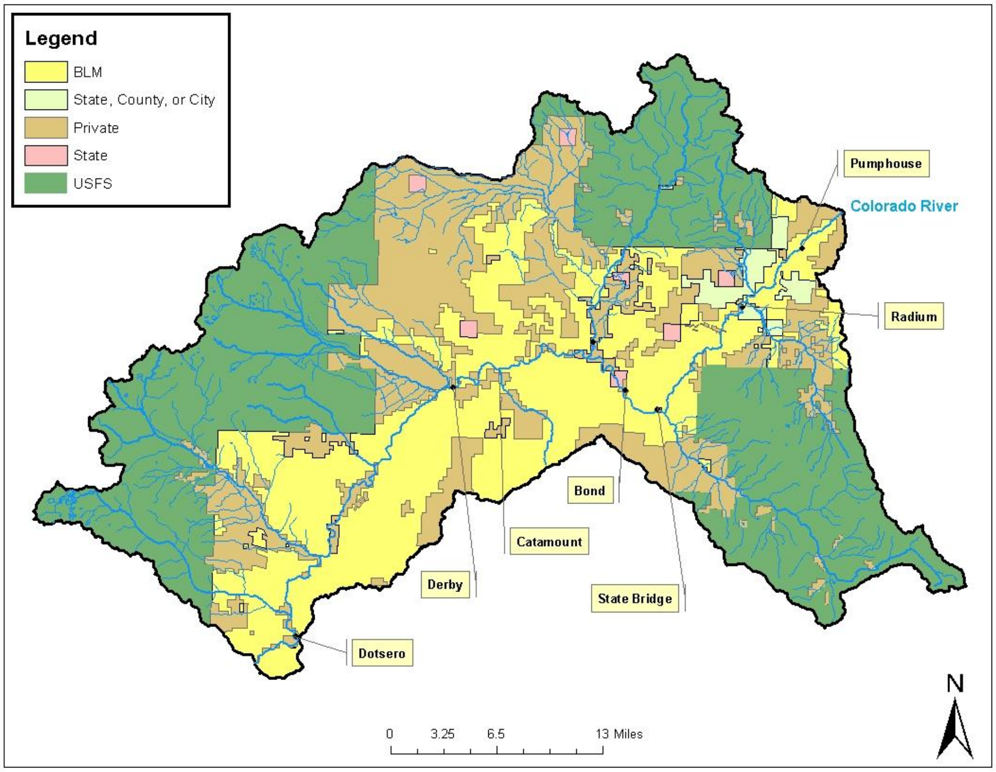


Figure 3.4 – Land surface ownership within the study area (BLM, 2013a).

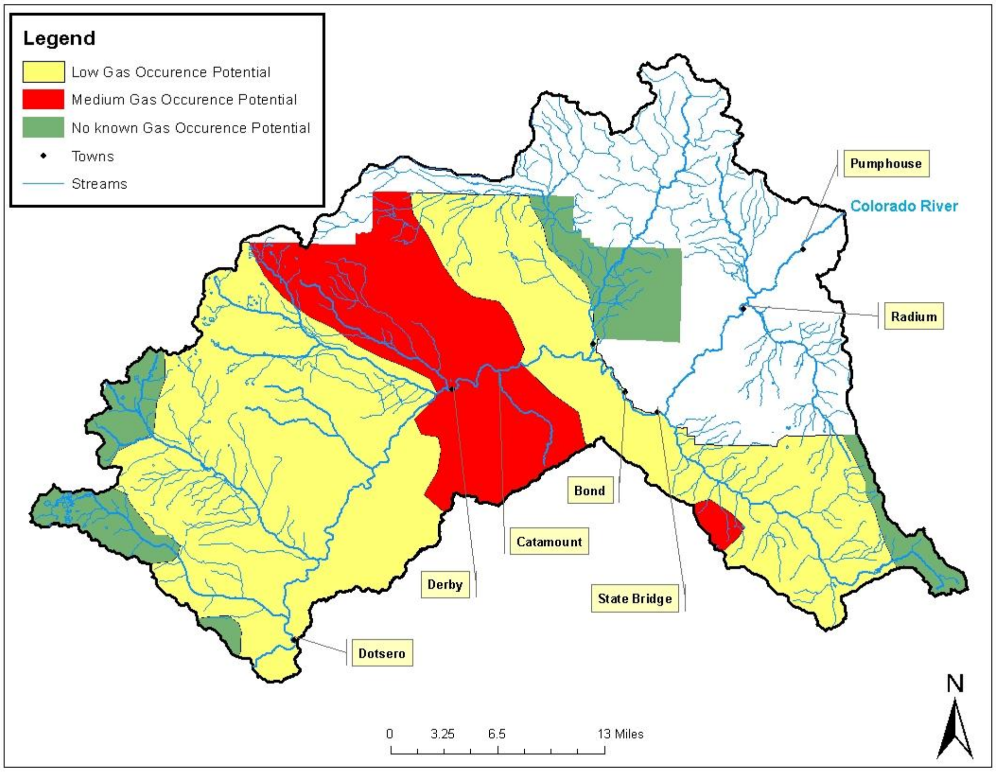


Figure 3.5 – Gas occurrence potential within the study area (BLM, 2013a).

3.2 Water Rights

The first water rights in the Colorado River basin within Eagle County date back to the 1880s when settlers began ranching in the area. The arid land required settlers to divert water by ditch, well, and pump in order to ranch. As of 2005, there were 496 diversion structures within the study area (Colorado Decision Support System (CDSS), 2013). Of these, only 151 have an absolute water right rate greater than 3 cfs. The largest single diversions in the study area occur in the Derby Creek (32 and 29 cfs) and Rock Creek (25 and 22 cfs) watersheds.

Water rights in Colorado are designated as either absolute or conditional. Absolute water rights are defined as a water right that has been placed to a beneficial use. Conditional water rights occur when the water court fixes the water right with a certain date, but does not give appropriation. The user then has time to complete their diversion project and have the court review the use of the water right to judge if it should then become an absolute right. The project must be reviewed every 6 years by the water court until it is completed to show progress is being made, otherwise the water right will be forfeited (Grantham, 2011). Current net absolute and conditional water-right quantity is provided below (Table 3.1).

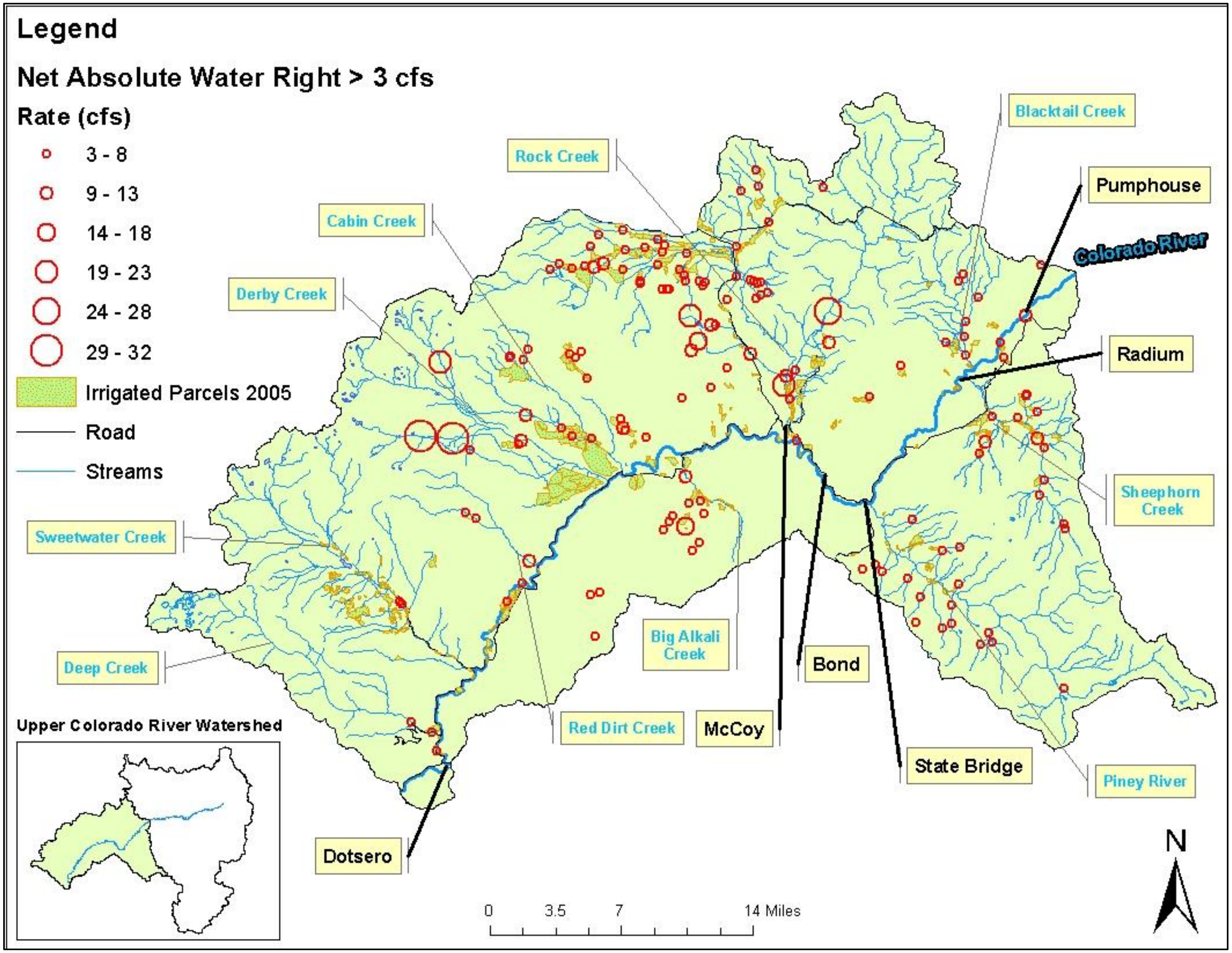


Figure 3.6 – Distribution of net absolute water right greater than 3 cfs and irrigated parcels within the study area.

Table 3.1 – Net absolute and conditional rates for river and streams within the study area (DWR, 2013).

Stream/River Name	Net Absolute Rate (cfs)	Net Conditional Rate (cfs)
Cabin Creek	111	
Colorado River	62	2
Deep Creek	6	
Derby Creek	101	
Piney River	124	
Red Dirt Creek	62	
Rock Creek	433	3
Sheephorn Creek	124	
Sweetwater Creek	23	
Total:	**1,047**	**5**

The most important water rights for maintaining flows in the main stem river are actually located downstream of the study area. The water rights held by the Shoshone Power Plant and the “Cameo Call” (Figure 3.7 and Figure 3.8, respectively) are two of the oldest held on the Colorado River. The Shoshone Power Plant has a right of 1,250 cfs (1902 appropriation) and an additional 158 cfs (1940 appropriation), which makes up a large portion of the water in the Colorado River year round. However, the Shoshone rights can be shutoff during runoff and “relaxed” during times of drought to allow more junior rights held by reservoirs upstream to store water.

Figure 3.7 – Shoshone Dam diverts water from the Colorado River to the Shoshone Power Plant downstream (http://krcc.org/post/shoshone-power-plant-big-dog-river).

Figure 3.8 – Grand Valley Diversion Dam (http://commons.wikimedia.org/wiki/File:Grand_Valley_Diversion_Dam.JPG).

The Cameo Call provides water primarily for irrigation and power in the Grand Valley near Grand Junction. The water rights are owned by five entities in the valley and date back from 1912-1934. The total water quantity owned by the right is 2,260 cfs during irrigation season and 800 cfs during non-irrigation season. Because of their downstream location and their senior standing, water provided for the two water rights actually keeps water in the Colorado River rather than it being diverted to the East Slope. In 2013, as part of the Colorado River Cooperative Agreement, Denver Water and West Slope parties will operate their diversions and reservoirs as if the Shoshone Power Plant was calling for its right even when the plant is not running (CRCA, 2013). This agreement will ensure flows to remain in the Colorado River and provide recreational and environmental benefits; however, the flow requirements for Shoshone and Cameo water rights can also be met by water from the Eagle and Roaring Fork Rivers downstream of the study area. This means that flows in the Colorado River through the study area are not necessarily stable and predictable due to these water rights.

An agreement made in 2010 by East Slope and West Slope water providers will guarantee flows in the late summer months to help with recovery of four federally endangered fishes that inhabit a 15-mi reach of the Colorado River near Grand Junction. The four species of fish, Colorado pikeminnow (*Ptyochocheilus lucius*), razorback sucker (*Xyrauchen texanus*), humpback chub (*Gila cypha*), and bonytail chub (*Gila elegans*), will benefit from an additional 10,825 AF of water. Initially, water was provided from the Williams Fork and Wolford Mountain Reservoirs which provided the benefit of additional late summer flows to the Colorado River through Eagle County. However, in 2013, two permanent sources, Ruedi and Granby Reservoirs, were designated to each release half of the 10,825 AF of water. Only Granby Reservoir is upstream of the study area; thus, less water will be sent through the area than in previous years under the new operations.

3.2.1 Upstream Reservoirs

The main source of water in Colorado is runoff from snowmelt. Peak runoff on the Colorado River usually occurs from late May to mid-June and numerous reservoirs have been constructed for storing and utilizing this water year round. Many reservoirs were initially built for agricultural use, but later for the growing municipalities along the Front Range. A summary of the largest reservoirs in the Colorado River watershed upstream of the study area is presented below (Table 3.2). A more-detailed overview of the reservoirs in the Colorado River watershed upstream of the study area is provided in Appendix B.

Table 3.2 – Summary table of the largest reservoirs upstream of the study area.

Reservoir	Operator	Year Constructed	River	Storage Capacity (AF)
Shadow Mountain Reservoir	NCWCD	1946	Colorado River	17,453
Lake Granby	NCWCD	1949	Colorado River	539,758
Willow Creek Reservoir	NCWCD	1953	Willow Creek	10,600
Williams Fork Reservoir	Denver Water	1959	Williams Fork	96,882
Wolford Mountain Reservoir	Colorado River District	1996	Muddy Creek	66,000
Dillon Reservoir	Denver Water	1963	Blue River	257,304
Green Mountain Reservoir	BLM	1943	Blue River	153,000

3.2.2 Upstream Diversions

The Colorado River basin has an extensive history of water storage and diversion. Some diversions are inbasin (the water never leaves the watershed). In contrast, transbasin diversions move water outside of the watershed where it fell as precipitation. Finally, transmountain diversions are transbasin diversions that move water from the West Slope of the state, over the Continental Divide, to the East Slope.

3.2.2.1 Transmountain Diversions in the Colorado River Watershed

An overview of transmountain diversions in Colorado is presented in Figure 3.9 and Table 3.3. The largest transmountain diversion project in Colorado, the C-BT Project built between 1938 and 1957, originally came about to deliver water from the West Slope to the East Slope primarily for agricultural purposes. Today, 12 reservoirs, 35 mi of tunnel, and 95 mi of canal deliver 213,000 AF of water per year to the East Slope to provide for agricultural and municipal uses (Figure 3.10).

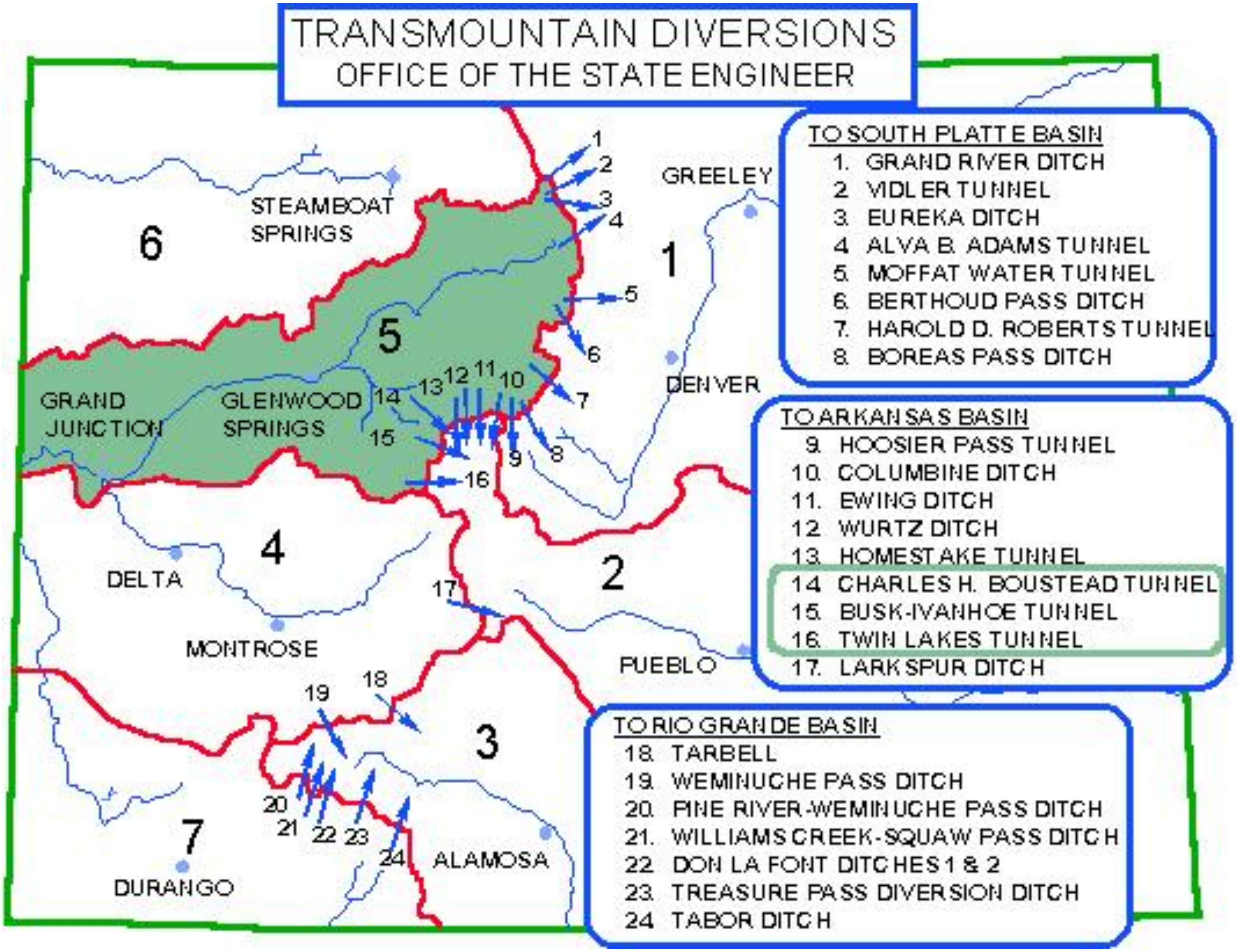


Figure 3.9 – Transmountain diversions within the state of Colorado (http://www.roaringfork.org/sitepages/pid170.php).

Table 3.3 – Summary of transmountain diversions carrying water out of the Colorado River basin.

Diversion Number	Structure	Quantity Diverted Water Year (Oct 1 - Sep 30) 10-year mean 1985[(1)] (AF)	1990-1999 (AF)	2000[(3)] (AF)	Principal Owner / Contact
1	Grand River Ditch	20,831	20,460	18,559	Water Supply and Storage Co.
2	Eureka Ditch	0	128	0	City of Loveland
3	Alva B. Adams Tunnel	285,200	205,718	247,735	NCWCD
4	Moffat Water Tunnel[(4)]	77,545	44,318	51,726	City of Denver
5	Berthoud Pass Ditch	567	950	0	City of Northglenn
7	Gumlick Tunnel	N/A	2,340	2,781	City of Denver
8	Straight Creek Tunnel	409	323	370	Adolph Coors Company
9	Vidler Tunnel	369	643	332	City of Golden
10	Harold D. Roberts Tunnel	299	61,789	93,645	City of Denver
11	Boreas Pass Ditch	40	139	111	City of Englewood
12	Hoosier Pass Tunnel	7,400	9,939	10,770	City of Colorado Springs
	Total:	**392,660**	**346,747**	**426,029**	

Notes:

(1) U. S. Geological Survey (USGS, 1985).

(2) This note regards the entire table: based on Irrigation year, November 1 – October 31.

(3) All year 2000 data should be considered preliminary.

(4) Does not include water carried in the Gumlick / Vasquez Tunnels.

N/A = not available

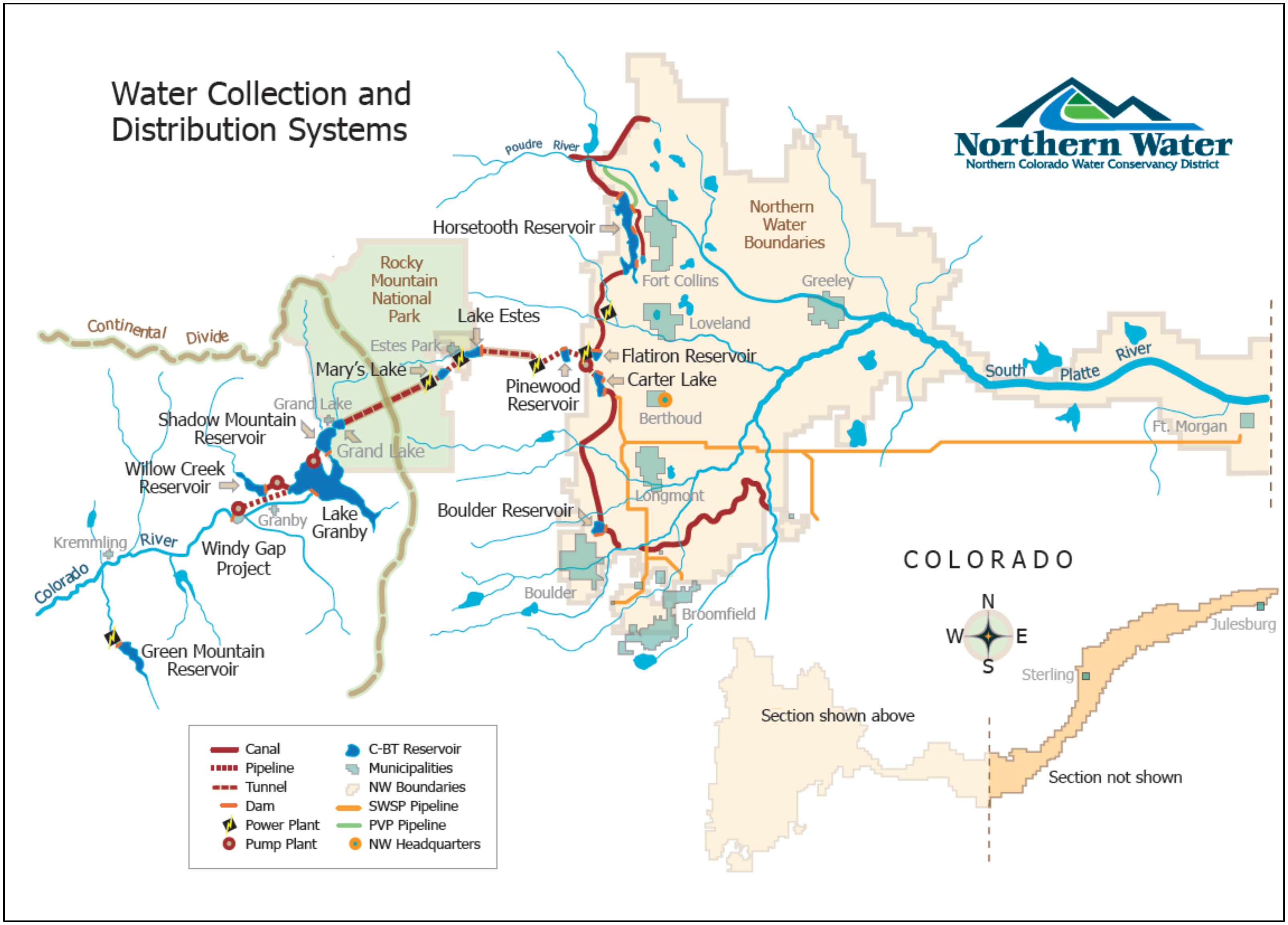


Figure 3.10 – Schematic of the Colorado – Big Thompson Project (http://www.northernwater.org/WaterProjects/C-BTProject.aspx).

A more recent addition to the C-BT Project is Windy Gap Reservoir. Built in 1985, Windy Gap Reservoir is a small impoundment (445 AF) used to pump water from the Colorado River, below the confluence with the Fraser River, up to Lake Granby. Windy Gap delivers an average of 48,000 AF/year of water. A new firming project for Windy Gap has been proposed and is currently under review. The project is being put forward by the NCWCD to address the fact that often times in wet years Windy Gap cannot pump water up to Lake Granby because it is full. The project proposes to build a new reservoir on the East Slope called Chimney Hollow Reservoir. This would provide an additional 90,000 AF of storage allowing for the NCWCD to fully utilize the 90,000 AF/year that can be diverted by Windy Gap. These additional water withdrawals from the Colorado River can have direct impacts on the river downstream of Windy Gap including through the study area. Possible impacts could include reduced flows in general but especially peak flows which could exacerbate sedimentation issues.

Within the Colorado River basin, Denver Water owns and operates two reservoirs and four tunnels that deliver water out of the basin to the East Slope. The Moffat Tunnel diversion system includes a series of pipes, tunnels, siphons, and canals to divert water from the headwaters of the Fraser River. The combined diversions from the Williams Fork and Fraser Rivers travel 6.1 mi under the Continental Divide into South Boulder Creek and eventually into Gross Reservoir on the East Slope. A proposal put forward by Denver Water to enlarge Gross Reservoir by 72,000 AF is currently under review. Denver Water is pursuing the project to ensure they can meet future water demands along the Front Range. Enlarging the reservoir means that Denver Water would be able to divert more water out of the Williams Fork and Fraser River basins. Reducing flows on these two major tributaries to the Colorado River could possibly impact peak flows and late summer water temperatures downstream including the study area.

3.3 Hydrology

The hydrologic regime of the Upper Colorado River is dominated by snowmelt from higher elevations in the watershed. Certain climatic factors that control snowpack influence how the hydrologic regime behaves in any given year. Spring snow depth and water equivalent are fundamental factors, but so is air temperature which directly affects whether the precipitation falls as rain or snow and the timing of the snowmelt. This section will review both the important meteorological and resulting hydrologic regime characteristics.

3.3.1 Meteorological Characteristics

One of the more crucial factors to determining the water quantity available to the Colorado River in any year is the peak SWE in the watershed. Six SNOTEL sites within the Upper Colorado River watershed were analyzed for upward or downward trends in SWE and average air temperature during their period of record. All trends analyses in this study were determined by running regression analyses in R®. Standard regression diagnostics were performed to ensure adherence to the assumptions of linearity, homoscedasticity, and independent and normally distributed residuals. Statistically significant trends were defined as having a p-value <0.10. Overall, four of six sites showed a decreasing trend in SWE with two of these being statistically significant. Five of six sites showed an increasing trend in average air temperature and these were all statistically significant (Table 3.4 and Figures 3.11 through 3.22). Basing future projections of SWE and temperature on these periods of record is questionable; however, if these trends continue it could mean less overall water for the Colorado River and earlier peak flows which could possibly result in lower and warmer flows in late summer.

Table 3.4 – Results from the SWE and air temperature analyses. Significance was defined as p-value <0.10 and are highlighted in yellow. Regression X and Y units were date and either air temperature (°F) or SWE (inches), respectively.

	Air Temperature			SWE		
SNOTEL Sites	Period of Record	Regression Equation	p-value	Period of Record	Regression Equation	p-value
Berthoud Summit	1985-2013	0.00063x+8.09	1.817E-37	1978-2013	-0.00013x+11.98	2.16E-12
Willow Creek Pass	1986-2013	0.00033x+19.95	6.513E-11	1978-2013	0.000037x+8.09	0.0049
Middle Fork Camp	2001-2013	0.00033x+23.26	0.0653	2001-2013	-0.000057x+5.57	0.2235
Arapahoe Ridge	2002-2013	-0.00020x+40.27	0.3328	2002-2013	-0.00011x+12.90	0.3374
Hoosier Pass	1986-2013	0.00041x+16.36	1.1E-16	1980-2013	-0.0000097x+5.93	0.5388
Buffalo Park	1995-2013	0.00059x+10.62	5.436E-09	1995-2013	0.000033x+3.15	0.3220

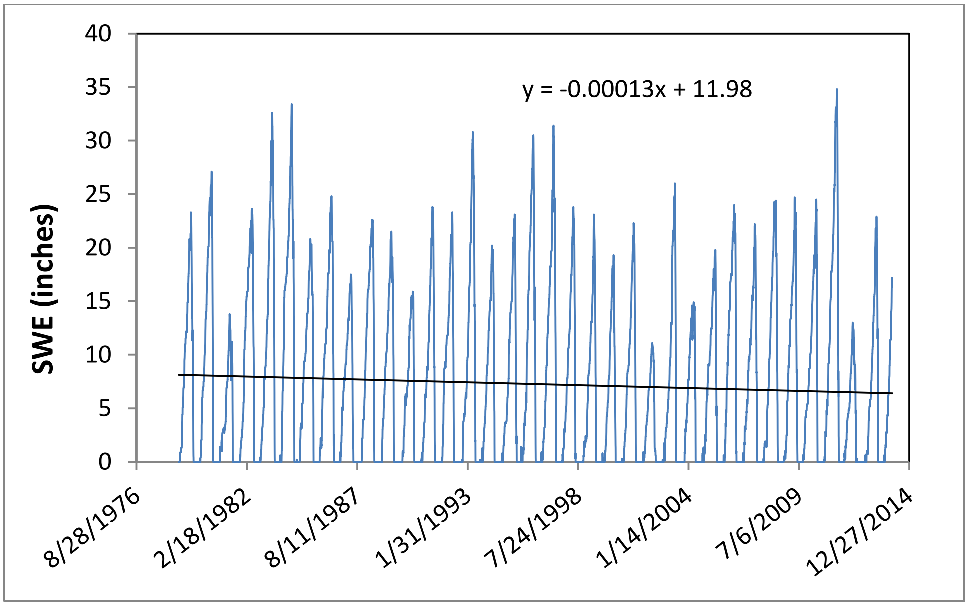


Figure 3.11 – SWE at the Berthoud Pass Summit SNOTEL site.

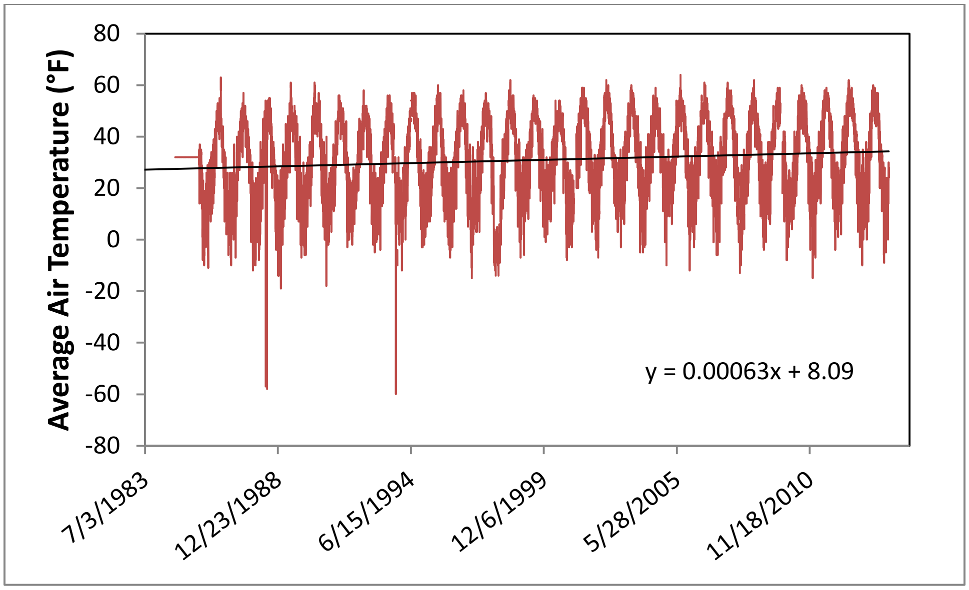


Figure 3.12 – Average air temperature at the Berthoud Pass Summit SNOTEL site.

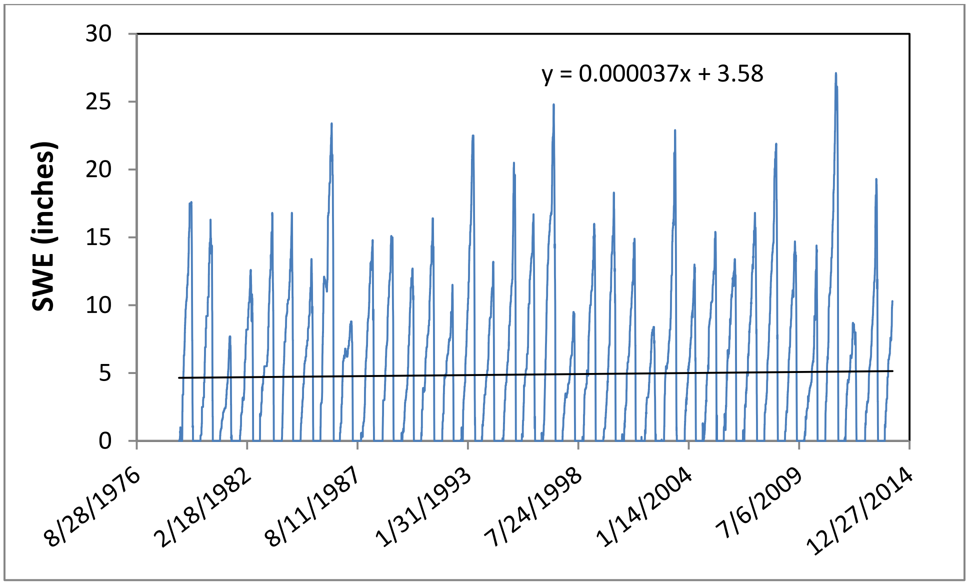


Figure 3.13 – SWE at the Willow Creek Pass SNOTEL site.

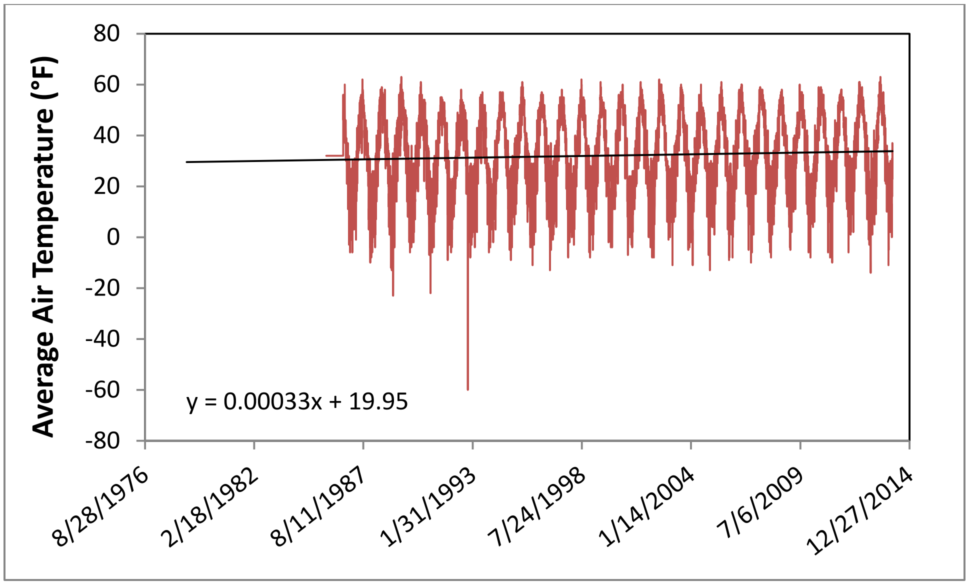


Figure 3.14 – Average air temperature at the Willow Creek Pass SNOTEL site.

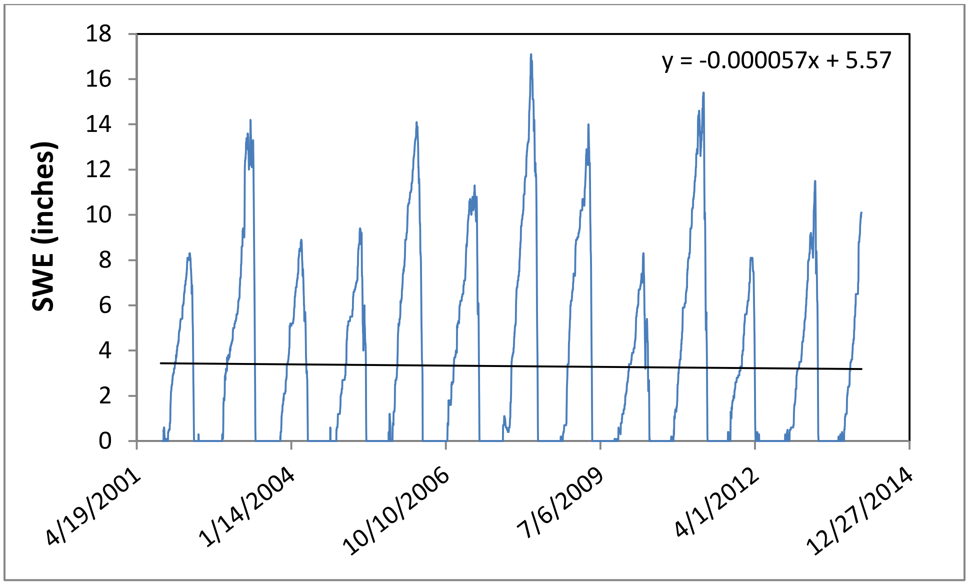


Figure 3.15 – SWE at the Middle Fork Camp SNOTEL site.

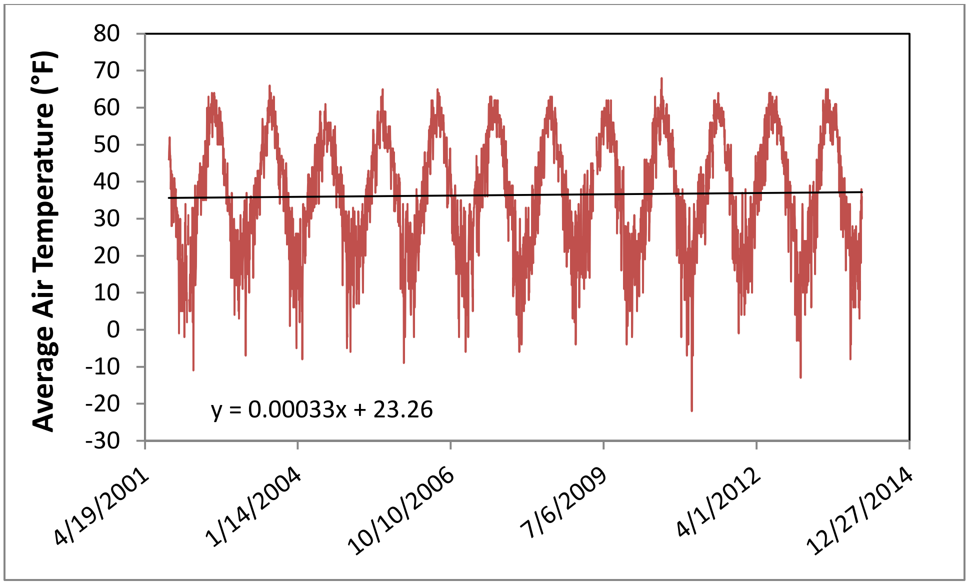


Figure 3.16 – Average air temperature at the Middle Fork Camp SNOTEL site.

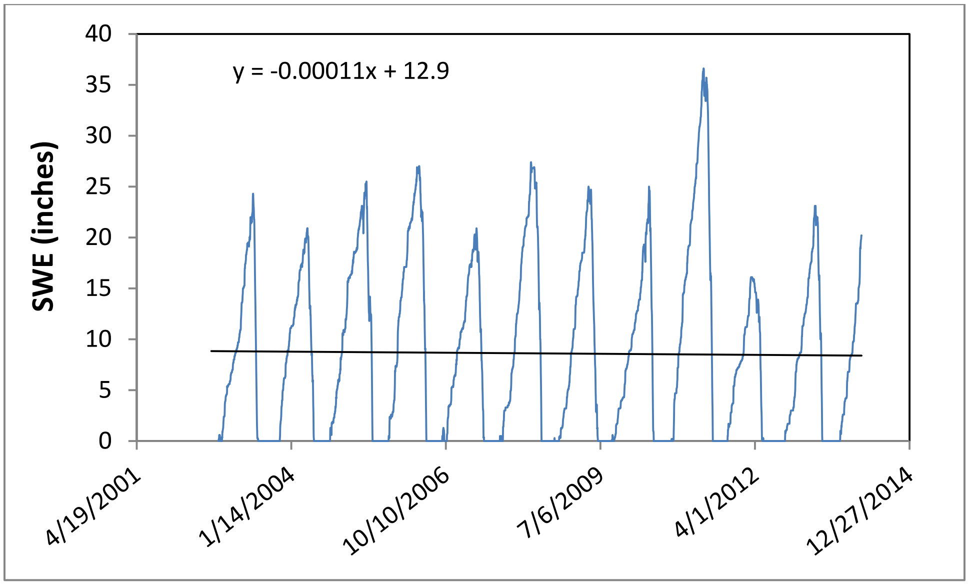


Figure 3.17 – SWE at the Arapahoe Ridge SNOTEL site.

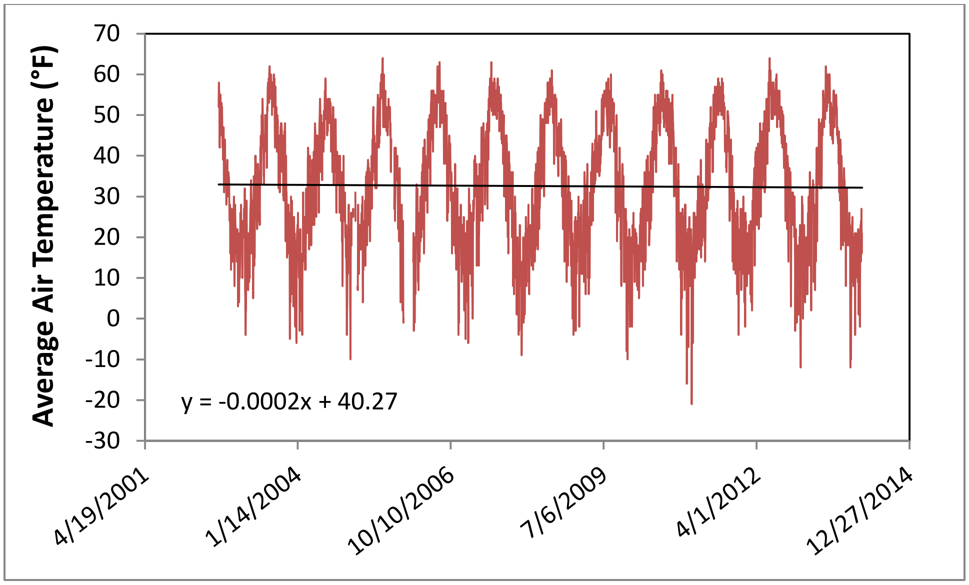


Figure 3.18 – Average air temperature at the Arapahoe Ridge SNOTEL site.

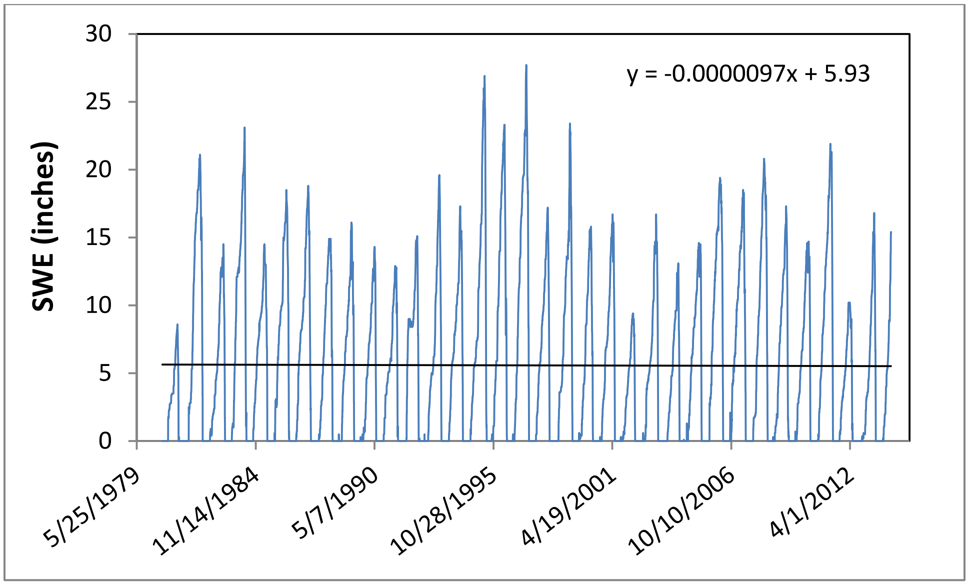


Figure 3.19 – SWE at the Hoosier Pass SNOTEL site.

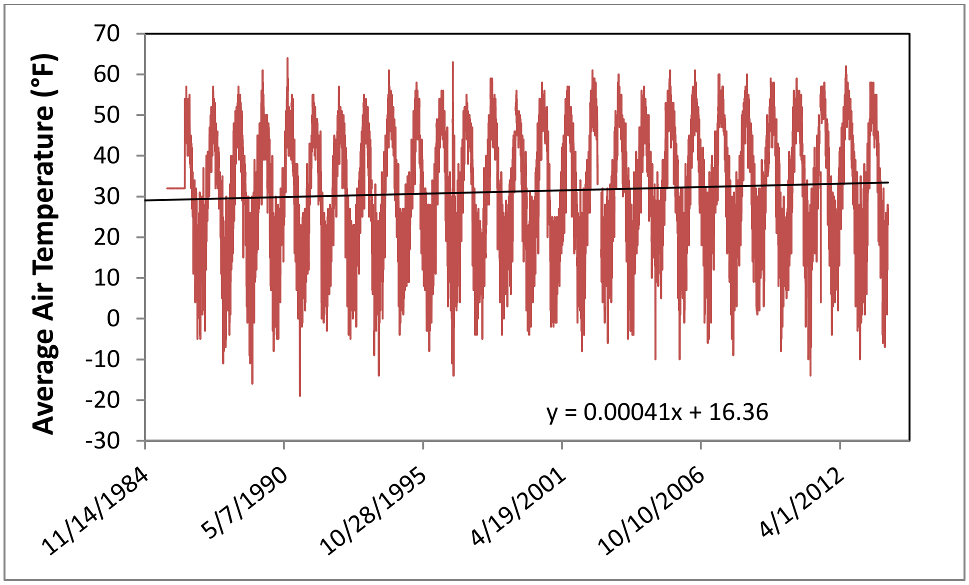


Figure 3.20 – Average air temperature at the Hoosier Pass SNOTEL site.

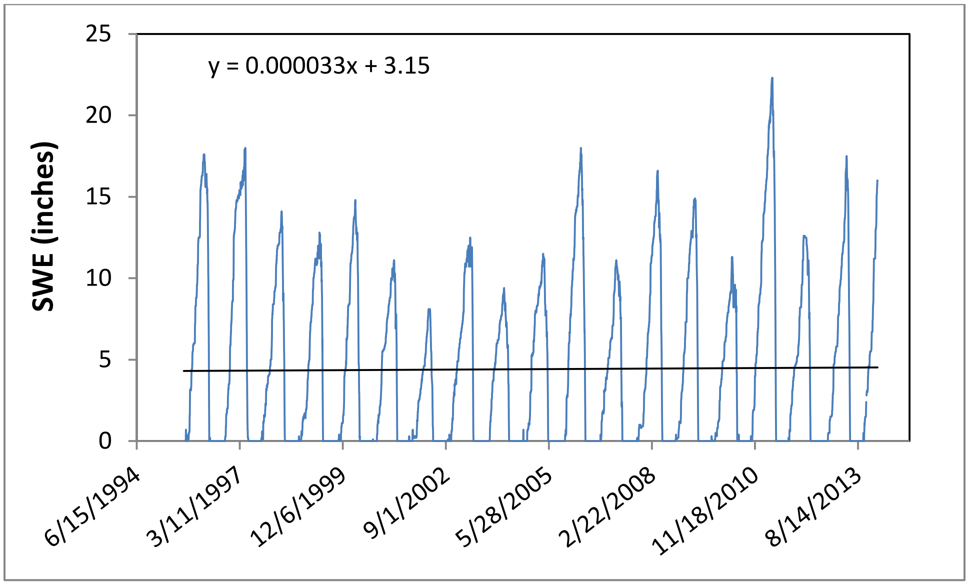


Figure 3.21 – SWE at the Buffalo Park SNOTEL site.

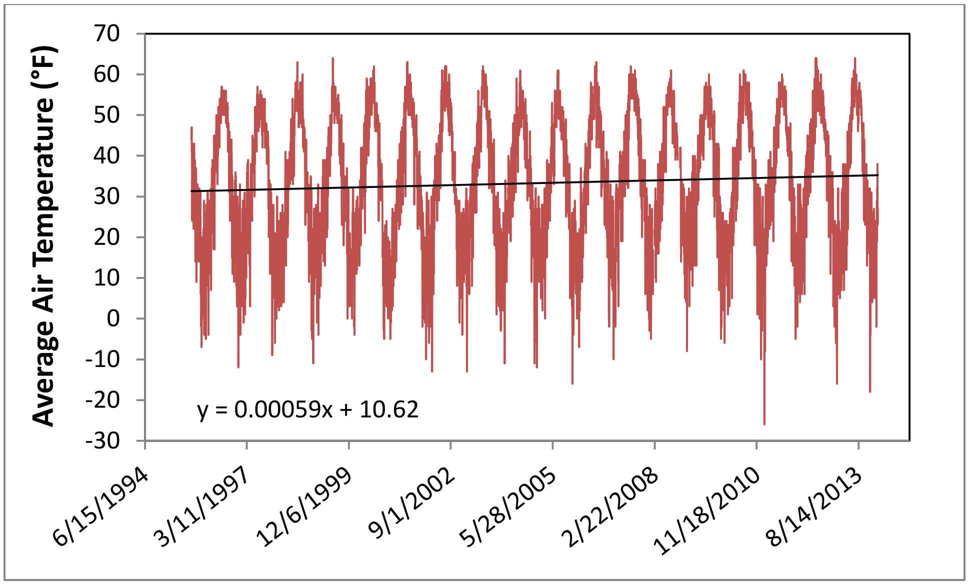


Figure 3.22 – Average air temperature at the Buffalo Park SNOTEL site.

3.3.2 *Flow Alteration*

Flow alterations within the Upper Colorado River began with the construction of the numerous diversion structures and reservoirs that are present today. The largest diversions exported water out of the watershed. Direct discharge measurements of these diversions were compared for the period between 1961 and 2011. Results indicate that the Moffat, Adams, and Roberts tunnel diversions exported 29% of the total yield at the Colorado River at Kremmling gage (USGS #09058000) (Figure 3.23). The majority of the water rights are diverted during spring runoff, effectively reducing annual peak flows.

The current flow regime within the study area during the post Windy Gap (1985-2013) period shows the annual average peak discharge at the Kremmling gage is approximately 2,240 cfs (Figure 3.24). The average annual peak flow (1985-2013) for the Colorado River above the confluence with the Eagle River is approximately 3,660 cfs. Tributaries within the study area on average (1985-2013) contribute up to 46% of flows during spring runoff, but tributary inputs decrease to a low of 16% during the summer months (Figure 3.25). Flow contribution from the Piney River, the largest tributary, peaks in spring runoff at 12% and decreases to an average of 2% in summer.

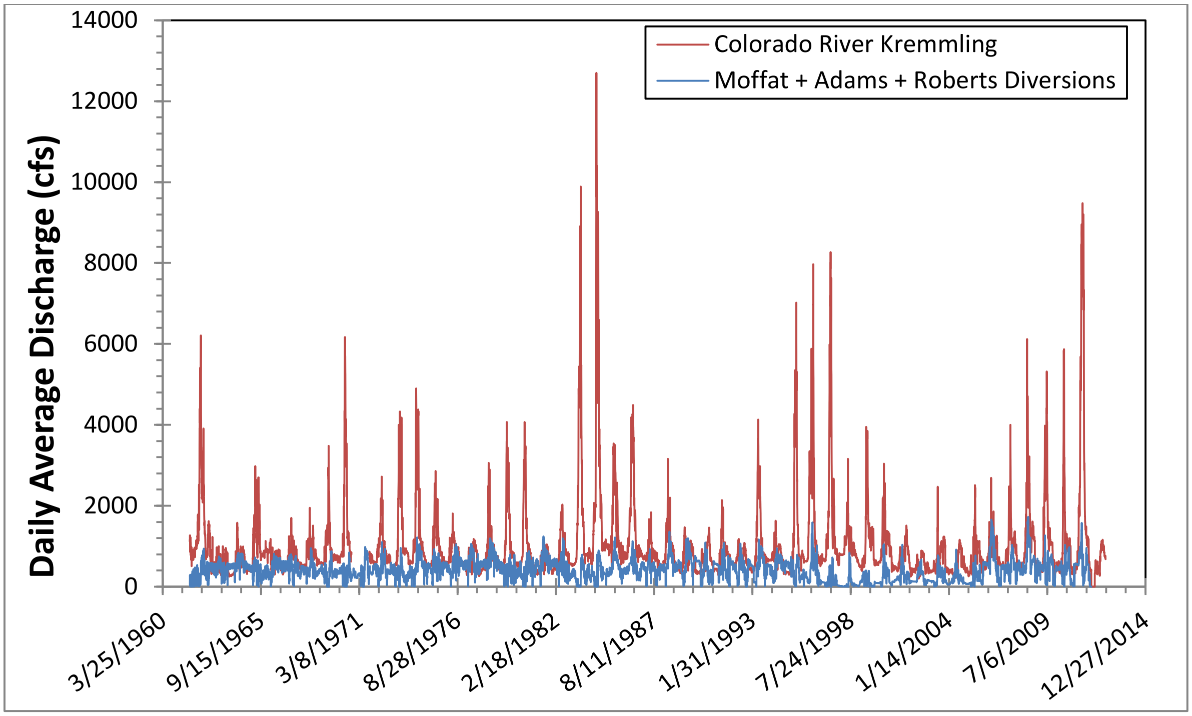


Figure 3.23 – Daily average discharge for the Colorado River at Kremmling and the Moffat, Adams, and Roberts tunnel diversions.

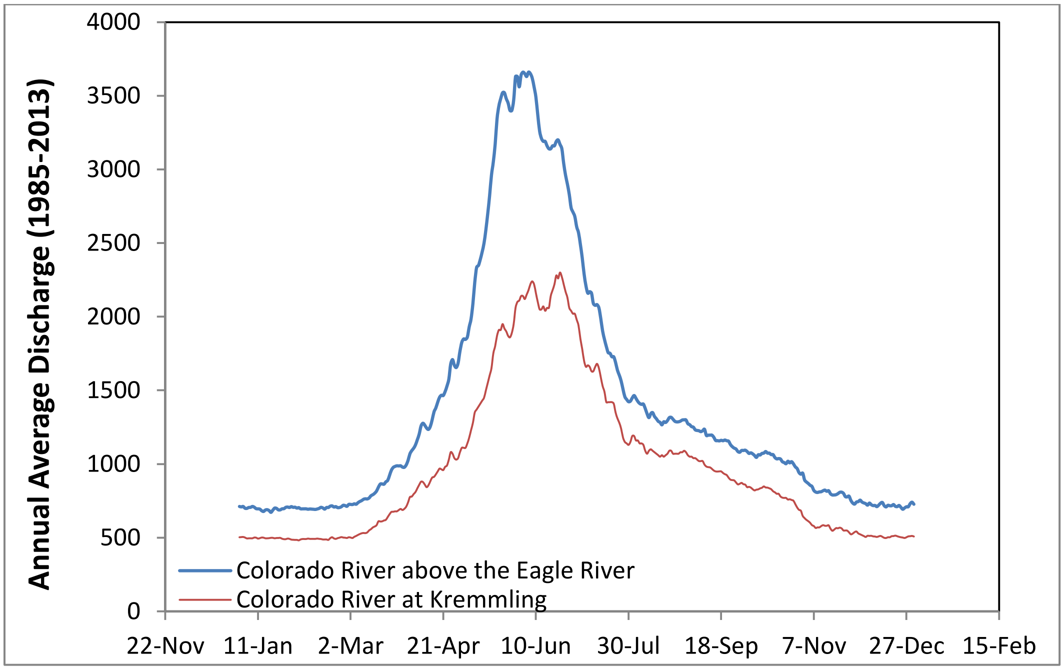


Figure 3.24 – Annual average discharge (1985-2013) for the Colorado River above the confluence with the Eagle River and at Kremmling.

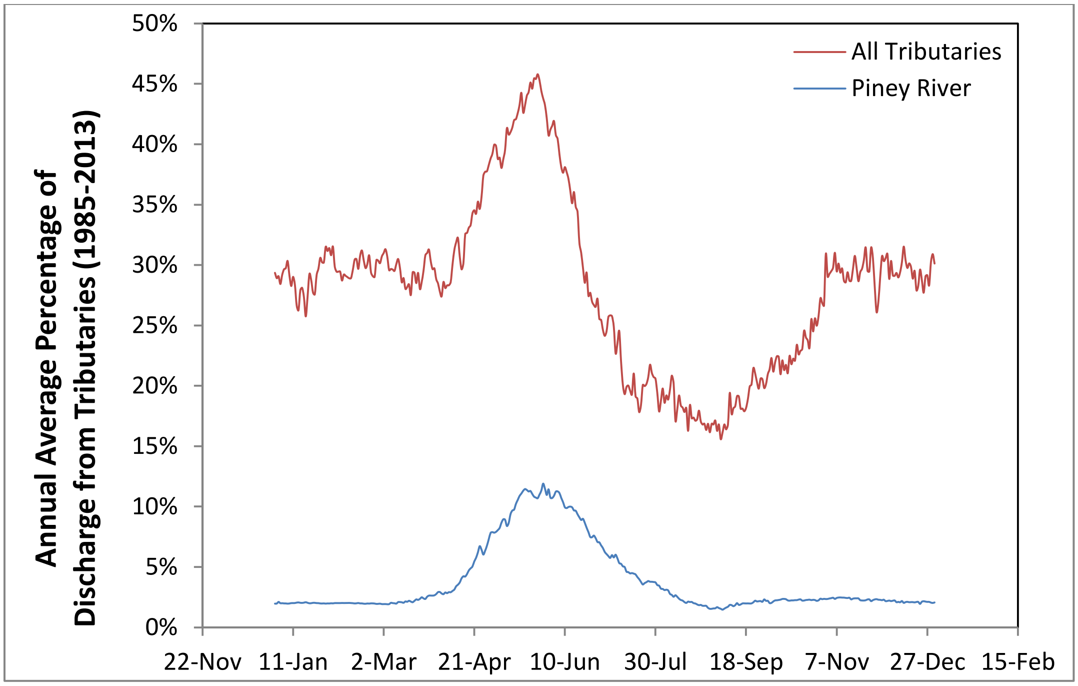


Figure 3.25 – Annual average percentage of discharge from tributaries (1985-2013).

Changes in streamflow characteristics (magnitude, frequency, duration, timing, rate of change) from pre- to post-development were analyzed using the Indicators of Hydrologic Alteration (IHA) program (Mathews and Richter, 2007). The Kremmling gage is located directly upstream of Gore Canyon and was used in the analysis. There is a stream gage directly downstream of the study area at Dotsero (USGS #09070500) below the confluence with Eagle River. However, only the Kremmling gage had data pre-existing the C-BT Project. The streamflow gage records at Kremmling date from 1904-1916 and from 1962-2013. The period from 1904-1916 was used in streamflow analyses performed in this study as an approximation of pre-diversion and reservoir flows on the Colorado River. Some diversions were already occurring during this time, including the transmountain Grand Ditch, but it pre-dates more major diversions and reservoirs occurring later. The period from 1962-2013 is representative of post-development flows in a period of evolving water operations and management.

The climate between 1905 and 1931 is characterized as a long wet period with brief dry periods in the early teens (McKee *et al*., 1999). When examining peak flows from the years 1905-1918, the maximum peak flow was 21,500 cfs in 1912 and the minimum peak flow was 6,690 cfs in 1908 (Table 3.5). The brief dry period in the early teens is most likely referencing the peak flow of 7,860 cfs in 1913. Although the peak flows may be slightly higher than average conditions due to the long wet period, a peak flow greater than the minimum peak flow of 6,690 cfs from 1905-1918 has only occurred six times between 1962-2013.

Table 3.5 – Peak streamflow for the Colorado River at Kremmling pre-alteration.

Date	Discharge (cfs)
6/4/1905	12,400
6/14/1906	11,800
7/2/1907	12,200
6/17/1908	6,690
6/20/1909	15,700
6/3/1910	7,920
6/9/1911	8,830
6/7/1912	21,500
6/1/1913	7,860
6/2/1914	16,400
6/21/1915	8,410
6/12/1916	81,002
6/19/1917	15,200
6/15/1918	16,800

3.3.3 Minimum Flows

The history of diversion on the Colorado River is extensive. The construction of major reservoirs within the watershed has increased minimum flows on the Colorado River. Reservoirs tend to increase base flows on a river due to the storage of water allowing for more flow to be released during what are normally low flow periods. The 1-day, 3-day, 7-day, 30-day, and 90-day minimum flows have all increased post-alteration by an average of 27% (Table 3.6). If the increase in minimum flows is occurring during the low-flow summer months it could help keep water temperatures below the critical threshold for trout. However, post-development median flows during July and August were 43% smaller than the wet pre-development period. Meanwhile, post-development median flows between October and March are 19% larger than pre-development. Therefore, increases in minimum flows due to reservoirs seem to be occurring primarily during the winter months.

Table 3.6 – Comparison of minimum flow metrics at the USGS Colorado River at Kremmling gage.

	Mean Daily Discharge (cfs)			
Flow Metric	**Pre-alteration**	**Post-alteration**	**Deviation Pre-post**	**Percent Change**
1-day minimum	300	391	91	30%
3-day minimum	321	395	74	23%
7-day minimum	338	416	78	23%
30-day minimum	360	454	94	26%
90-day minimum	379	510	132	35%

3.3.4 Maximum Flows

Maximum flows on the Colorado River have been substantially altered by transmountain diversions. Flow events with magnitudes and durations high enough to perform channel maintenance, flushing of the bed material, and inundation of the riparian area are essential to a river maintaining its ecological health (Poff *et al.*, 1997). The 1-day, 3-day, 7-day, 30-day, and 90-day maximum flows have all decreased post-alteration by an average of 74% (Table 3.7). This value is somewhat influenced by the wet period in the early 20th century, but would likely remain high under average conditions. The overall hydrograph from the two periods of record breaks flow into different environmental components including large floods (>17,900 cfs), small floods (>11,700 cfs), and high-flow pulses (>1,800 cfs) (Figure 3.26). Thresholds for identifying large floods, small floods, and high-flow pulses were defined using the default values in IHA (Mathews and Richter, 2007). During the pre-alteration period, 8 of 14 peak flow events were considered a small flood or larger and the remaining six were high-flow pulses. Applying the same thresholds to the post-alteration period indicates the occurrence of one small flood, 31 high-flow pulses, and 19 peak events below 1,800 cfs. Comparison of exceedance probabilities for all pre- and post-alteration flows indicates that flows with an exceedance probability greater than 57% (~700 cfs), post-alteration flows are on average 51% smaller than pre-alteration (Figure 3.27). This reduction in peak flows post-alteration becomes more apparent when comparing the exceedance probability of flows in June when the peak usually occurs. For all exceedance probability values in June, post-alteration flow values are on average 78% smaller than pre-alteration (Figure 3.28).

Table 3.7 – Comparison of maximum flow metrics at the USGS Colorado River at Kremmling gage.

Mean Daily Discharge (cfs)				
Flow Metric	**Pre-diversion**	**Post-diversion**	**Deviation Pre-post**	**Percent Change**
1-day maximum	11,600	2,980	8,620	-74%
3-day maximum	11,400	2,777	8,623	-76%
7-day maximum	10,740	2,516	8,224	-77%
30-day maximum	7,591	1,909	5,682	-75%
90-day maximum	4,651	1,558	3,093	-67%

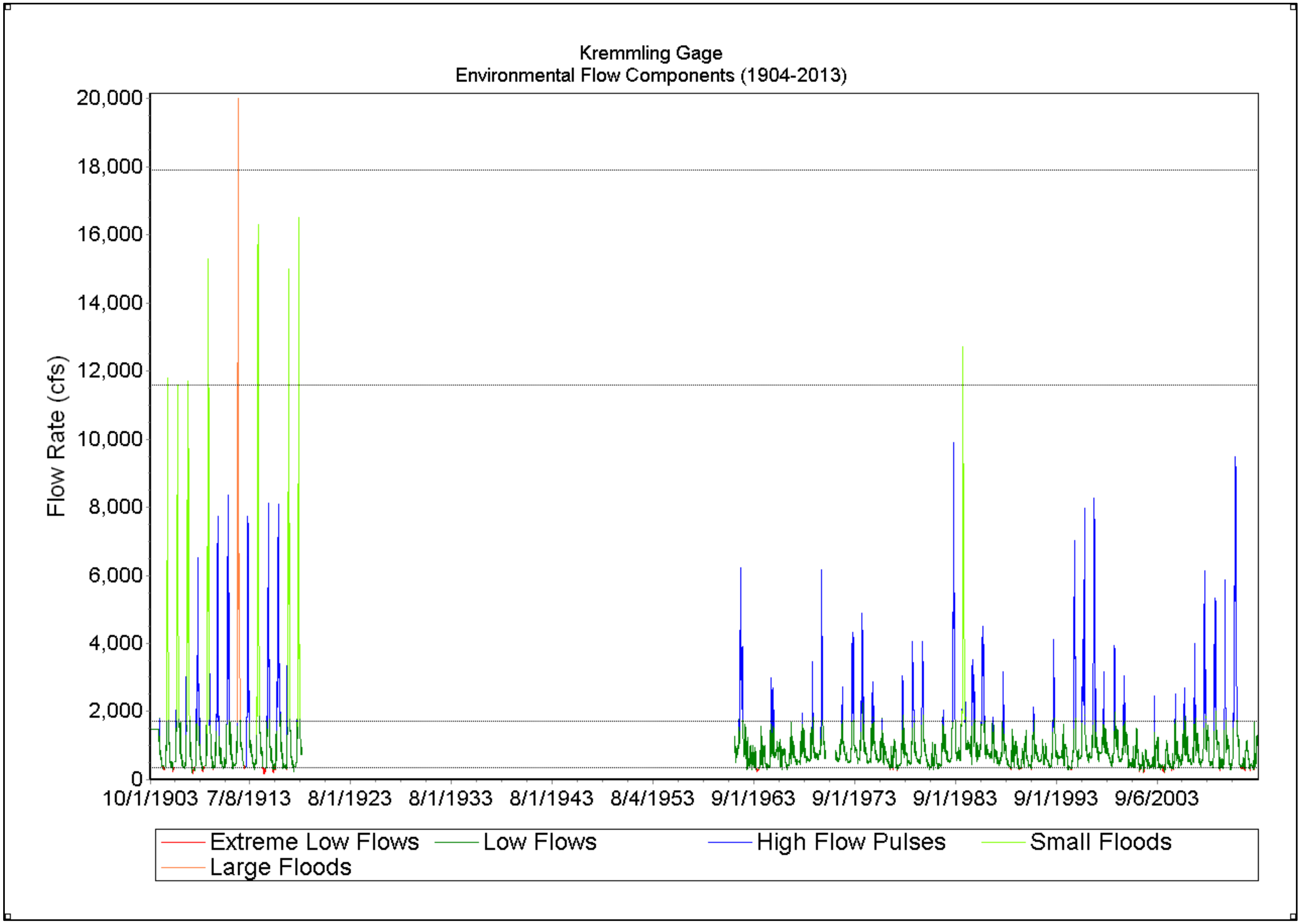


Figure 3.26 – Hydrograph for the USGS gage on the Colorado River at Kremmling broken down into different environmental flow components.

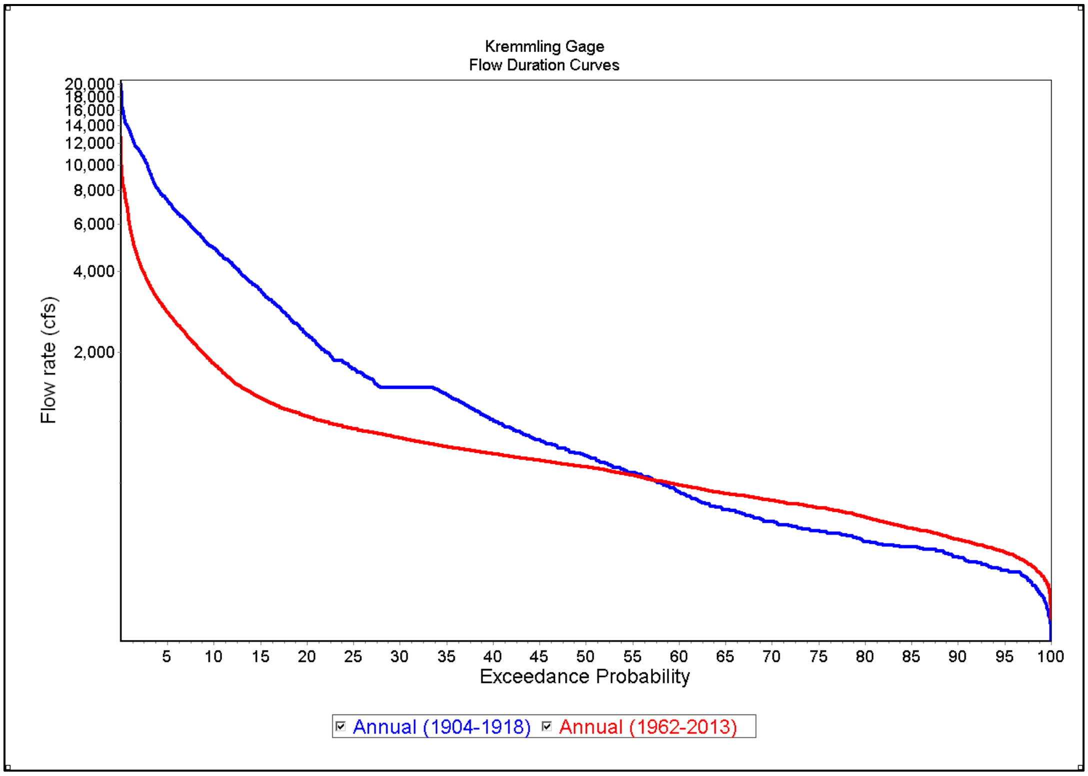


Figure 3.27 – Comparison of exceedance probability for all flows pre- and post-alteration.

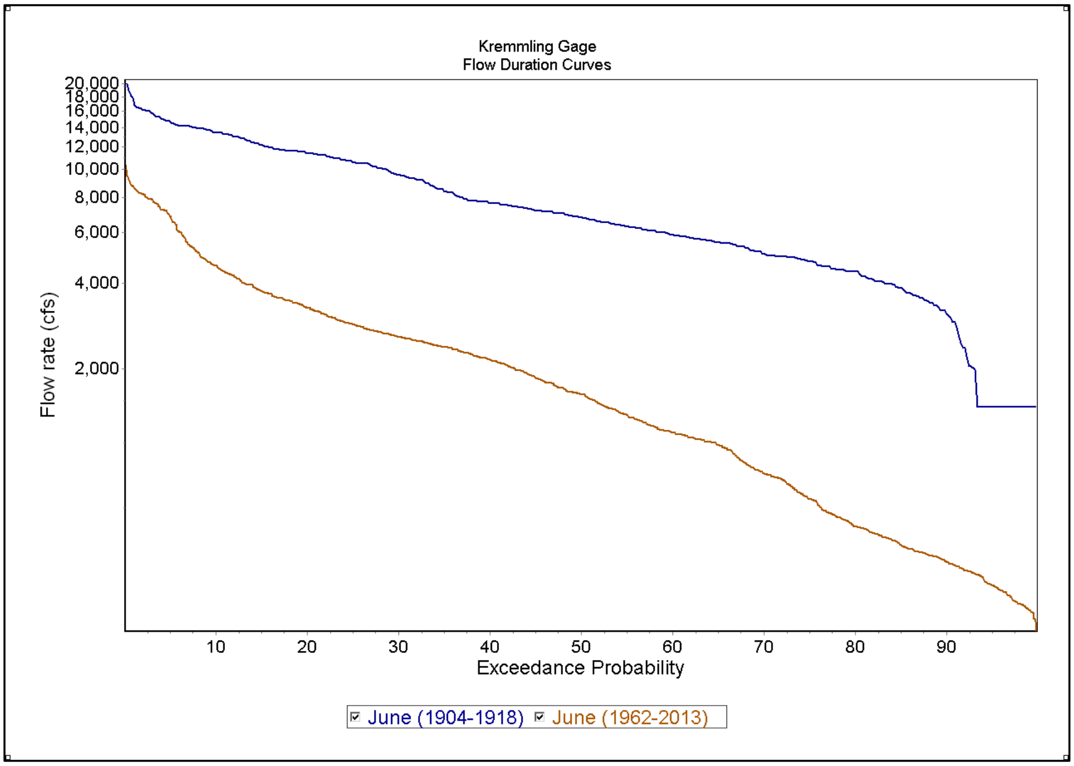


Figure 3.28 – Comparison of exceedance probability for June flows pre- and post-alteration.

The durations of these peak flow events have also decreased substantially. The median duration of the pre-alteration peak flows remaining above 1,800 cfs was 91 days. The median duration of post-alteration peak flows remaining above 1,800 cfs is 12 days. The timing of the peak flow event has also shifted. Pre-alteration, the average peak flow occurred on June 13. Post-alteration the average peak flow occurs on June 2. Earlier timing of peak flows may exacerbate higher water temperatures during the low-flow months of summer. Reductions in post-alteration peak flow magnitude and duration may be reducing the frequency of environmental flows that perform channel maintenance, bed material flushing, and promote riparian vigor in order to maintain the ecological health of the river corridor.

3.4 Aerial Photograph Analysis

The river corridor has been shaped through time by the erosion and depositional processes of water as it moves through the land. An examination of fluvial forms and processes is necessary to understand the impacts of land use changes, flow regime alterations, and physical habitat characteristics. A review of relevant geomorphic characteristics of the river corridor on a reach-by-reach basis follows.

In general, the river throughout the study area is mostly confined by steep-sided hillslopes and canyon. Changes in channel morphology through time become harder to discern in confined valleys as the channel does not have the usual room to move across its floodplain. One aspect of a channel in a confined valley that can possibly change through time is the formation and adjustment of islands. Two sets of aerial photographs from October 22, 1938 were compared to Google Earth® images from August 31, 2011.The two sets of photographs are of the river above and below the bridge and campsite at Radium (Figure 3.29 and Figure 3.30). It does not appear that the channel width or shape has drastically changed since 1938 in any of the photographs. However, the most noticeable adjustment has been vegetation establishment on the islands and channel margins. In the 1938 photographs, the islands and some channel margins appear to be mostly unvegetated, possibly indicating there were enough frequent disturbances (scouring and/or extended inundation) by higher flows preclude vegetation establishment. The encroachment of vegetation since 1938 may indicate flows are no longer disturbing these areas frequently enough to prevent vegetation establishment. It is important to note that there was some diversions pre-1938. However, construction did not begin on the C-BT Project until 1938 and water was not stored in reservoirs or diverted until the 1940s.

(a) (b)

Figure 3.29 – Aerial photographs: (a) from August 31, 2011 and (b) October 22, 1938 of the Radium Bridge and campsite. The islands and channel margins seems to have become densely vegetated over time.

(a) (b)

Figure 3.30 – Aerial photographs: (a) from August 31, 2011 and (b) October 22, 1938 of directly downstream of the Radium campsite. The red arrows indicate where material deposited by a gully has become vegetated through time.

3.5 Riparian Analysis

Field-based analysis of the riparian corridor was conducted between September 26 and October 2, 2012 and from October 1 to October 4, 2013 while floating the river through the study area. Every instance of accelerated bank erosion or failure, riparian buffer encroachment, or sparsely to unvegetated riprap was documented with photographs and GPS. Sites where riprap banks had vegetation established were not designated as potential restoration sites due to the low feasibility of either eliminating or reducing encroachment by the road or railroad. Russian olive (*Elaeangnus angustifolia*) was also noted but was not a focus of the analysis as Russian olive was widespread from Two Bridges to Dotsero (~35 mi) making eradication possibly unfeasible. Tamarisk (*Tamarix aphylla*) was documented with GPS; however, the resulting estimates of impacted bank lengths do not represent dense stands as tamarisk was not observed to be continuously established along any banks. Rather, individual plants were spotted either infrequently. Type and magnitude of impact, along with a quantitative analysis of impacted bank length was conducted within Google Earth® and have been provided as a supplement to this report. Access, feasibility, and specific notes on individual sites are also incorporated into the Google Earth® product. Results show that the largest impact to the riparian area is encroachment from hay fields which tend to have a narrow riparian buffer dominated by upland plants species such as reed canarygrass (*Phalaris arundinacea*) (Table 3.8). Overall, the estimated percentage of impacted riparian area is low at 8%. Most of the riparian impacts stem from human activities on private land. In general, the impacts from these riparian encroachments appear minimal and rehabilitation efforts in these areas, although desirable, provide limited local ecological benefits compared to system wide management efforts (e.g., environmental flows).

Table 3.8 – Impacted riparian area analysis results within the study area.

Total River Left Bank Length (mi)	Total River Right Bank Length (mi)
62.02	62.62

Type of Impact	Impacted River Left Bank Length (mi)	Impacted River Right Bank Length (mi)	Left Bank (%)	Right Bank (%)	Total Impacted Bank (%)
Hay Field Encroachment	0.64	3.52	1.0%	5.6%	**3.3%**
Unvegetated or Sparsely Vegetated Riprap	0.38	1.36	0.6%	2.2%	**1.4%**
Mowing Encroachment	0.37	0.29	0.6%	0.5%	**0.5%**
Grazing Encroachment	0.42	0.00	0.7%	0.0%	**0.3%**
Bank Erosion	0.70	0.00	1.1%	0.0%	**0.6%**
Total Affected Bank Length:	**2.5**	**5.2**	**4.0%**	**8.3%**	**6.2%**

3.6 Physical Subreach Descriptions

Detailed descriptions of physical habitat, morphology, substrate, and riparian condition in nine reaches of the Colorado River through the study area follow (Figure 3.31). Observations were made during two float trips through the study area between September 26 – October 1, 2012 and October 1 – 4, 2013. Flows during the trips averaged approximately 740 cfs and 730 cfs, respectively. Presented bed material data including median grain diameter (d_{50}), embeddedness, and percent fines, algae, and coarse material are averages from two samplings occurring November 27 – December 14, 2012 and July 3, 2013. Detailed sampling methods are provided in Section 3.10. Slope values presented from Miller and Swaim (2011) were taken from topographic maps and only provide an overall indication of valley slope that does not accurately represent reach scale variations in bedslope and water surface slope.

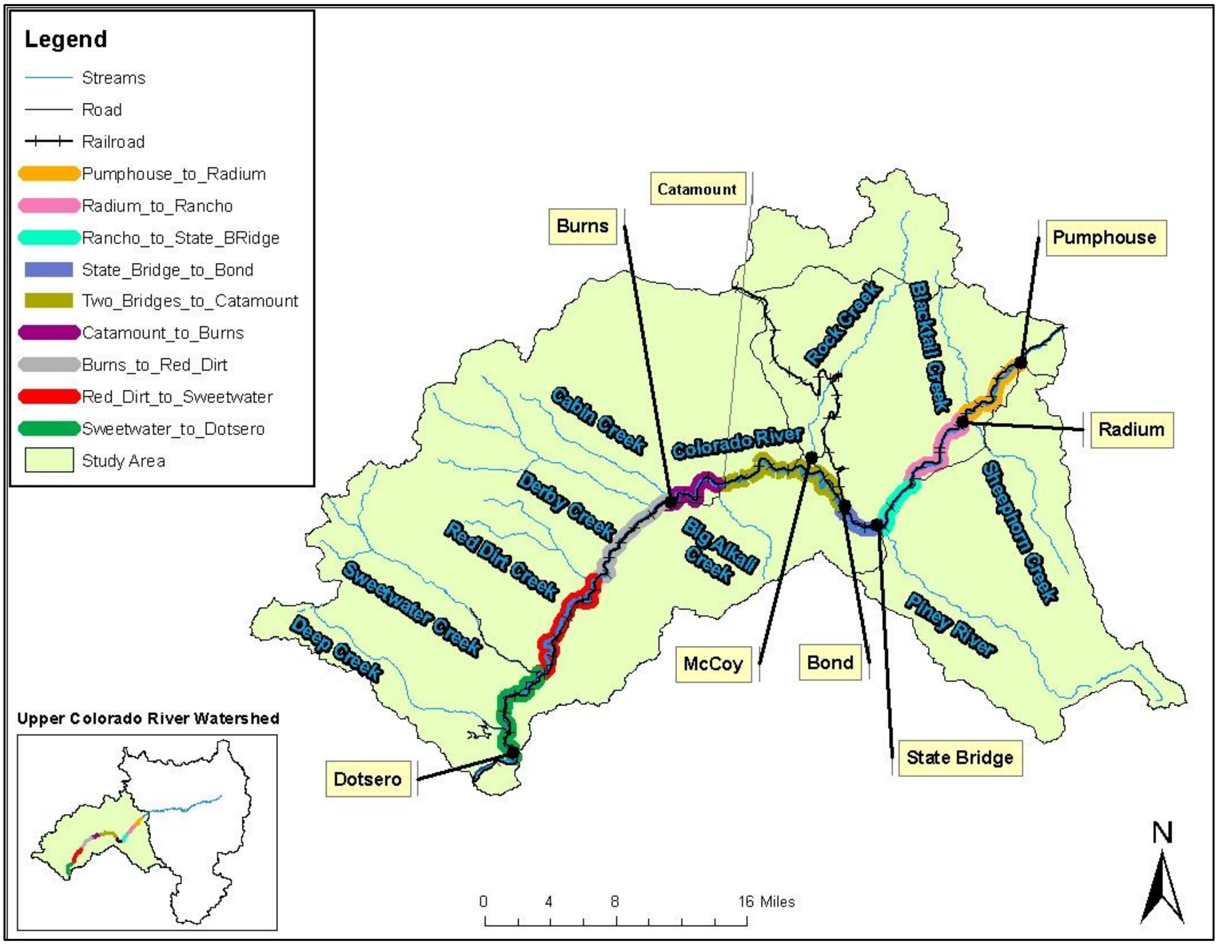


Figure 3.31 – Location map of the nine reaches used to summarize physical habitat, morphology, substrate, and riparian characteristics.

3.6.1 Pumphouse to Radium (River Miles 0.0 – 5.9)

Downstream from Pumphouse, the river winds its way through a wider but still confined floodplain (Figure 3.32). The sinuosity of the reach was 1.17. Willows lined the banks along with a few pines. Sagebrush was dominant in the sparsely vegetated upland. Some older narrowleaf cottonwoods were present along the floodplain but no regeneration appeared to be occurring.

Figure 3.32 – Looking upstream at the Pumphouse section before it enters Little Gore Canyon.

The substrate at Pumphouse consisted of large boulders and cobbles transported from Gore Canyon and deposited on the flatter valley floor as a result of decreasing stream power. The average d_{50} of a single transect sampled at Pumphouse was 118 mm. Fine gravel and sand were abundant around the larger bed material throughout the reach. The average embeddedness was 30% and the average percent fines, algae, and coarse material were 6%, 62%, and 31%, respectively.

Little Gore Canyon is a narrow, steep canyon formed in gneiss, schist, and granite rock with the railroad track located directly adjacent to the river. Willows were established on the lower riprap banks of the railroad track. Blacktail Creek joins the Colorado River at the bottom of Little Gore Canyon (Figure 3.33). A small confluence bar consisting mostly of cobble and gravel had formed at the mouth of Blacktail Creek. An active beaver dam was located upstream from the mouth.

Figure 3.33 – The mouth of Blacktail Creek before it enters the Colorado River.

Below Blacktail Creek is Cottonwood Campground. Multiple age classes of narrowleaf cottonwoods were present throughout the campground (Figure 3.34). Sheephorn Creek merges with the Colorado River just upstream of Radium (Figure 3.35). The debris fan at the mouth of Sheephorn Creek consisted mostly of cobbles deeply embedded with clay and silt.

Figure 3.34 – Narrowleaf cottonwood regeneration is occurring at Cottonwood Campground.

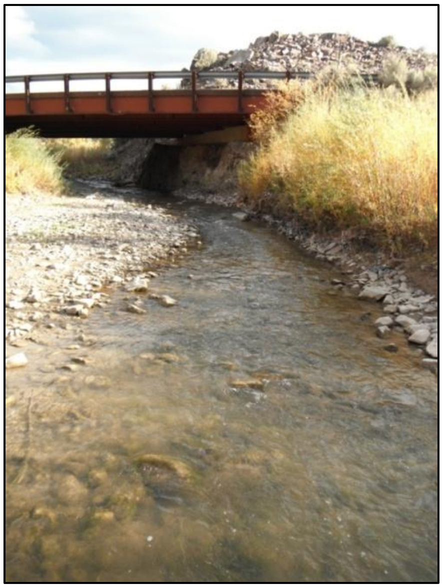


Figure 3.35 – Sheephorn Creek directly upstream from its junction with the Colorado River.

At Radium the valley opens up and a small settlement is located on the right side of the river. A developed campground is located on the left. The observed riparian vegetation consisted of dense willow, some upland grasses, and scattered pines. The river substrate at Radium was made up of some larger boulders, but mostly cobble and gravel. Sand and fines were present around larger bed material and along the channel margins. The average d_{50} of a single transect sampled at River Mile 7.2 was 67 mm and the average embeddedness was 35%. Average percent fines, algae, and coarse material were 20%, 45%, and 36%, respectively.

From Gore Canyon to Radium, the aquatic habitat was characterized as 27% riffle, 50% run, and 22% island (Miller and Swaim, 2011). Run habitat was most prevalent in Gore and Little Gore Canyons but also dominant outside of the canyon sections. Five islands in this section were all densely vegetated with willows. Shoals created by the islands formed riffle-like habitat. The sinuosity of the reach was 1.19.

3.6.2 Radium to Rancho Del Rio (River Miles 5.9 – 11.9)

Downstream from Radium, a hay field was mowed almost to the tops of banks leaving only a narrow ~5 ft riparian strip along 0.6 mi of river bank (Figure 3.36). From here, the river enters the Red Gorge, a narrow and steep-sided granite canyon (Figure 3.37). At the downstream end of the gorge, the bed material noticeably fined from cobble to gravel and sand. Deposition of fines in back eddies became more prominent (Figure 3.38). Closer to Rancho Del Rio the river was dominated by glide habitat. The bed material at Rancho Del Rio consisted of gravels, sand, and fines with a few cobbles (Figure 3.39). The geologic history of the area indicated that multiple large landslides created a debris fan of glacial alluvium in the area. This may help explain the flatter bedslope and smaller bed material. Unvegetated sand bars were also present, indicating a depositional area. Rancho Del Rio is located on river left (Figure 3.40).

Riparian vegetation along the reach was dominated by willows and upland grasses with pine and sagebrush dominating the uplands. The railroad follows river right throughout most of the reach. Sinuosity of the reach was 1.17. Aquatic habitat was characterized as 31% riffle, 42% run, and 27% island (Miller and Swaim, 2011). Glide habitat also occurred, especially around Ranch Del Rio. Willows dominated the 19 well-vegetated islands present in the section. Shoals created by the islands formed riffle-like habitat.

Figure 3.36 – A hay field downstream of Radium was observed leaving a very narrow (~5 ft) riparian buffer.

Figure 3.37 – Looking downstream at Radium with the Red Gorge in the distance.

Figure 3.38 – Sand deposition in back eddy areas is more prominent directly downstream of Red Gorge.

Figure 3.39 – Bed material at Rancho Del Rio primarily consisted of medium to fine gravel, sand, and fines.

Figure 3.40 – Ranch Del Rio looking downstream.

3.6.3 Rancho Del Rio to State Bridge (River Miles 11.9 – 15.9)

Glide habitat with a depositional sand bed dominated from Rancho Del Rio downstream to the Colorado River Trough Road Bridge. Below the bridge, the bed material coarsened again. The river alternated between flat glides and plane-bed morphology in this location. The road and railroad both parallel the river on river right through most of the reach (Figure 3.41). Closer to State Bridge, the river steepens and exhibits some pool/riffle sequencing. The Piney River enters the Colorado River just upstream of State Bridge. A large confluence bar at the mouth of the Piney River consisted mostly of cobbles, gravel, and sand (Figure 3.42). The sinuosity of the reach was 1.16.

Figure 3.41 – Looking downstream at a section of the Colorado River above State Bridge.

Figure 3.42 – Looking upstream at the mouth of the Piney River. A large confluence bar has formed.

The riparian vegetation through the reach primarily consisted of dense willows and upland grasses. Pines and sagebrush dominated the upland area. The railroad tracks encroach on the riparian area in a few locations but overall a moderate buffer >50 ft was intact. Some willows had established along the toe of riprap banks below the train tracks along the railroad but the vegetation was sparse. Willows were dominant on the eight well-vegetated islands within this section.

3.6.4 State Bridge to Bond (River Miles 15.9 – 19.1)

Directly downstream from State Bridge the valley narrows as the river enters a sandstone canyon. The railroad is directly adjacent to the river most of the way to Bond (Figure 3.43). A few willows had established along the toe of riprap banks below the train tracks but ~1 mi remained unvegetated (Figure 3.44). Riparian areas not encroached by the railroad had dense willows, narrowleaf cottonwoods, and upland grasses. Narrowleaf cottonwood regeneration was occurring along the campsites at Windy Point. Bed material in the riffles appeared armored and proliferations of long filamentous green algae were evident. Plane-bed morphology dominated the reach but there was an occasional pool/riffle sequence. The sinuosity was the lowest of all sections of the reach at 1.05.

Figure 3.43 – Looking downstream above Bond. The train closely parallels the river throughout most of this reach.

Figure 3.44 – Some willows have established on the riprap banks along the train tracks.

3.6.5 Two Bridges to Catamount (River Miles 19.1 – 31.1)

In the wider river valley below Bond, hay fields became more prominent in the floodplain (Figure 3.45). Most of the hay fields had a small riparian buffer <50 ft that could be widened to increase benefits to the river. There was evidence that some private landowners mow to the top of bank, and in some instances, the edge of water in this reach (Figure 3.46). There were isolated patches of regenerating narrowleaf cottonwoods (Figure 3.47). A few mature plains cottonwoods were spotted above and below Catamount but no regeneration was occurring. Most of the riparian vegetation consisted of dense willow, narrowleaf cottonwoods, and upland grasses. Pine and sagebrush dominated the sparsely vegetated upland. Dense willows covered 22 well-vegetated islands within the section. Approximately 1.5 mi downstream of Bond was the most upstream location where Russian olive was observed. Tamarisk was spotted ~3.8 mi upstream of Catamount, but only along banks along the railroad corridor.

Figure 3.45 – Hay fields along the Colorado River downstream of Bond.

Figure 3.46 – Private land mowed right to the river banks.

Figure 3.47 – Multiple age classes of narrowleaf cottonwoods are present along this reach.

A noticeable transition in the geologic setting occurs between Two Bridges and Catamount. Relatively frequent gullies and washes were delivering sand and fines to the river. Bank failures were present in some bends along the reach. Lateral migration into a terrace had caused some banks to begin to fail (Figure 3.48). The sinuosity was the second highest at 1.42.

Figure 3.48 – Bank failures were present in some bends along the reach.

Glide habitat was prevalent in the upper half of the section with an occasional riffle or run. Islands tended to be large and densely vegetated. Shoals created on island margins create riffle-like habitat. Boulders and cobbles in most of the riffles were embedded with sand and fines (Figure 3.49). Green filamentous algae were also abundant. Closer to Catamount the bedslope steepened and more run and pool/riffle habitat was present.

Figure 3.49 – Boulder and cobbles in the reach were embedded with fine gravel, sand, and fines.

Substrate sampling was performed on a riffle approximately 3 mi upstream from Catamount. The average d_{50} of a single transect sampled at River Mile 27.4 was 91 mm and the average embeddedness was 35%. Average percent fines, algae, and coarse material were 5%, 70%, and 25%, respectively.

Rock Creek joins the Colorado River below Two Bridges (Figure 3.50). A large active beaver dam was present just upstream from the confluence. A small debris fan formed at the river mouth consisted of cobbles and gravel but mostly fines over 3-ft deep.

Figure 3.50 – Rock Creek entering the Colorado River from the left.

3.6.6 Catamount to Burns (River Miles 31.1 – 35.5)

Big Alkali Creek enters the Colorado River at Catamount. The tributary debris fan consisted of large boulders, cobble, and gravel all heavily embedded with fines (Figure 3.51). Downstream from Catamount, the river valley narrows and steepens. The morphology of the river was mostly plane-bed and run habitat was prevalent (Figure 3.52). No islands were present and the sinuosity of the reach was the highest at 1.50. Bed material of runs and riffles observed in this section was composed of armored boulders and cobbles. The substrate was moderately embedded with sand and proliferations of green filamentous algae were also abundant.

Figure 3.51 – The turbid waters of Big Alkali Creek trickle into the Colorado River on river right.

Figure 3.52 – Most of the Catamount to Burns reach was characterized as run habitat.

The railroad closely parallels the river through most of this reach. The riparian zone along the railroad tracks was <50 ft in most areas and was dominated by willows and upland grasses. Narrowleaf cottonwood regeneration was occurring in riparian areas not encroached upon by the railroad. Pine and sagebrush dominated the upland vegetation with some cottonwoods established in narrow ravines on the surrounding hillslopes. Overall, the riparian area vegetation was dense, had multiple age classes, and was displaying good vigor.

3.6.7 Burns to Red Dirt Creek (River Miles 35.5 – 43.8)

Directly downstream from Burns, Cabin Creek joins the Colorado River. An active beaver dam was present on Cabin Creek just upstream from the confluence. A debris fan had formed at the mouth of Cabin Creek and the substrate consisted of mostly cobble and gravel moderately embedded with fines (Figure 3.53). Downstream from Cabin Creek a long glide section was created by the natural downstream grade control at Rodeo Rapids (Figure 3.54). River otter were spotted alongside their lodge just upstream from Rodeo Rapids.

Figure 3.53 – Confluence bar at the mouth of Cabin Creek where it joins the Colorado River from the right.

Figure 3.54 – Glide habitat created by the natural grade control at Rodeo Rapids.

The confluence with Derby Creek is located just below Rodeo Rapids. A large debris fan was present at the mouth of Derby Creek (Figure 3.55). The debris fan deposits consisted mostly of cobble and gravel with some sand and fines. Downstream from Derby Creek, the river valley remains narrow and confined. The aquatic habitat between Derby Creek and Pinball Point alternated between long persistent glides and runs with occasional riffles. Large sand bars were present in back eddies just upstream of Pinball Point (Figure 3.56). The surrounding hillslopes were predominately steep and sparsely vegetated. Erodible sandstone and siltstone on the hillslopes were becoming rilled and gullied and directly delivering fine material to the river (Figure 3.57). The influx of sediment continued down through Pinball Point as debris fans formed at multiple gullies and washes along the river (Figure 3.58).

Figure 3.55 – A large debris fan is present at the mouth of Derby Creek where it joins the Colorado River on river left.

Figure 3.56 – Large sand bars deposited in back eddies became more prevalent in the lower half of the reach.

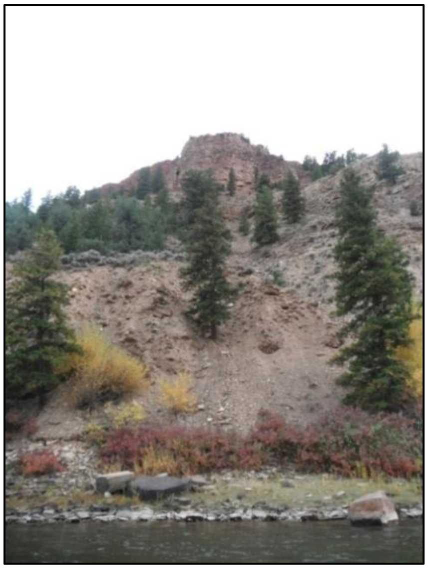


Figure 3.57 – Typical surrounding hillslope in the reach. The highly erodible faces are delivering sediment directly to the river.

Figure 3.58 – One of many debris fans formed at the mouth of a gully. The debris fan deposits consisted of cobble, gravel, and abundant sand.

Downstream of Pinball Point the valley steepens and remains confined by steep-sided hillslopes. The observed morphology was plane-bed dominated by one long run. The sinuosity of the reach was 1.14. No islands were present from Pinball Point to Red Dirt Creek. Bed material in the runs mainly consisted of cobbles and gravel embedded with sand and fines. The riparian corridor was narrow and vegetation consisted of multiple age classes of willows, narrowleaf cottonwoods, sedges, and upland grasses. The upland was dominated by sagebrush and pine. Despite encroachment from the railroad, the riparian vegetation displayed good vigor on both sides of the river.

3.6.8 Red Dirt Creek to Sweetwater Creek (River Miles 43.8 – 53.1)

A large debris fan formed where Red Dirt Creek joins the Colorado River consisted of boulder, cobbles, and gravel, all heavily embedded by sand (Figure 3.59). The finer material was over 2-ft deep in some locations. This red sand was observed in embedded coarse substrates for 1.5 mi below Red Dirt Creek.

Figure 3.59 – Looking downstream at the Colorado River over the debris fan formed at the confluence with Red Dirt Creek.

The valley widens downstream of Red Dirt Creek and opens up the floodplain for ranching and private homes. Some private homes had their lawns mowed directly the river edge (Figure 3.60). Most of the mowed banks were undercut and failing. Two landowners have placed riprap along their banks to stop the erosion. Ranches further downstream also had riparian buffers <50 ft if any at all (Figure 3.61). Where there was vegetation along the banks, it was predominantly upland grasses lacking the root depth and density to stop erosion.

Figure 3.60 – Many private homes have lawns mowed to the edge of the river banks.

Figure 3.61 – Bank erosion occurring along a fenced ranch property without a riparian buffer.

In areas not ranched or privately owned, the riparian area appeared healthy in this reach. Vegetation was dominated by willows, narrowleaf cottonwoods, and upland grasses. Multiple age classes of willow and narrowleaf cottonwood were present. Russian olives were abundant along disturbed banks on private lands and have become established throughout the reach.

There were multiple ephemeral streams and gullies delivering sediment to the river in this reach. Poison Creek, Willow Creek, and Horse Creek all had large debris fans where they joined the Colorado River (Figure 3.62). Most of the debris fans consisted of boulders, cobble, gravel, and abundant sand (Figure 3.63). Large wood was also observed in the debris fans of larger ephemeral streams. The influx of fine sediment to the river from these streams and gullies was evident in the embedded riffles downstream.

Figure 3.62 – Looking downstream at the Colorado River over the debris fan of ephemeral Willow Creek.

Figure 3.63 – A large debris fan formed at the mouth of a gully that drains into the Colorado River.

The geomorphic habitat units in the upper part of the reach were more diverse than the lower part and contained mostly runs with some pool/riffle habitat. As the valley slope flattened and the floodplain widened, the geomorphic habitat was dominated by runs and glides with occasional riffles. The sinuosity of the reach was second lowest at 1.14.

3.6.9 Sweetwater Creek to Dotsero (River Miles 53.1 – 60.3)

Sweetwater Creek was running turbid during the September 2012 field investigations (Figure 3.64). Rainstorms on July 24 caused debris flows and landslides throughout the lower Colorado Trough Road. However, the lower Sweetwater Creek watershed was had the most damage from mudslides and flooding (Miller, 2012). According to the Eagle County Road and Bridge Department, mudslides occur every summer and the Colorado River Road usually has at least two occurrences per year needing repair (Adams, 2012). The large amount of sediment that entered the river during the storms was responsible for killing thousands of native and non-native suckers, along with a few trout (Figure 3.65) (*Vail Daily*, 2012). The turbidity on our visit was caused by ongoing construction work on the roads and properties upstream (Figure 3.66). The large debris fan at the mouth of Sweetwater Creek consisted of boulders, cobble, and gravel deeply embedded with sand and fines (Figure 3.67).

Figure 3.64 – Turbid water from Sweetwater Creek mixing with the Colorado River.

Figure 3.65 – The Colorado River near Glenwood Springs after the rain storm on July 24, 2012 (Ewert and Bakich, 2014).

Figure 3.66 – Ongoing construction, to clean up mudflows that had crossed the Sweetwater Creek road, made the water extremely turbid in Sweetwater Creek.

Figure 3.67 – Sweetwater Creek debris fan where it joins the Colorado River.

Downstream from Sweetwater Creek, the valley remains confined except for historic large debris flows that have provided enough flat open land for growing hay. Upstream from Lyons Gulch, the geomorphic habitat remained mostly runs with some pools and shoal features created by islands. Sand bars were abundant especially along the channel margins and in back eddies (Figure 3.68). This trend continued downstream of Lyons Gulch where the bedslope flattened out and the riffles continued to be embedded with sand and fines. The geomorphic habitat units were a more diverse mix of riffles and long run/glide habitat (Figure 3.69). The sinuosity of the reach was 1.20.

Figure 3.68 – Large sparsely vegetated sand bars were abundant along the channel margins and in back eddies throughout the Sweetwater Creek to Dotsero reach.

Figure 3.69 – Typical section of Sweetwater Creek to Dotsero reach (looking downstream towards Dotsero) Composed of some riffle habitat mixed with longer sections of run/glide habitat.

The riparian area through this reach was closely paralleled by railroad and Trough road on either side of the river. Despite this encroachment, the riparian area vegetation appeared dense and healthy. Willows, narrowleaf cottonwood, and upland grasses dominated the vegetation. Narrowleaf cottonwood regeneration was occurring on many of the wider floodplain areas and on larger islands (Figure 3.70). Where the road encroached upon the riparian area some willows had established, but the vegetation remained sparse. Most of the private lands and agricultural fields in the reach were set above or back from the river sufficiently to not disturb the riparian area.

Figure 3.70 – Narrowleaf cottonwood recruitment was strong in many parts of the riparian corridor between Sweetwater Creek and Dotsero.

Bed material sampling occurred at two cross sections within this reach. The first was downstream from Sweetwater Creek where the average d_{50} sampled at River Mile 53.8 and 93 mm and the embeddedness was 45%. Percent fines, algae, and coarse material were 11%, 24%, and 66%, respectively. At the other cross section located at River Mile 59.3, the average d_{50} was 49 mm and the embeddedness was 50%. Percent fines, algae, and coarse material were 17%, 64%, and 19%, respectively.

3.7 Water Quality

Water quality is strongly influenced by interactions with water quantity (streamflow) in the study area. Water-quality point samples were collected on the main stem and tributaries of the Colorado River between September 26 to October 2, 2012 and October 1 to 4, 2013 to determine if any nonpoint or point source issues were occurring within the study area. Water-quality parameters sampled include: temperature, pH, turbidity, conductivity, dissolved oxygen, and oxygen reduction potential. Resulting water quality samples are summarized in Appendix C.

The two primary issues identified in this study are elevated water temperatures, especially during low flows of late summer, and deposition of fine sediment. There are no 303d listed segments that are not supporting designated uses on the Colorado River through the study area, but a 303d listed segment (temperature) is designated upstream above the confluence with the Blue River. The temperature classification for the main stem Colorado River from the outlet of Lake Granby to the confluence with the Roaring Fork is Cold Stream Tier II (CS-II). The Table Value Standard (TVS) for a CS-II stream from April to October is to not exceed a Mean Weekly Average Temperature (MWAT) of 64.8°F, or a Daily Maximum (DM) temperature of 74.8°F. Between November and March the MWAT and DM temperatures are 48.2°F and 55.4°F, respectively.

3.7.1 Water Temperature in the Study Area

Water temperatures were recorded in 2012 and 2013 by the Wild & Scenic Group at three locations within the study area: 1) State Bridge, 2) Below Red Dirt Creek, and 3) Dotsero. In 2012, the data logger below Red Dirt Creek was buried by sediment and the resulting data were unusable. Hence, the analysis of temperature data performed in this study focused on the more complete data set from 2013.

As expected, results indicate that water temperatures increase moving downstream (Figure 3.71). In 2013, temperatures at Dotsero were on average ~4°F warmer than at State Bridge (3/29-11/7). Compared to water temperature data from the Colorado River at Kremmling, Dotsero was 3.1°F warmer (3/28-9/30) (Figure 3.72). Between July 1 and September 30, Dotsero was 5.6 F warmer than Kremmling and 6.3°F warmer from July 1 to August 31.

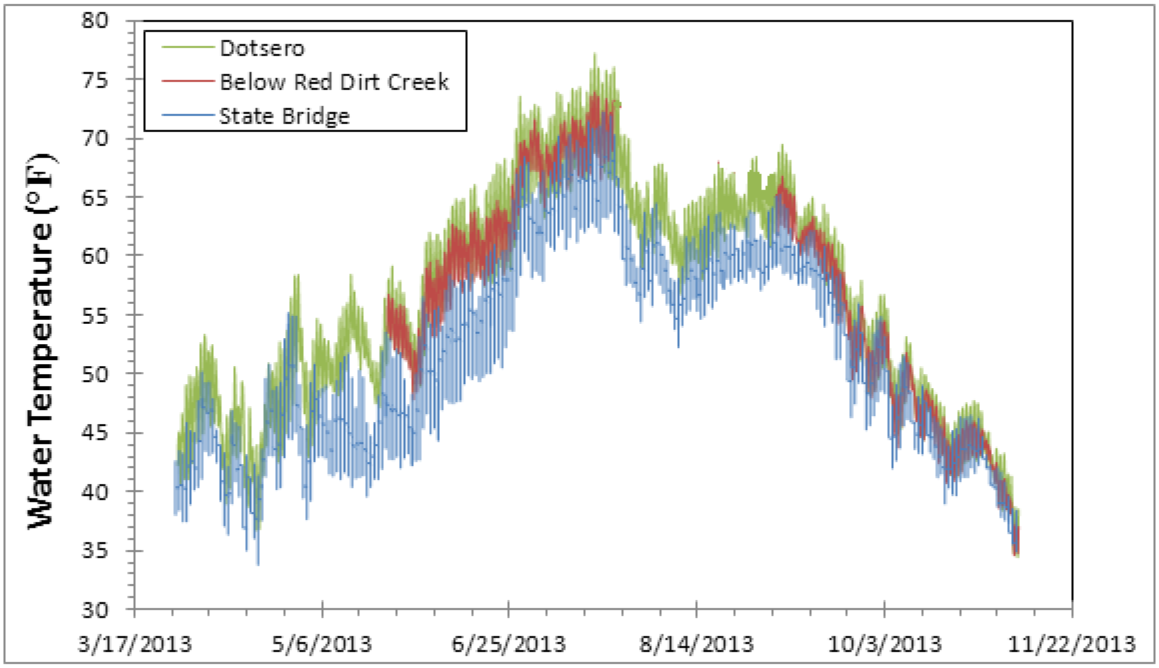


Figure 3.71 – Water temperature data for the Colorado River at State Bridge, below Red Dirt Creek, and Dotsero.

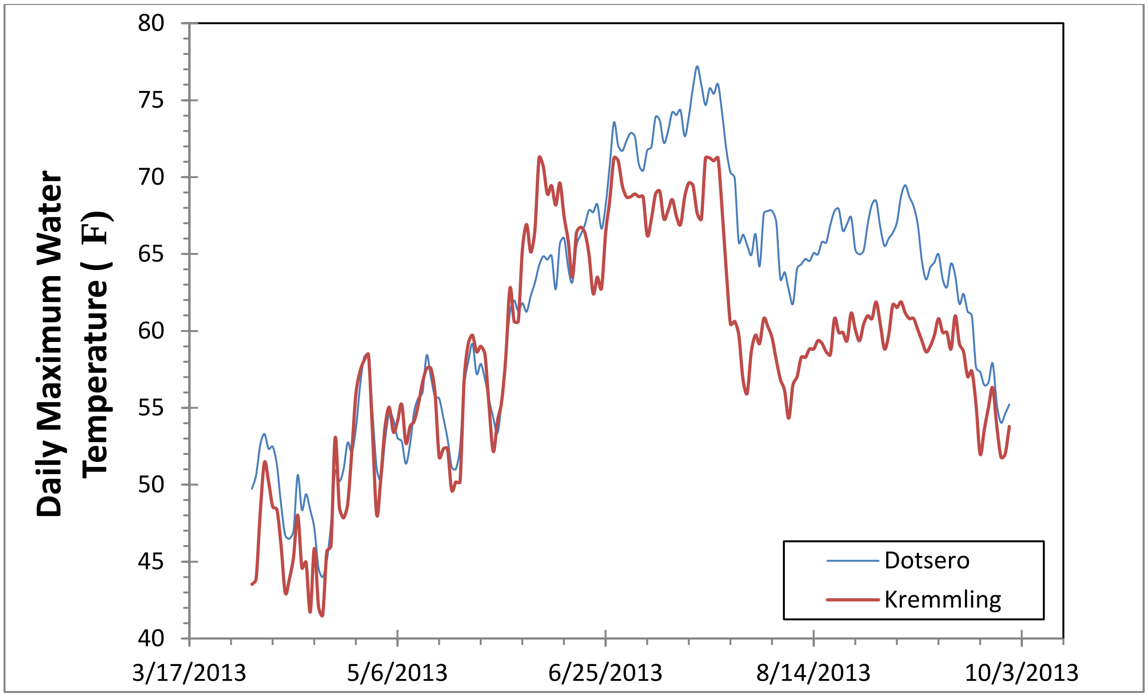


Figure 3.72 – Daily maximum water temperatures for the Colorado River at Kremmling and Dotsero.

Single point water temperatures were collected, between September 26 and October 1, 2012, in all perennial tributaries to determine if they were contributing to increases in water temperature on the main stem. Water temperature samples were collected as far upstream from the confluence with the Colorado River as possible to negate any possible influences from main stem water table. Results indicate that all tributaries were colder than the Colorado River except for Sheephorn Creek which was 1°F warmer (Figure 3.73). Combining these single point measurements with the fact that on average the largest tributary, the Piney River, only contributes 2% of flow to the main stem through the summer months it appears unlikely that any single tributary, nor the cumulative contribution of all tributaries, would have a substantial effect on main stem warming during the period of observation. Additional analyses described below suggest that elevated temperatures within the study area are primarily a consequence of tributary influences and reservoir operations in the upper watershed. Further investigation during the summer months by collecting continuous data from each tributary and in the main stem above and below each tributary, especially in August, is recommended to fully understand the influence of tributaries on main stem temperatures.

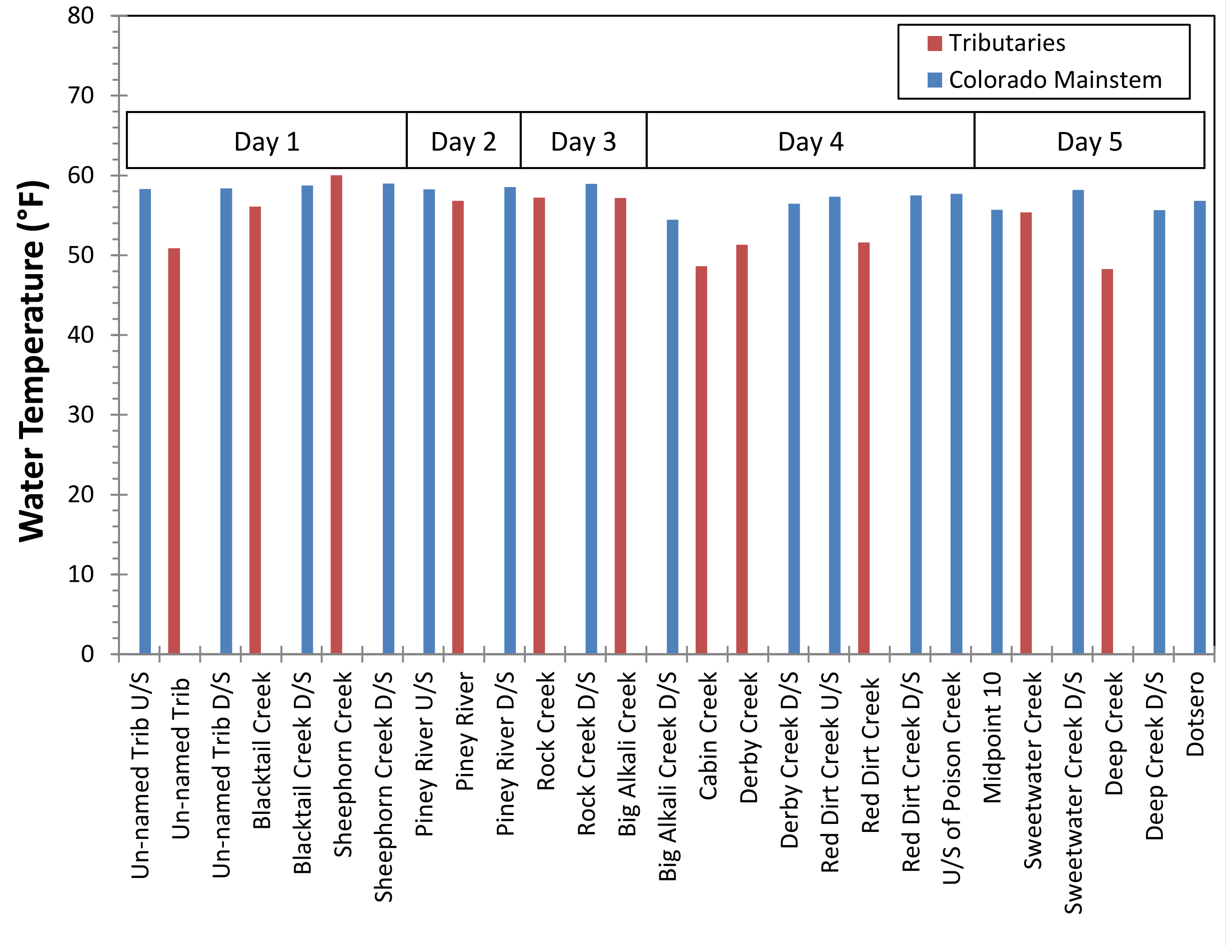


Figure 3.73 – Water temperatures in perennial tributaries and the main stem of the Colorado River between September 26 and October 1, 2012.

3.7.2 Stream Temperature and Water-quality Standards

Multiple entities monitored temperature in the project area during the 2012 and 2013 field seasons including CPW, BLM, and Wild and Scenic (W&S) Stakeholder Group Monitoring Work Group. USGS collected temperature data at the gages below Kremmling and Dotsero as well. Water temperature controls vital aspects of aquatic systems; warmer temperatures may negatively impact metabolic processes in cold-water evolved organisms like trout, leading to thermal stress, refuge-seeking, and potentially death. For this reason, temperature is an important and frequently-monitored water-quality constituent, and may serve as the basis for a determination of stream impairment under the Clean Water Act Section 303(d). This section compares temperature data to state standards to provide context and better understanding of current water-quality conditions in the river. The analysis does not assert any legal designation of water-quality impairment, only CDPHE Water Quality Control Commission (WQCC) may perform that action after review of all available data.

Using publicly-available temperature data hosted in the Grand County Water Information Network (GCWIN, www.gcwin.org), temperatures for three sites in the project area were compared to CDPHE WQCC standards for Cold Water Tier II Aquatic Life streams (Table 3.9). The Colorado River sites selected were State Bridge, Red Dirt Creek, and Dotsero above the Eagle River. W&S Stakeholder Group Monitoring Work Group deployed and maintained loggers at these three locations in 2013. CDPHE WQCC standards exist for two parameters: 1) the DM and 2) the MWAT. DM is defined as the highest recorded 2-hour average each day, and can be viewed as an acute-exposure temperature event for aquatic life. MWAT is a rolling 7-day average of the daily mean temperature, and can similarly be viewed as a chronic-exposure event. The daily mean must consist of a minimum of three evenly-spaced measurements during a 24-hour time period. Observations for each monitoring site occurred every 15 minutes—a period adequately short to calculate all applicable standards. CDPHE WQCC provides a publicly-available spreadsheet macro to calculate temperature standards exceedances, available at http://www.colorado.gov/cs/Satellite/CDPHE-WQ/CBON/1251596876811.

Table 3.9 – Temperature standards for Upper Colorado project reach (from Regulation 5 CCR 1002-33 (CDPHE WQCC, 2012)).

Stream Classification	Applicable Months	MWAT	DM
Cold Stream Tier II (CS-II)	April – October	18.2	23.8
	November – March	9.0	13.0

During 2013, the most-upstream W&S temperature monitoring site at State Bridge recorded no observations exceeding recommended state standards. At Red Dirt Creek, sedimentation at the probe site rendered a portion of the mid-season data unusable, but generated a viable record overall. During the period from June 29 to July 22, observations exceeded MWAT standards for 4 weeks (Figure 3.74). In the final week of July, upstream water releases increased and temperature concerns abated (Figure 3.75); this time period in 2013 also featured plentiful monsoonal moisture in the mountain region, easing diversion pressures and temperatures on many streams across the West Slope. At the Dotsero site, observations exceeded MWAT standards for 4 weeks between June 29 and July 30. DM exceedances also occurred for a shorter period within that time, surpassing the 23.8°C threshold for 8 days from July 15 to 24 (Figure 3.76). Analysis of a limited subset of data from 2012 shows a similar MWAT exceedance for nearly 6 weeks between July 4 and August 15 (Figure 3.77). Taken together, these observations support the conclusion that warm temperatures, associated with low flows, are a continuing concern to aquatic ecosystems in the Eagle County reach of the Colorado River.

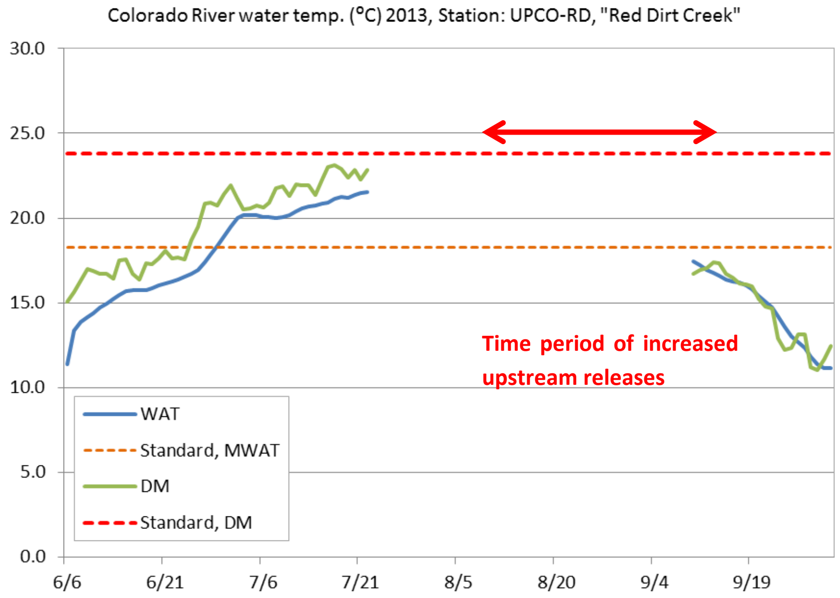


Figure 3.74 – Temperatures at the Red Dirt Creek monitoring site exceeded the MWAT standard from late June until mid-July when sediment flows buried the logger.

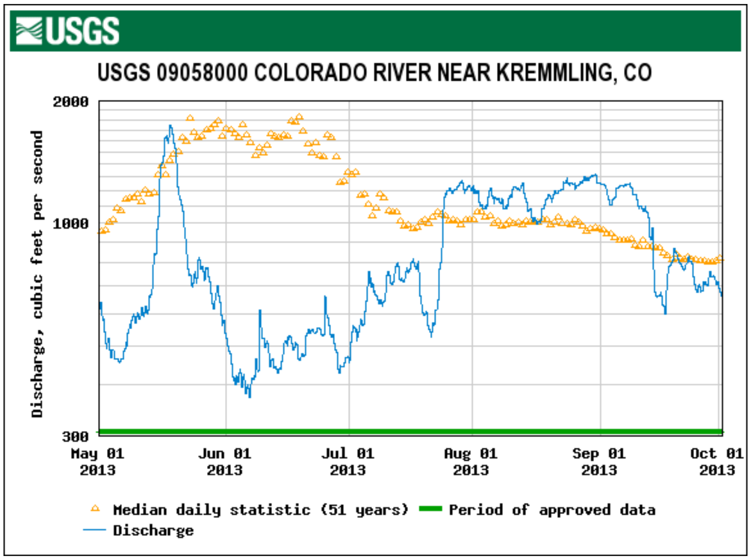


Figure 3.75 – Discharge increases from upstream reservoir releases helped abate temperature concerns in the project area during July 2013 (available at http://waterdata.usgs.gov/co/nwis/rt).

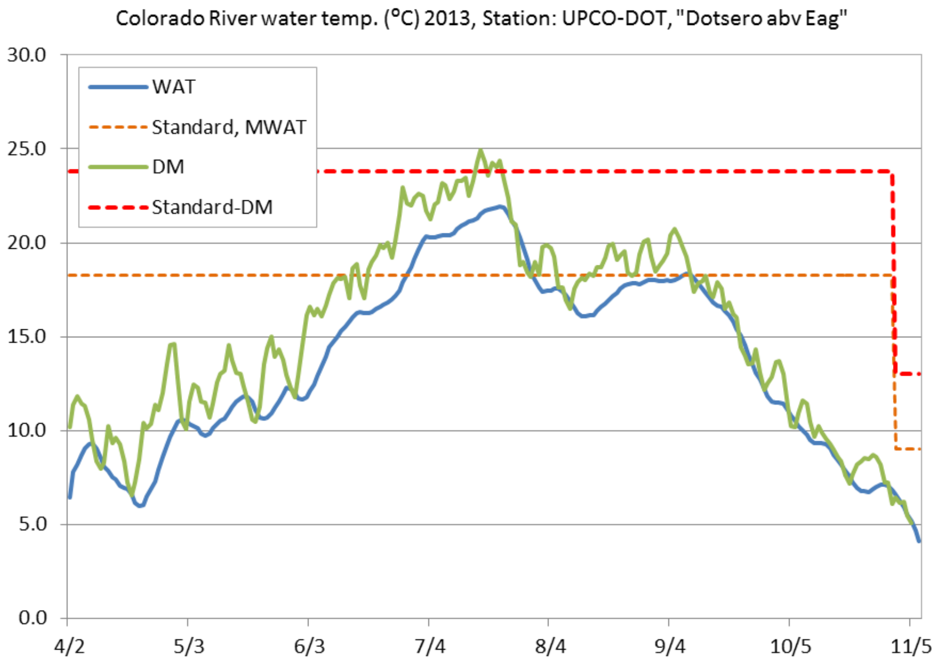


Figure 3.76 – During late July 2013, temperature observations exceeded both the DM and MWAT standards at the Dotsero monitoring site. Temperature concerns eased with increased streamflows in the last week of July.

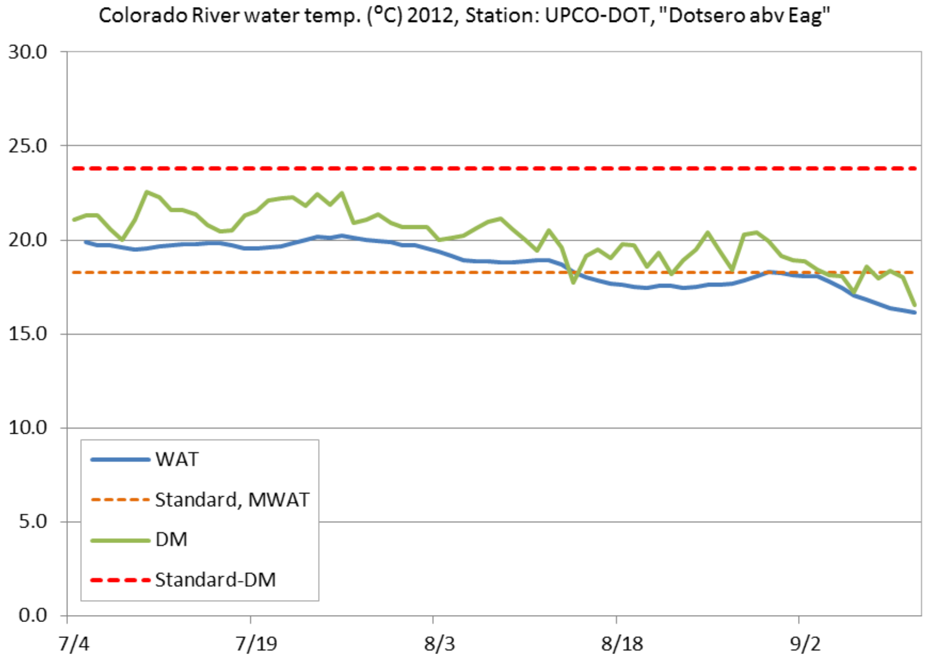


Figure 3.77 – In 2012, the Dotsero site experienced similar temperature concerns during the month of July. MWAT exceedances occurred between July 4 and August 14.

To determine whether DM and MWAT exceedances actually represent non-attainment of CDPHE WQCC standards, exceedances must occur more than 1 in 3 years (CDPHE WQCC, 2012). The W&S Stakeholder Group Monitoring Work Group is conducting monitoring again in 2014, and data will be publicly-available through GCWIN. Analysis of several additional seasons of data during various runoff and summer flow regimes will provide further clarification on the spatial and temporal extents of temperature issues in the reach between State Bridge and Dotsero.

3.7.3 Water Temperature in the Upstream Watershed

A GIS time-series animation was created to explore water temperature dynamics in the Colorado River watershed upstream of the study area. With the high number of major tributaries, diversions, and dams within the upper watershed, these analyses are aimed at understanding upstream controls on water temperatures. Water temperature and discharge data collected between 2010-2012 by the USGS and GCWIN for many of the tributaries and locations along the main stem were used in this study to develop three GIS animations depicting spatial and temporal temperature patterns. The animations show both the DM temperature and daily average flow. The legend for temperature colors is presented in Figure 3.78, while the width of the black line around the river is proportional to discharge. The animations files are not included in the report but are available from the ERWC. The first GIS animation depicts the watershed upstream of the study area between 2010 and 2012. The study area was then added to the upstream watershed and one animation each was generated for 2012 and 2013. The time period 2010-2012 consisted of two extremely dry low-flow years (2010 and 2012) and one above average wet year (2011). The April 1 snowpack for the Colorado basin between 2010 and 2013 was 76%, 130%, 49%, and 79% of average, respectively (Figure 3.79). Analysis of the time-series animations focused on summer temperatures. Although only individual examples of the tributaries' influence on main stem summer water temperatures are provided in the discussion below they were chosen to be representative of general patterns seen during the summer months of the dry years 2010, 2012, and 2013. The GIS animations in their entirety provide numerous similar examples and readers are encouraged to view them. A more rigorous dynamic simulation to determine what tributary discharges would reduce temperatures in the main stem for various main stem discharges would prove useful for future water-management decisions.

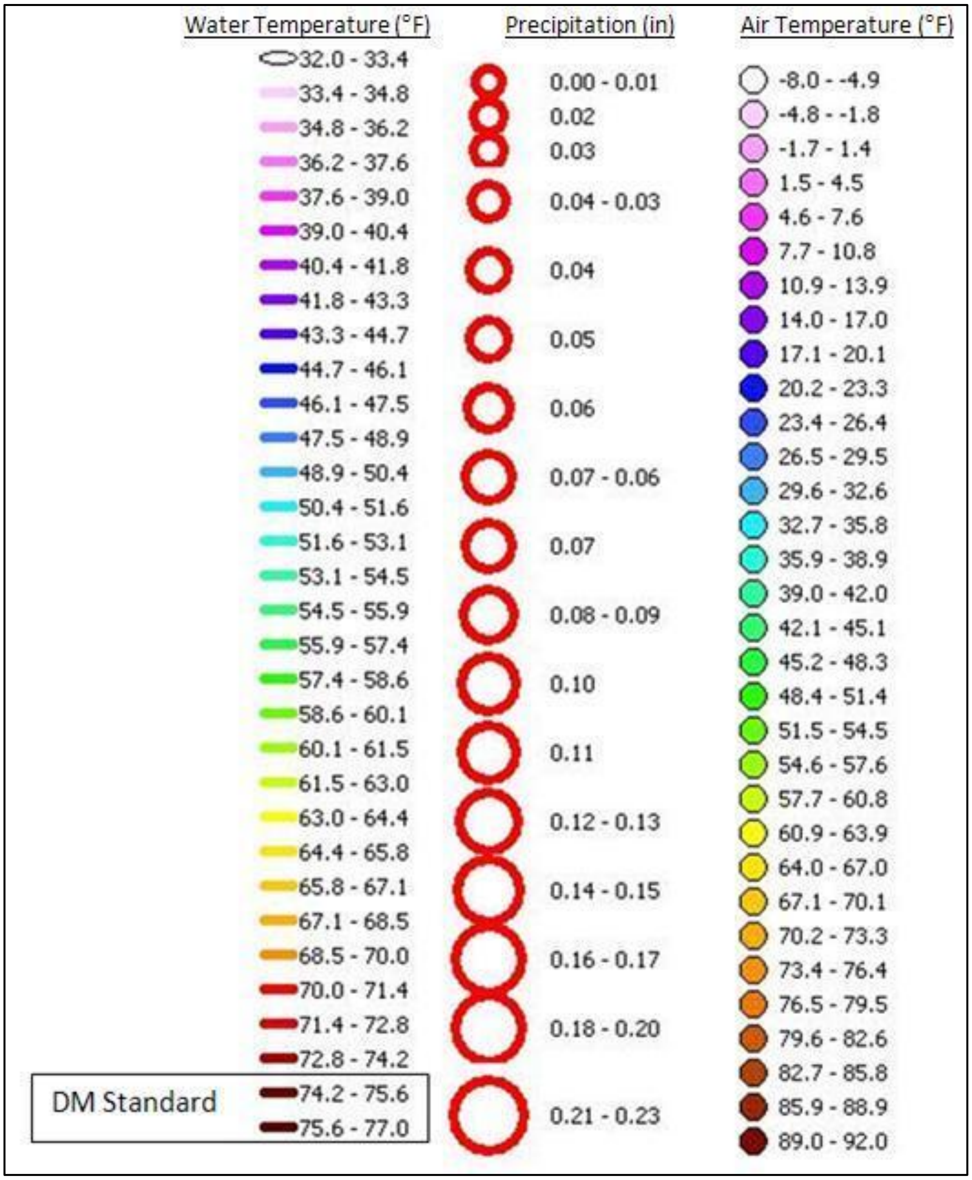


Figure 3.78 – From left to right: legend of daily maximum water temperatures (°F) for GIS time-series animations, temperatures above 74.8°F (brown) are above the daily maximum standards. Red circles indicate daily total precipitation (inches) and the color inside the circle represents daily maximum air temperature (°F). Percentages in maps indicate reservoir storage.

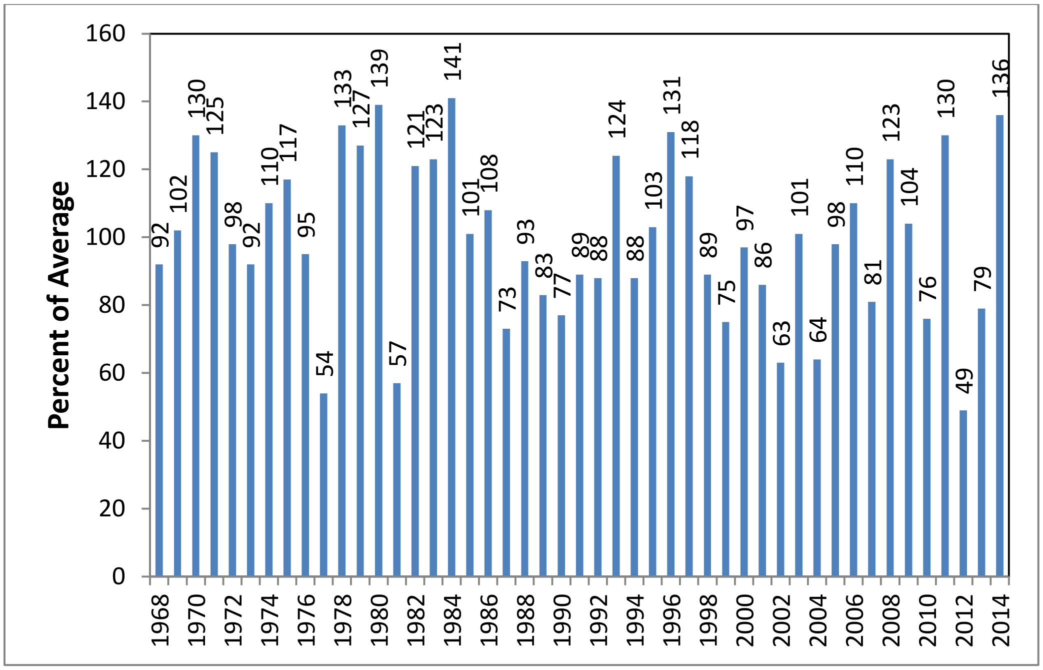


Figure 3.79 – Colorado River basin April 1 snowpack as a percentage of average from 1968-2012.

Overall, it appears that the Fraser River is contributing more flow and is substantially warmer than the Colorado River at their confluence (Figure 3.80). Downstream temperatures appear to be strongly influenced by the Fraser watershed indicating that future trans-basin diversions through the Moffat Tunnel could potentially impact temperatures downstream on the Colorado River. Below the Fraser confluence, water temperatures again become elevated in the Colorado River prior to reaching the Williams Fork (Figure 3.81). The Williams Fork appears to substantially decrease water temperatures during the summer in the main stem when enough flow is being contributed. On June 8, 2012 the Williams Fork below Williams Fork Reservoir was releasing 18 cfs and the main stem Colorado River reached a maximum temperature of 68.9°F (Figure 3.82). On June 14, the Williams Fork flow increased to 236 cfs and the main stem Colorado River decreased to a maximum temperature of 57.6°F. Despite an apparent cooling effect by Williams Fork, Colorado River main stem temperatures become elevated again by the time it reaches the confluence with Muddy Creek. If the Williams Fork is not contributing enough flow to cool the main stem, temperatures remain elevated and continue to increase upstream of Muddy Creek. Thus, water releases from the Williams Fork Dam appear to play a pivotal role in moderating summer temperatures along the main stem Colorado River.

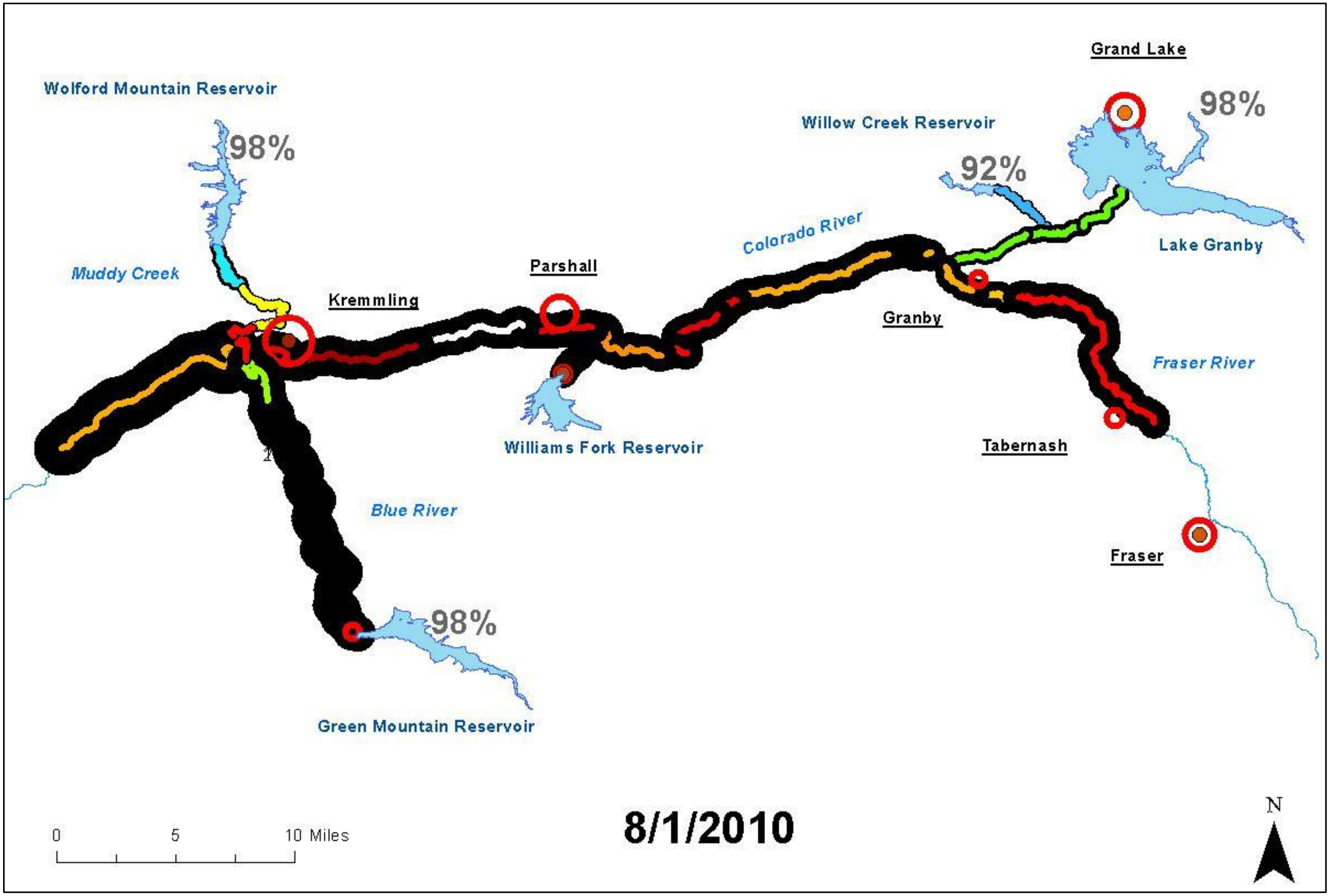


Figure 3.80 – GIS animation of discharge and water temperature for the Upper Colorado watershed indicating that the Fraser River is substantially warmer and contributing more flow than the Colorado River at their confluence.

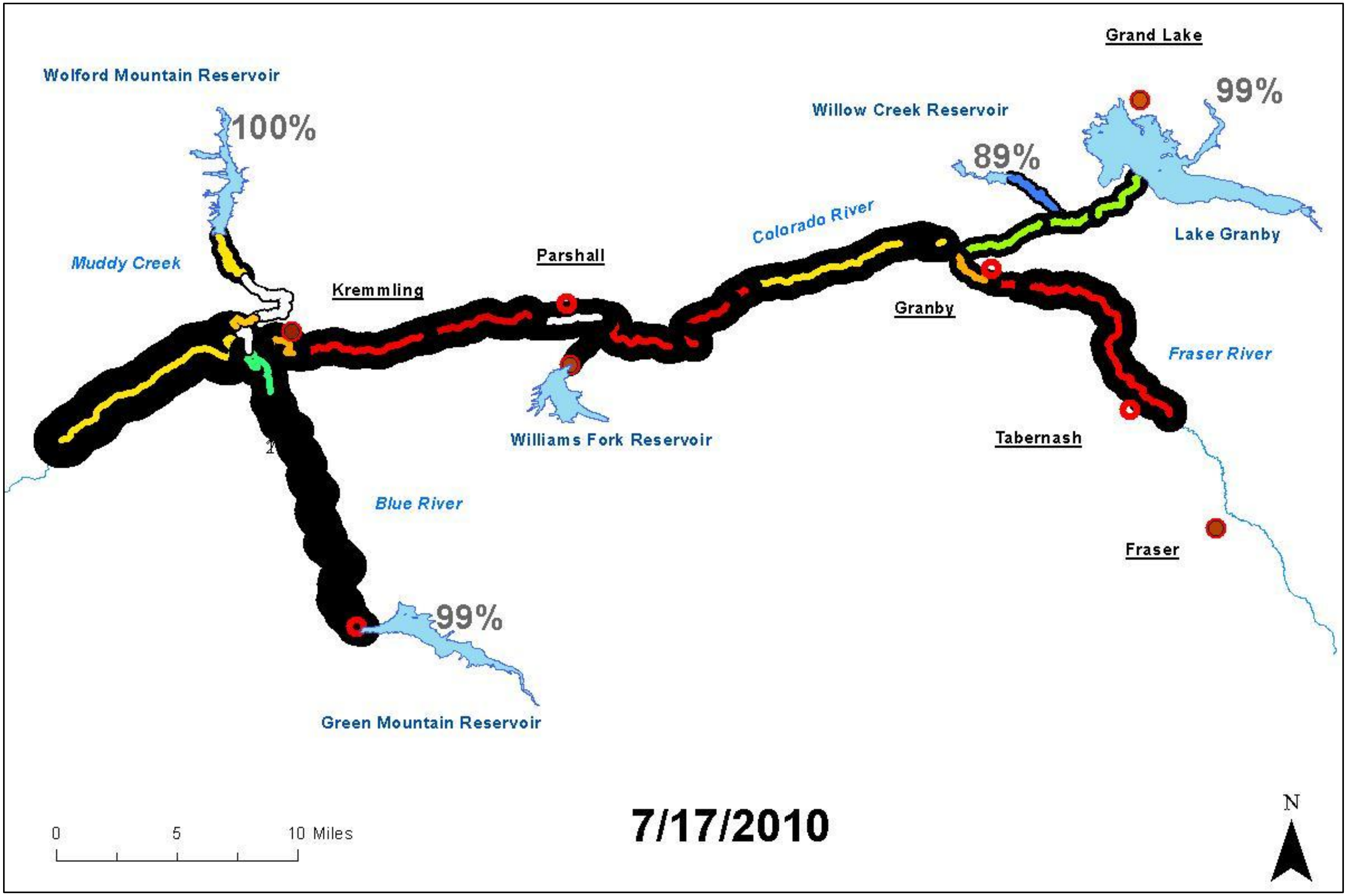


Figure 3.81 – GIS animation of discharge and water temperature for the Upper Colorado watershed indicating that the Colorado River warms from Windy Gap to the confluence with the Williams Fork.

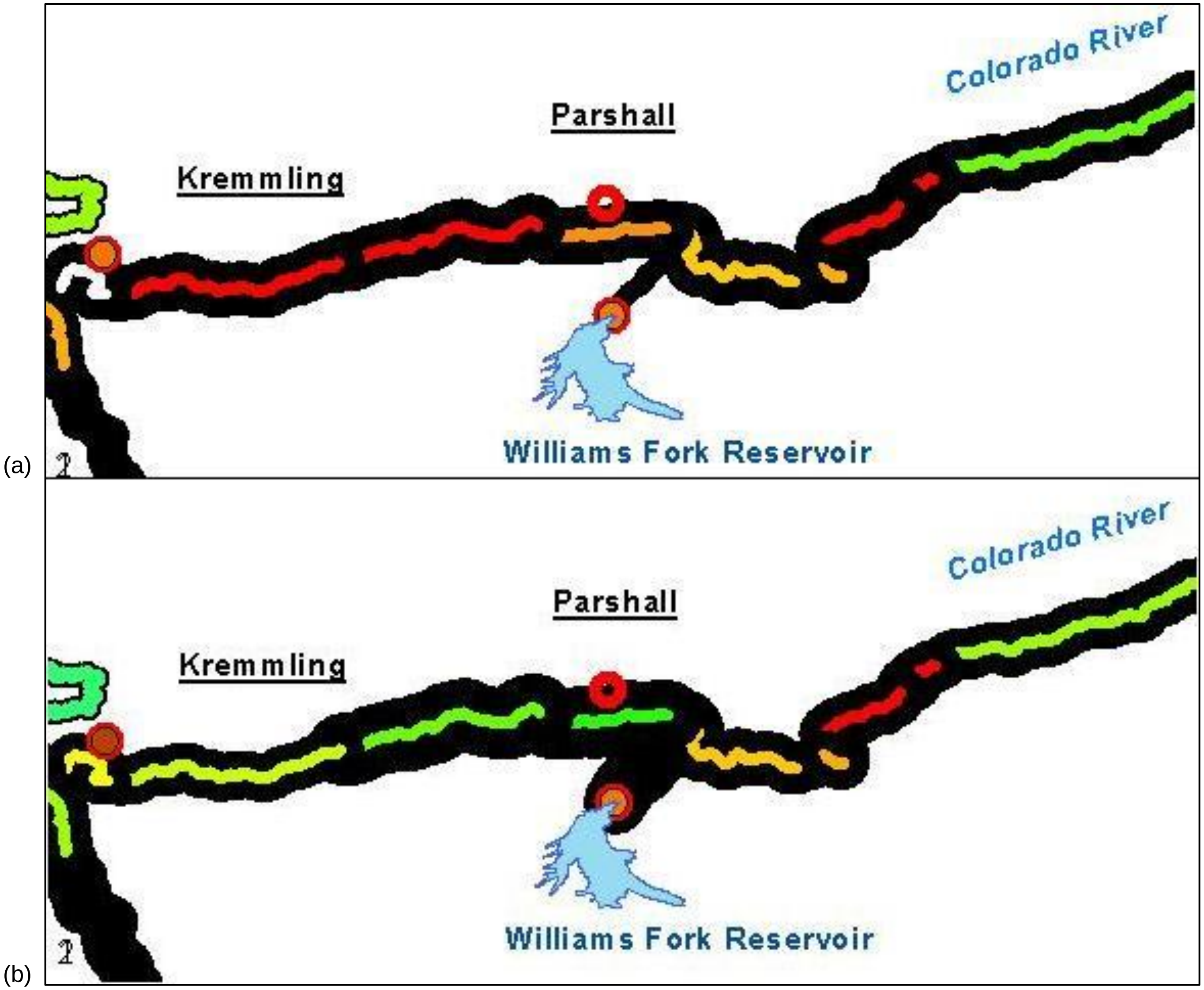
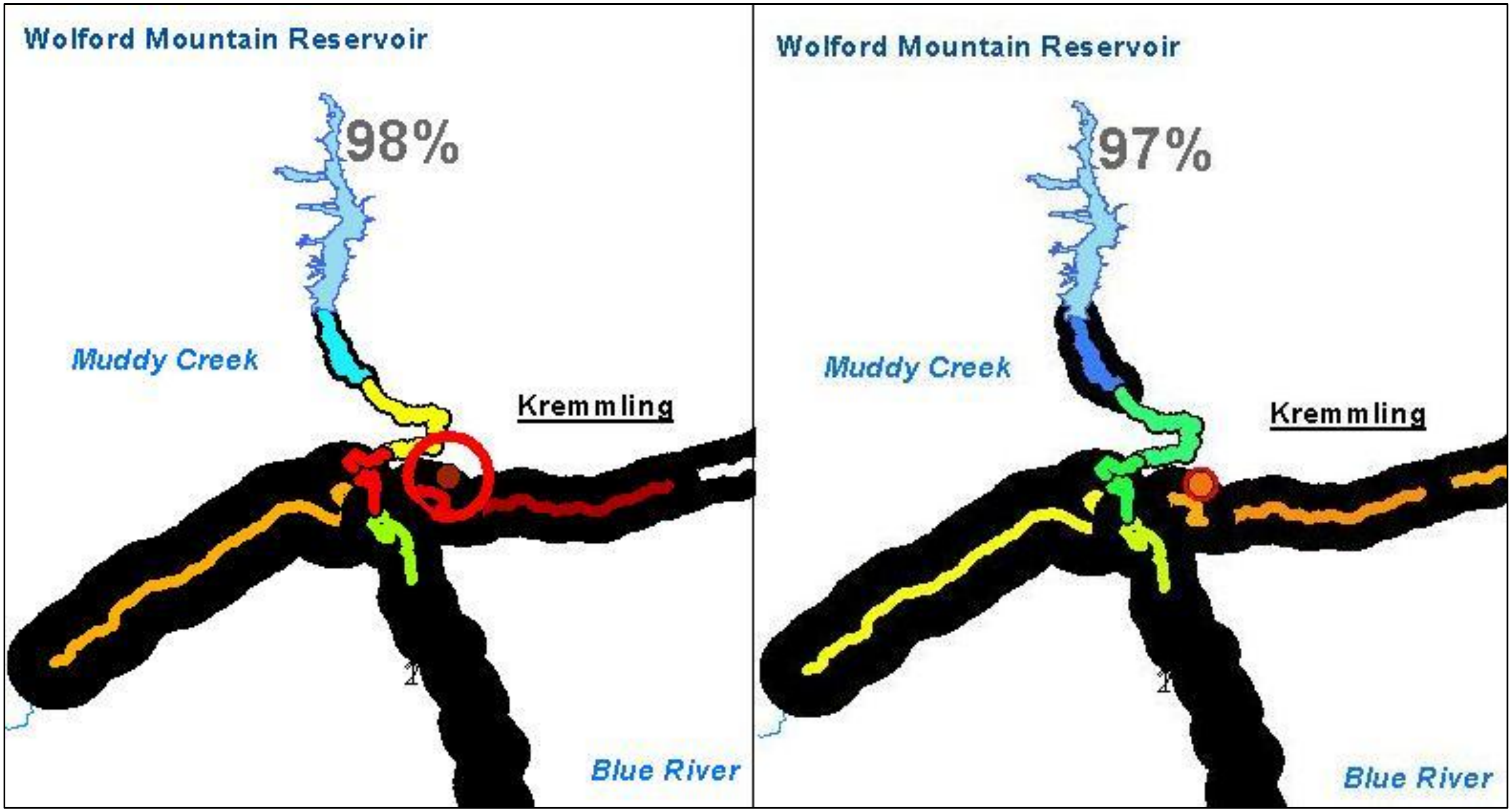


Figure 3.82 – Discharge and water temperature animation for the Upper Colorado watershed depicting differences in water temperatures from (a) June 8, 2012 when the main stem remains warm downstream of the Williams Fork to (b) June 14, 2012 when the Williams Fork contributes more flow and cools the main stem.

GIS animations indicate that Muddy Creek temperatures during summer increase substantially between Wolford Mountain Reservoir and the confluence with the Colorado River. This is particularly apparent below the Kremmling Wastewater Treatment Facility. On August 1, 2010, the flow being released from Wolford Mountain Reservoir was 24 cfs and the temperature in Muddy Creek at the confluence with the Colorado River was 70.5°F. On August 14, 2010 flows were increased to 102 cfs and the temperature in Muddy creek at the confluence dropped to 56.7°F (Figure 3.83).

The Blue River appears to normally be substantially colder during summer than the main stem and provide a cooling effect in the main stem, especially when enough flow is being released from Green Mountain Reservoir. On July 20, 2013, the flows below Green Mountain Reservoir and Williams Fork Reservoir were 100 cfs and 66 cfs, respectively (Figure 3.84). Temperatures on the Colorado River above Dotsero hit a maximum value of 75.8°F. On July 26, 2013 flows on the Blue River and Williams Fork were bumped to 597 cfs and 279 cfs, respectively. The temperatures on the Colorado River above Dotsero decreased to 69.9°F. The Blue River also appears to play an important role in moderating summer water temperatures through the study area. Hence, it is important to note that with the agreement to allow substitution of water from the Blue River with Muddy Creek, the water temperatures and the consequent influence on the Colorado River main stem may not be the same. If large quantities of water from the Blue River are swapped with Muddy Creek water, this pronounced cooling effect may be diminished; however, Wolford Dam has three vertical release points allowing for greater control over the water temperature being released as compared to the other bottom release dams in the upper watershed. If possible, management of release point(s) to on Wolford Dam should be informed by specific targets for reduced water temperatures in Muddy Creek.



(a) (b)

Figure 3.83 – Discharge and water temperature animation for the Upper Colorado watershed on (a) August 1, 2010 when Muddy Creek is substantially warming by the time it reaches the Colorado River; and (b) August 14, 2010 when flows from Wolford Mountain Reservoir were increased in Muddy Creek and the warming was substantially less.

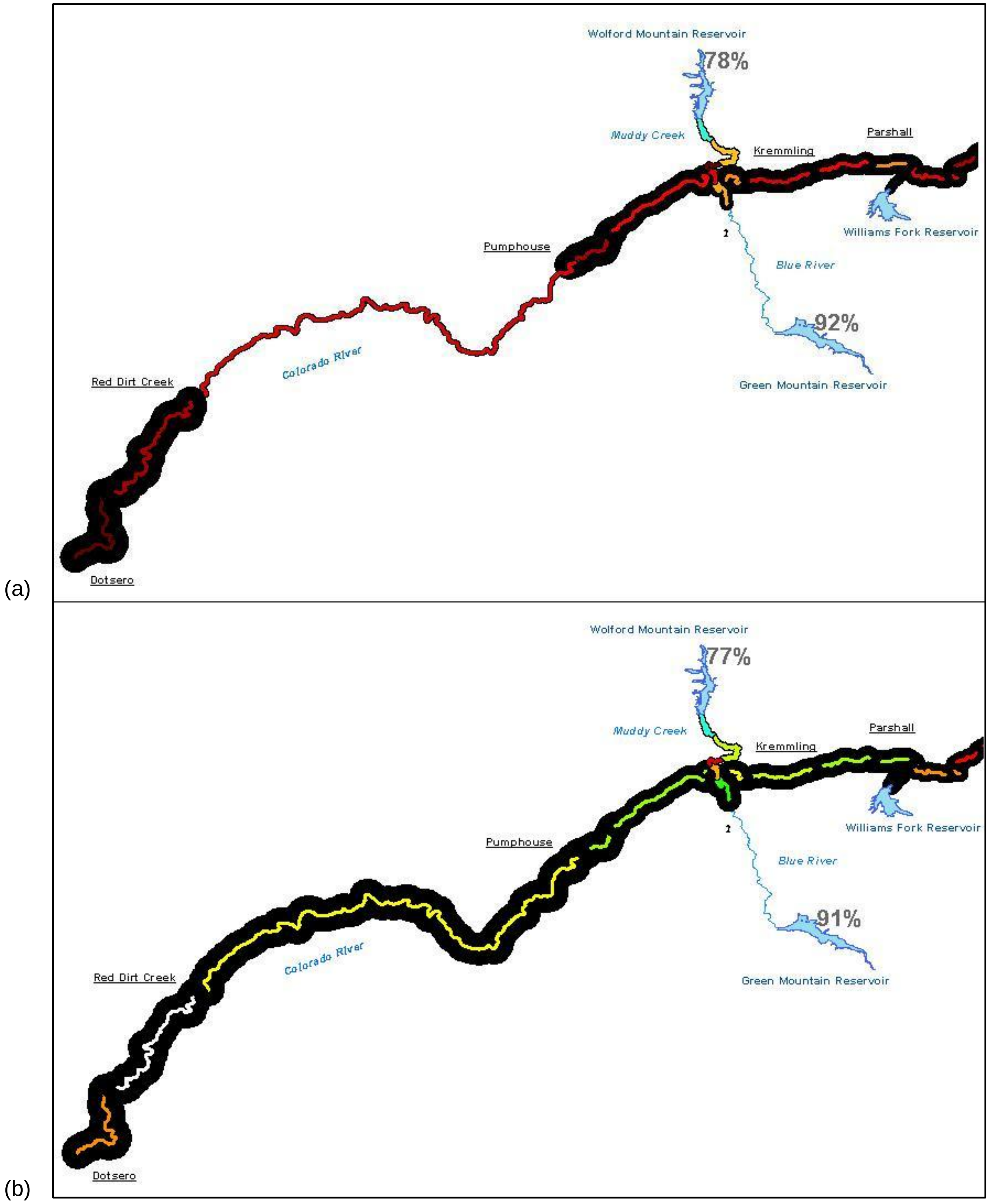


Figure 3.84 – Discharge and water temperature animation for the Upper Colorado watershed on (a) July 20, 2013, water temperatures through the study area were elevated and even above the DM standards at Dotsero; and (b) July 26, 2013 when more water was released from both Green Mountain and Williams Fork Reservoirs and temperatures were substantially reduced.

3.7.4 Turbidity and Sediment

Turbidity samples were collected from September 26 to October 2, 2012 and from October 1 to October 4, 2013 (Figure 3.85). In general, turbidity increased in a downstream direction (Figure 3.86). Although concurrent rainfall events limited the interpretability of turbidity readings upstream of Catamount in 2012, turbidity began to increase around Catamount in 2013. Big Alkali Creek was the most turbid tributary in 2012 and 2013; however, the relatively small channel size and contributing area have minimal influence on the main stem water quality (Figure 3.87). The previously mentioned flooding on Sweetwater Creek in 2012 and post flood construction made Sweetwater Creek the second most turbid tributary in 2012.

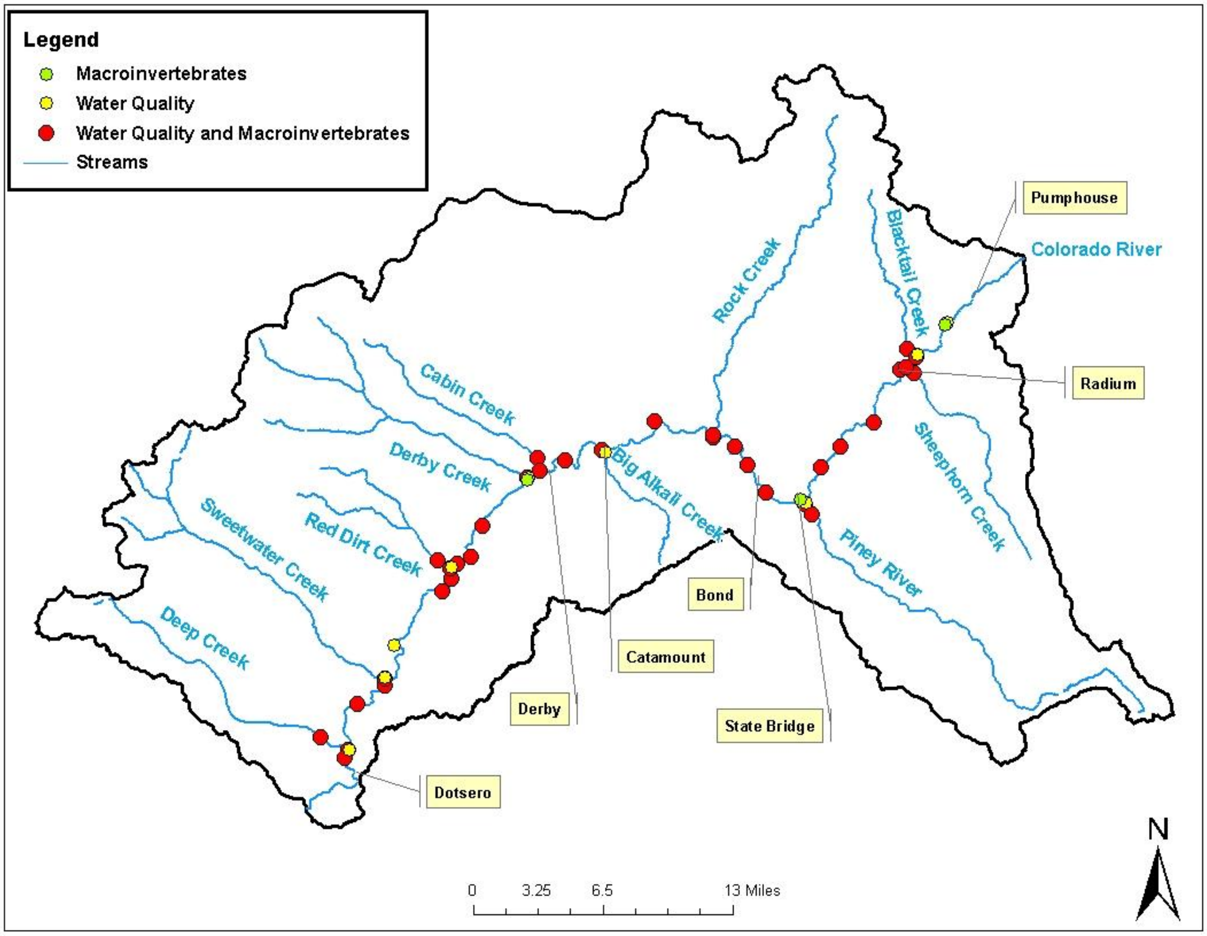


Figure 3.85 – Sampling locations for water quality (temperature, turbidity, pH, conductivity, dissolved oxygen, and oxygen reduction potential) and macroinvertebrates.

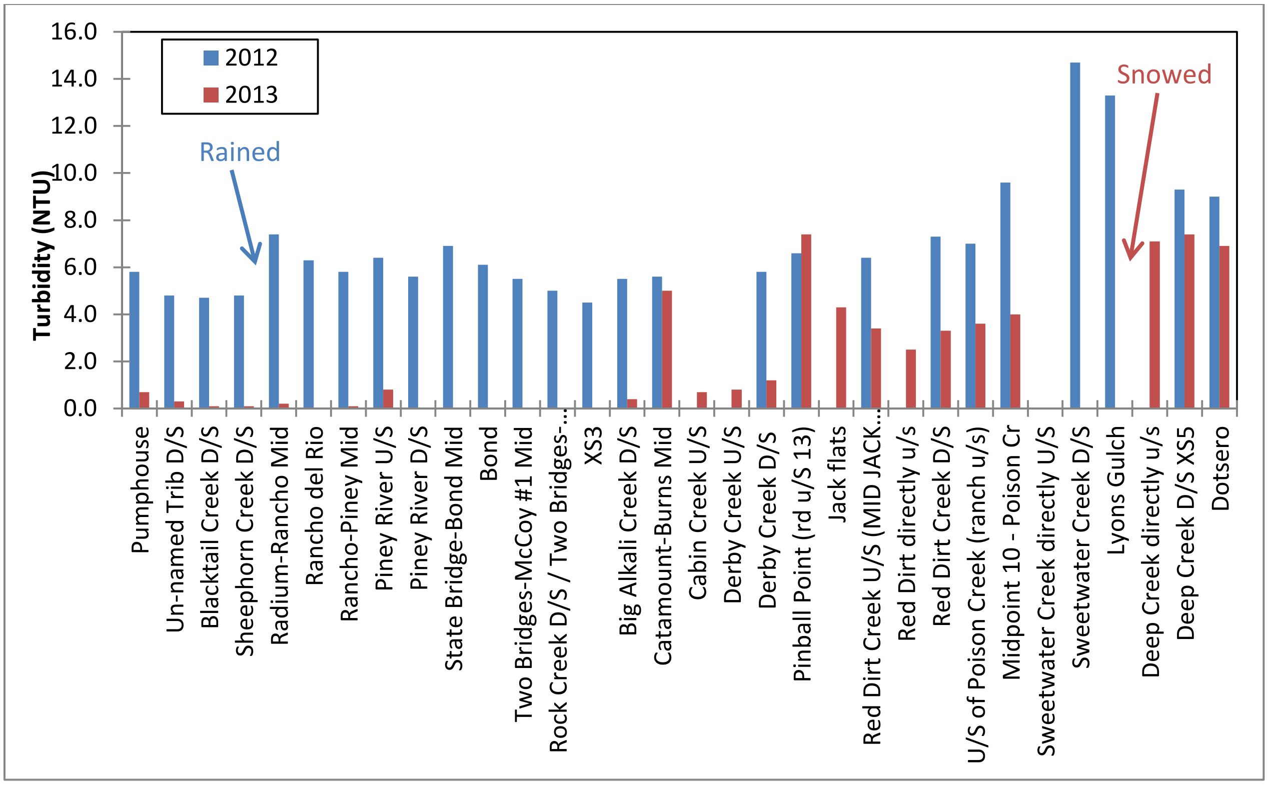


Figure 3.86 – Turbidity on the main stem Colorado River from upstream to downstream (left to right). Sampling occurred from September 26 to October 2, 2012 and from October 1 to October 4, 2013.

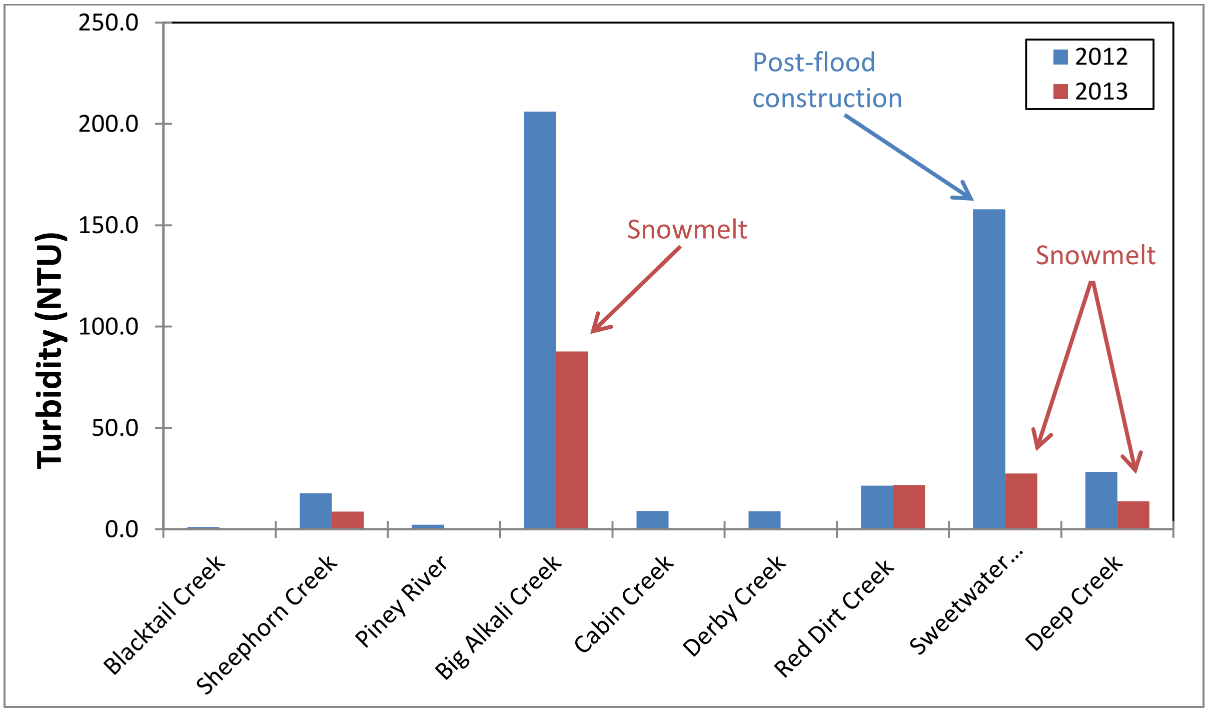


Figure 3.87 – Tributary turbidity measurements collected in 2012-2013.

During 2013, a storm dropped 2 to 4 inches of snow throughout the study area. Turbidity was measured in the tributaries during the snowmelt from this event to possibly identify differences in the contribution of fine sediments. The majority of sediment entering the main stem from tributaries undoubtedly occurs during intense summer thunderstorms, but snowmelt may provide some semblance of a baseline indication. Big Alkali Creek, Red Dirt Creek, and Sweetwater Creek were the most turbid (Figure 3.88). The Piney River was the least turbid.

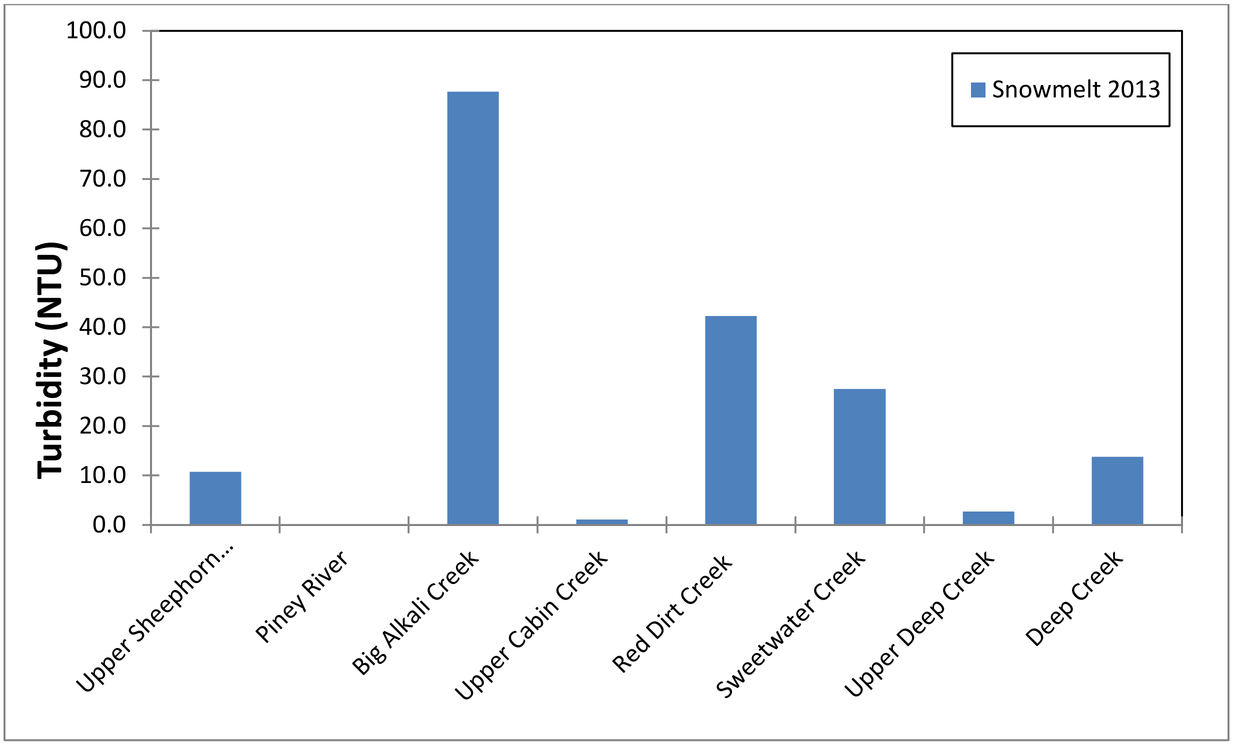


Figure 3.88 – Tributary turbidity measurements during snowmelt after a storm dropped 2 to 4 inches of snow over the study area.

3.7.5 Sedimentation Above and Below Catamount

As described above, there is a general shift from a mix of igneous and sedimentary rocks to sedimentary-dominated geologic setting moving downstream. This change becomes most apparent downstream from Two Bridges to Catamount where an appreciable increase in sediment delivery occurs due to increasing numbers of gullies and washes (Figure 3.89). This increased influx of fine sediment from surrounding hillslopes, gullies, and tributaries continues all the way to Dotsero.

Figure 3.89 – Typical debris fan from a gully below Catamount.

Upstream of Catamount, the geology within the study area is: 36% igneous, 1%, metamorphic, 41% sedimentary, and 22% other rock types. Below Catamount, the geology consists of: 15% igneous, 0% metamorphic, 57% sedimentary, and 27% other (Figure 3.90). The increase in sedimentary rock downstream of Catamount also creates changes in the surrounding topsoil and its erodibility. Part of the well-known Universal Soil Loss Equation (USLE) is the K-factor or soil erodibility factor. The higher the K-factor value the higher the soil erodibility. The K-factors for soils within the study area were mapped and the results indicate more readily erodible surfaces downstream of Catamount (Figure 3.91). The steepness of the surrounding hillslopes also plays a central role in delivering eroded sediment to the river. Therefore, the product of slope and USLE K-factor was mapped to represent the synergistic interaction between slope and soil erodibility (Figure 3.92). Again, areas with higher erodibility appeared to be more prevalent downstream of Catamount.

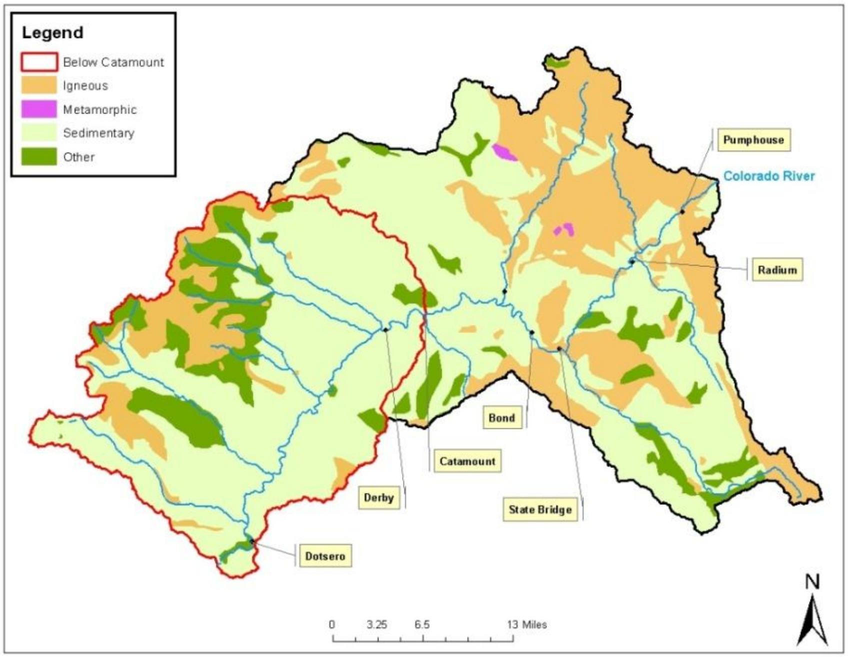


Figure 3.90 – General geology of the study area. Below Catamount (area in red boundary) becomes more dominated by sedimentary rock.

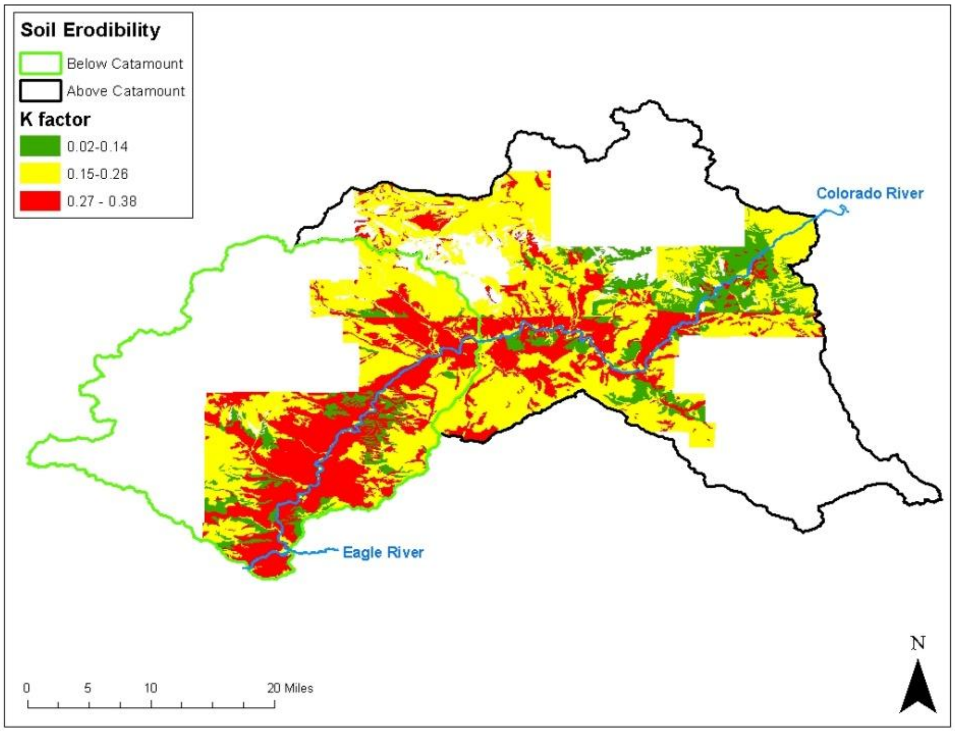


Figure 3.91 – K-factor, or USLE soil erodibility factor, values are depicted with red areas indicating higher soil erodibility.

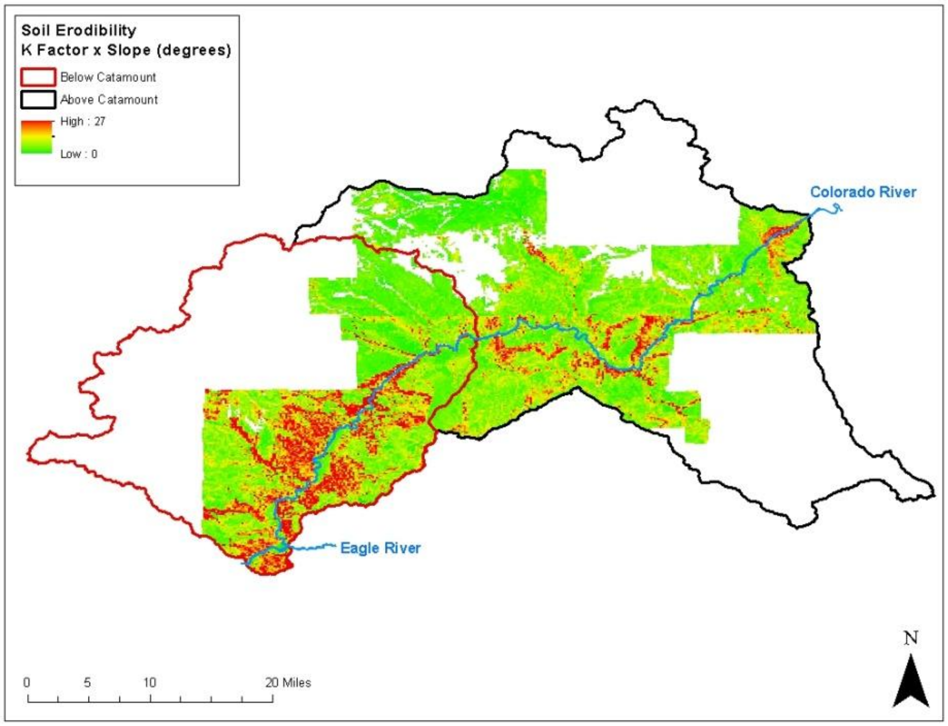


Figure 3.92 – Slope multiplied by K- factor values. Areas in red have a higher erodibility and slope.

With increased sediment delivery occurring downstream of Catamount, a resulting shift in river bed slope, width, or planform might be expected. The bedslope from Pumphouse to Rancho Del Rio, from Rancho Del Rio to Burns, and from Burns to Dotsero have all been estimated at 0.0027 (Miller and Swaim, 2011); however, these slopes are estimated from topographic maps and do not reveal local trends and variations in the longitudinal profile of the river. Detailed longitudinal surveys along the length of the study area are not currently available. This finding is consistent with previous research indicating that coarse sediment (larger than d_{50}) is more influential than fine sediment in controlling channel gradient (e.g., Knighton (1998)). Due to low variability in the valley slope, the sinuosity is also very similar: 1.29 above Catamount and 1.31 below. Finally the average channel width at ~1,000 cfs above Catamount was estimated at 174 ft, and 164 ft downstream. Another factor that could potentially change with increased sediment deposition is the frequency and size of mid-channel islands. Above Catamount there were on average 2.4 vegetated islands per mile, while below averaged 2.3. No substantial difference in island frequency is apparent; however, the islands below Catamount tended to be larger and occupy more of the channel. Thus, it appears that the highly constrained river channel in the study area exhibits no substantial differences in slope, geometry, or planform above and below Catamount despite increases in sediment deposition. Despite no substantial differences in channel shape and geometry or islands, there is clearly an increase in sediment delivery to the river below Catamount as observed by the influx of sediment from surrounding gullies, hillslopes, and tributaries. Substrate sampling only occurred at five cross sections during 2012 and 2013 due to water depths and velocities being too extreme to sample across the river (Figure 3.93). The representativeness of five sampling points to over 50 mi of river is uncertain. Pebble counts, percent embeddedness, and percent fines, algae, coarse material data were recorded in winter 2012 and summer 2013 at each cross section. Detailed descriptions of the sampling methods used in this study are provided in the Section 3.10. For this analysis, data from both years were combined to have a more representative account of bed substrate through the year and not solely either pre- or post-runoff. Results from the pebble counts data show that the river bed surface at the cross section located ~1 mi above Dotsero contained substantially more material less than 8 mm and 2 mm as compared to other cross sections (Table 3.10). Percent embeddedness was also highest at the two cross sections downstream of Catamount. Percent fines were highest at Radium followed by the two cross sections downstream of Catamount. Although more cross-sectional samples would benefit this analysis, the substrate data show some evidence of increased sedimentation below Catamount. The photographic evidence along with the apparent increases in: turbidity, soil erodibility, percent bed material less than 8 mm and 2 mm, percent embeddedness, and percent fines below Catamount, provide multiple lines of evidence suggesting that sediment delivery is relatively high in this part of the river corridor. This increase becomes more evident when examining benthic macroinvertebrate data as described in the following section.

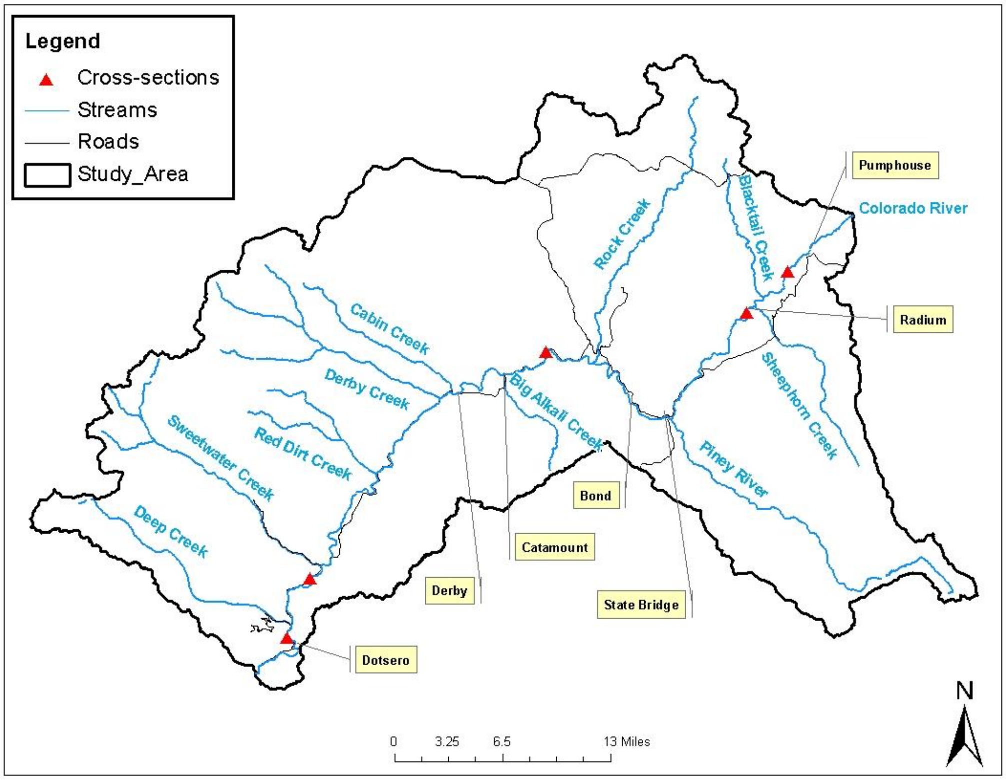


Figure 3.93 – Location of cross sections for substrate sampling.

Table 3.10 – Percent of substrate less than 8 mm and 2 mm; percent embeddedness; and percent fines, algae, and coarse count at each cross section.

	Percent of Substrate		Percent	Percent		
Cross Section	**<8 mm**	**<2 mm**	**Embeddedness**	**Fines**	**Algae**	**Coarse Material**
Pumphouse	13%	8%	30%	6	62	31
Radium	14%	10%	37%	20	44	36
Above Catamount	9%	4%	35%	5	70	25
Below Sweetwater	8%	8%	47%	11	23	66
Above Dotsero	30%	26%	49%	17	64	19

3.8 Macroinvertebrates

Three macroinvertebrate samples were taken at each riffle site using a 900-cm^2 Surber sampler with a 500-µm mesh size. Density was calculated as the number of macroinvertebrates per 2,700 cm^2 and richness was determined by identifying species to the lowest practical taxonomic level. Due to high and fast water, samples at Pumphouse and Blacktail downstream (D/S) were collected along the channel margins. The resulting density and richness at these two sites appear lower than expected based on the quality of the fishery between Pumphouse and Radium. Sites at State Bridge, Sweetwater D/S, Lyons Gulch, Deep Creek D/S, and Dotsero could not be resampled in 2013 due to higher water. Full macroinvertebrate sample data are tabulated in Appendix D.

Macroinvertebrate data were analyzed for upward or downward trends in density and richness from upstream to downstream. Overall, only the 2012 Total Richness and Ephemeroptera, Plecoptera, and Tricoptera (EPT) Richness trends were significant (Table 3.11). Total density appeared to show a downward, although not statistically significant, trend moving downstream in 2012 (Figure 3.94). Total richness increased slightly downstream in 2012 and 2013 (Figure 3.95). The riffle directly downstream from Derby Creek (River Mile 37.0) had a substantially higher total density and richness in 2012 as compared to other sites, possibly indicating an influx of macroinvertebrates from Derby Creek itself. EPT density and richness appeared to increase 0.7 mi below Two Bridges (River Mile 21.3) (Figure 3.96 and Figure 3.97, respectively). This increasing trend in EPT below Two Bridges runs counter to the notion that increased sediment delivery below Two Bridges would negatively affect macroinvertebrate density and richness. However, many of the EPT taxa collected in this study have some tolerance of fine sediment.

Table 3.11 – Trend analysis results for macroinvertebrate metrics in 2012 and 2013. Statistically significant trends are defined as p-value <0.10 and are highlighted in yellow. Regression X and Y units were miles downstream and either density (#/2700 cm^2) or richness, respectively.

	2012		2013	
Metric	**Regression Equation**	**p-value**	**Regression Equation**	**p-value**
Total Density	-2.03x+458	0.422	0.42x+371	0.901
Total Richness	0.10x+20	0.060	0.003x+22	0.945
EPT Density	1.44x+193	0.462	-0.16x+307	0.977
EPT Richness	0.09x+11	0.008	0.0004x+14	0.991

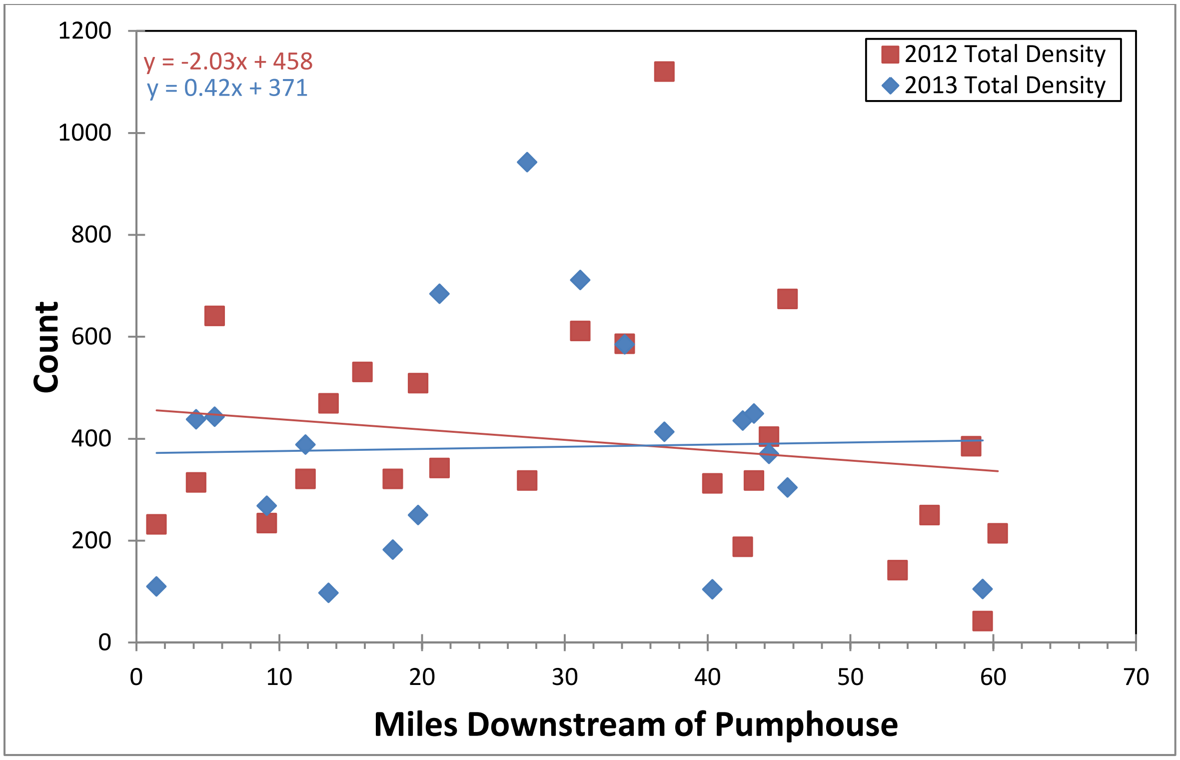


Figure 3.94 – Total density (#/2700 cm^2) of macroinvertebrates by river mile below Pumphouse in 2012 and 2013.

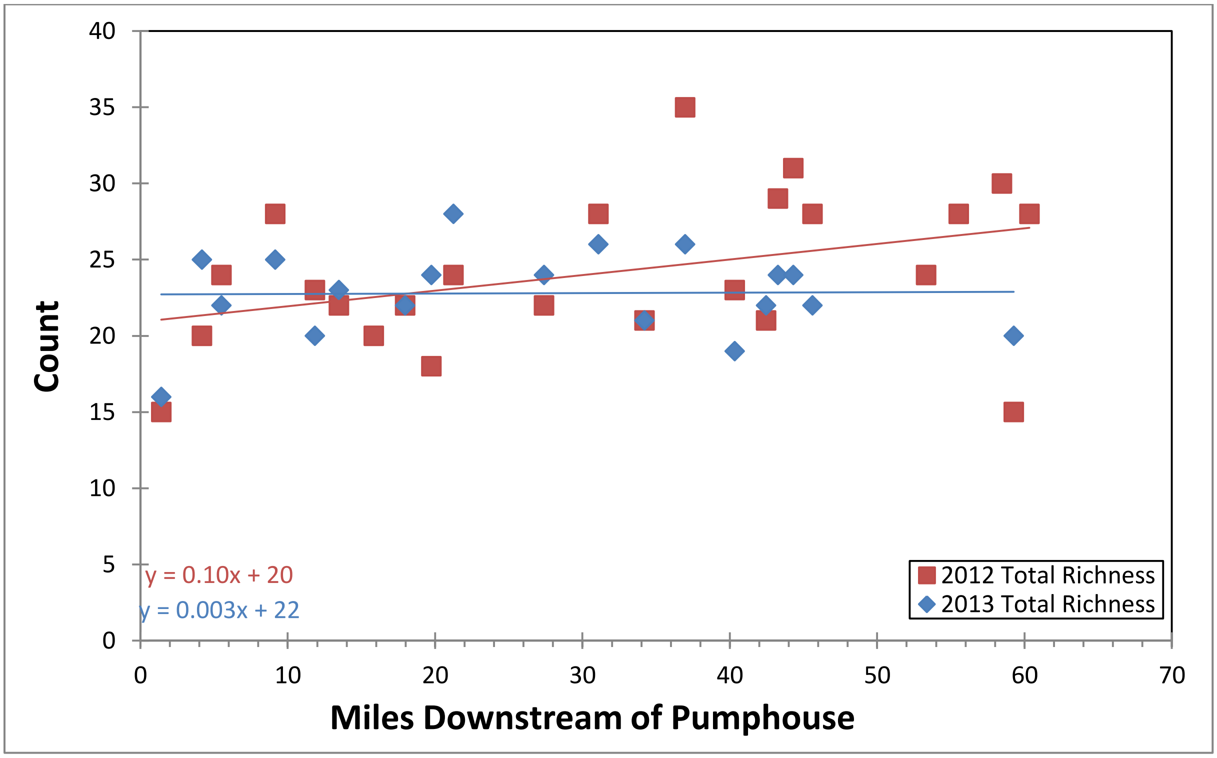


Figure 3.95 – Total richness of macroinvertebrates by river mile below Pumphouse in 2012 and 2013.

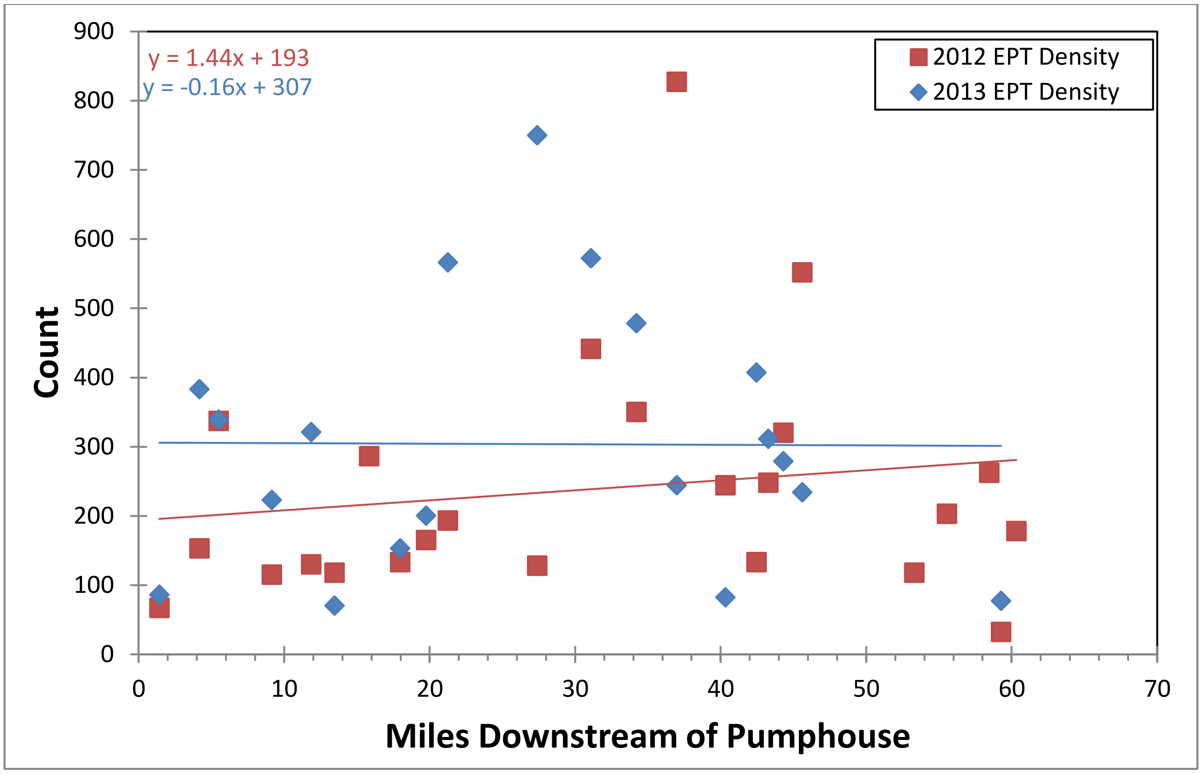


Figure 3.96 – EPT density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

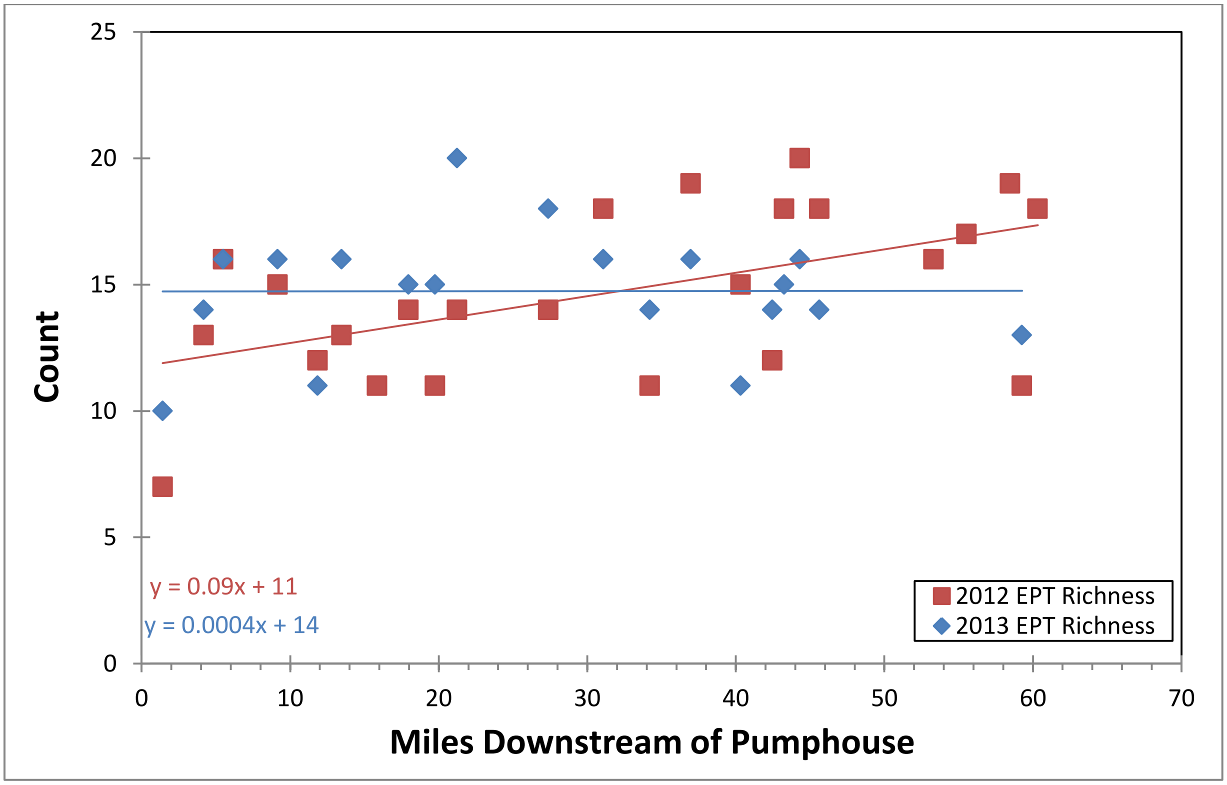


Figure 3.97 – EPT richness by river mile below Pumphouse in 2012 and 2013.

When considering taxa known to be sediment-tolerant or sediment-intolerant as defined by the Fine Sediment Bioassessment Index (FSBI) (Relyea *et al*., 2000), there appears to be a more discernable trend occurring. The FSBI scores macroinvertebrates in four categories: 1) intolerant to fine sediment, 2) moderately intolerant to fine sediment, 3) moderately tolerant to fine sediment, and 4) intolerant to fine sediment. For the purpose of this analysis, species were combined into just two groups: tolerant and intolerant. Only sites that had samples from 2012 and 2013 were used. Trends in both richness of sediment tolerant taxa and density of sediment intolerant taxa were statistically significant (Table 3.12). Sediment-tolerant richness increased downstream and sediment-intolerant richness decreased downstream (Figure 3.98). Sediment-tolerant density also increased downstream, with a substantial increase occurring at Two Bridges (Figure 3.99). Sediment-intolerant taxa density again decreased downstream.

Table 3.12 – Trend analysis results for sediment tolerance macroinvertebrate metrics. Statistically significant trends are defined as p-value <0.10 and are highlighted in yellow. Regression X and Y units were miles downstream and either density (#/2700 cm^2) or richness, respectively.

Metric	Regression Equation	p-value
Sediment Tolerant Richness	0.06x+8.6	0.009
Sediment Intolerant Richness	-0.02x+5.6	0.302
Sediment Tolerant Density	3.00x+405	0.429
Sediment Intolerant Density	-0.67x+59	0.072

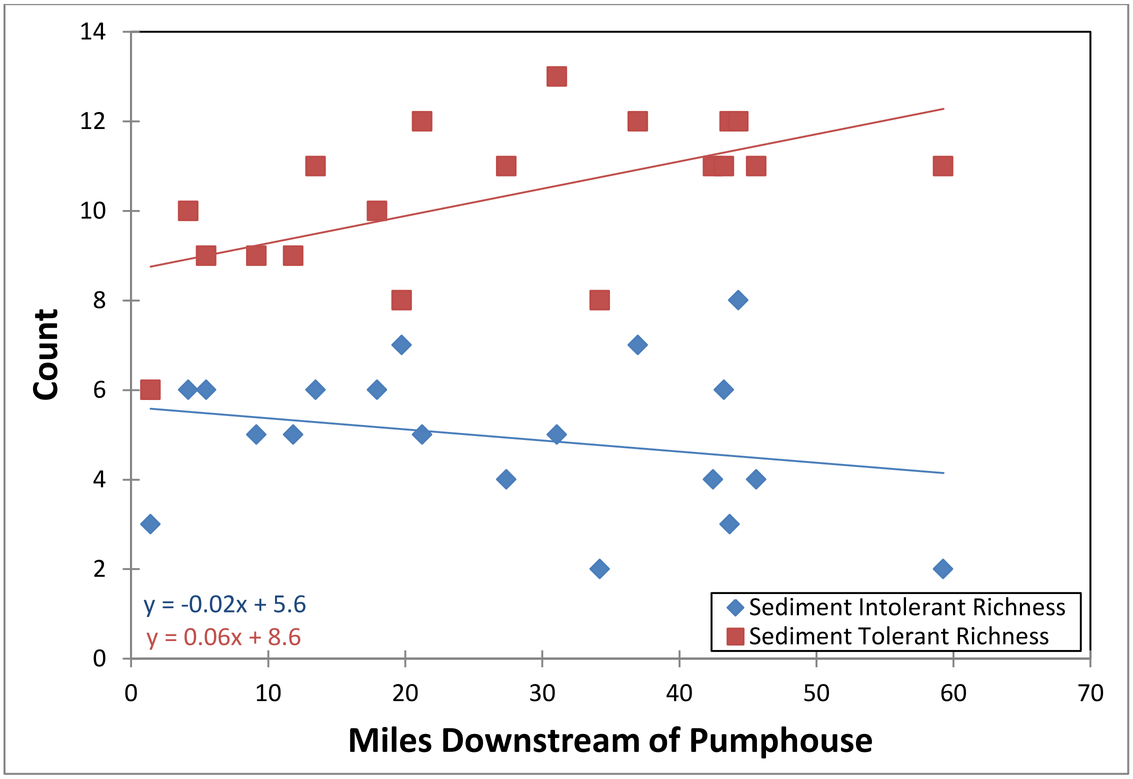


Figure 3.98 – Sediment-tolerant and sediment-intolerant species richness by river mile below Pumphouse in 2012 and 2013.

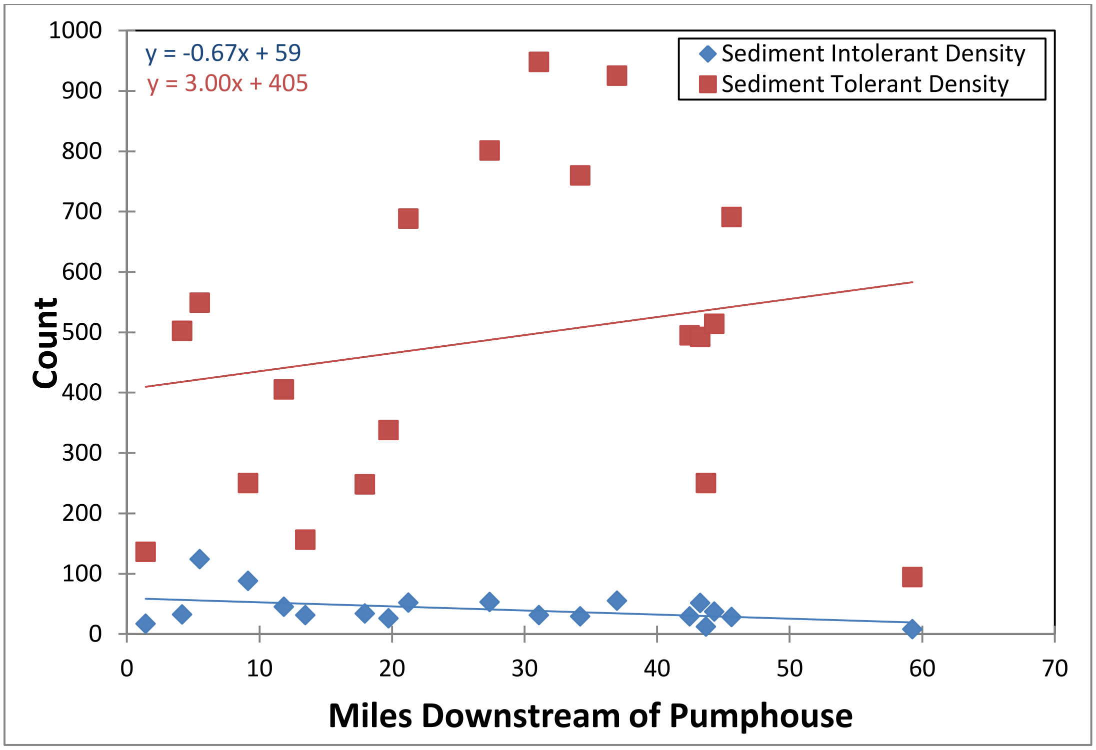


Figure 3.99 – Sediment-tolerant and sediment-intolerant species density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

As described above, there appears to be an increase in sediment influx to the main stem beginning at Catamount and continuing downstream to Dotsero. This sediment influx appears to be the key influence on macroinvertebrate density and richness. Certain indicator species were examined to show how density of sediment-tolerant taxa changes upstream and downstream of the Two Bridges and Catamount area. The total density of each taxon was summed for 2012 and 2013. Macroinvertebrate taxa collected in the study area that are relatively tolerant of fine sediment include: *Baetis tricaudatus, Ephemerella* sp., *Paraleptophlebia* sp., *Tricorythodes explicates, Hydroptila* sp., *Heptagenia* sp., *Isoperla* sp., and *Cheumatopsyche* sp. All of these sediment tolerant species showed an increasing trend in density moving downstream but only *Hydroptila* sp. and *Heptagenia* sp. were considered significant (Table 3.13). Taxa that are relatively intolerant of fine sediment in the study area include: *Orthocladiinae, Chironomini, Epeorus* sp., *Cultus* sp., *Lepidostoma* sp., *and Pteronarcys californica.* These taxa all showed a decrease in density downstream and four of the six trends were significant. Charts for these individual species are provided in Appendix E.

Table 3.13 – Trend analysis results for sediment tolerant and intolerant species density. Statistically significant trends are defined as p-value <0.10 and are highlighted in yellow. Regression X and Y units were miles downstream and either density (#/2700 cm^2) or richness, respectively.

Sediment Tolerant		
Species	**Regression Equation**	**p-value**
Baetis tricaudatus	0.51x+229	0.807
Ephemerella sp.	1.22x+58	0.269
Tricorythodes explicatus	0.37x+23	0.493
Paraleptophlebia sp.	0.52x+7.9	0.122
Hydroptila sp.	0.52x-3.4	0.027
Heptagenia sp.	0.19x-1.2	0.002
Isoperla sp.	0.04x+1.8	0.249
Cheumatopsyche sp.	0.19x+2.1	0.198

Sediment Intolerant		
Species	**Regression Equation**	**p-value**
Orthocladiinae	-2.17x+114	0.001
Chironomini	-0.15x+7.7	0.136
Epeorus sp.	-0.11x+5.2	0.005
Cultus sp.	-0.06x+5.9	0.313
Lepidostoma sp.	-0.17x+7.0	0.004
Pteronarcys californica	-0.78x+33	0.011

Macroinvertebrates were also sampled in perennial tributaries. Most tributaries were sampled just above the mouth of the confluence with the main stem and then again farther upstream, but still within 1 mi of the confluence. Sites at Upper Piney River, Upper Red Dirt Creek, and Rock Creek were not resampled in 2013 due to access issues. Rock, Blacktail, and Derby Creeks had the highest total macroinvertebrate densities (Figure 3.100). Total macroinvertebrate richness was highest in Rock Creek, Upper Piney River, and Derby Creek (Figure 3.101). Upper and Lower Red Dirt Creeks had the lowest total densities and richness. EPT density was the highest in Derby Creek, Upper Piney Rivers, and Blacktail Creek (Figure 3.102). The Upper and Lower Piney Rivers, Derby Creek, Blacktail Creek, and Upper Sheephorn Creek had the highest EPT richness (Figure 3.103). Upper and Lower Red Dirt Creeks had the lowest EPT densities and richness. Overall, it appears that tributaries farther downstream in the study area generally tended to have lower macroinvertebrate and EPT densities and richness. This could be indicative of the changing geology and increase in fine sediment delivery in the lower parts of the study area.

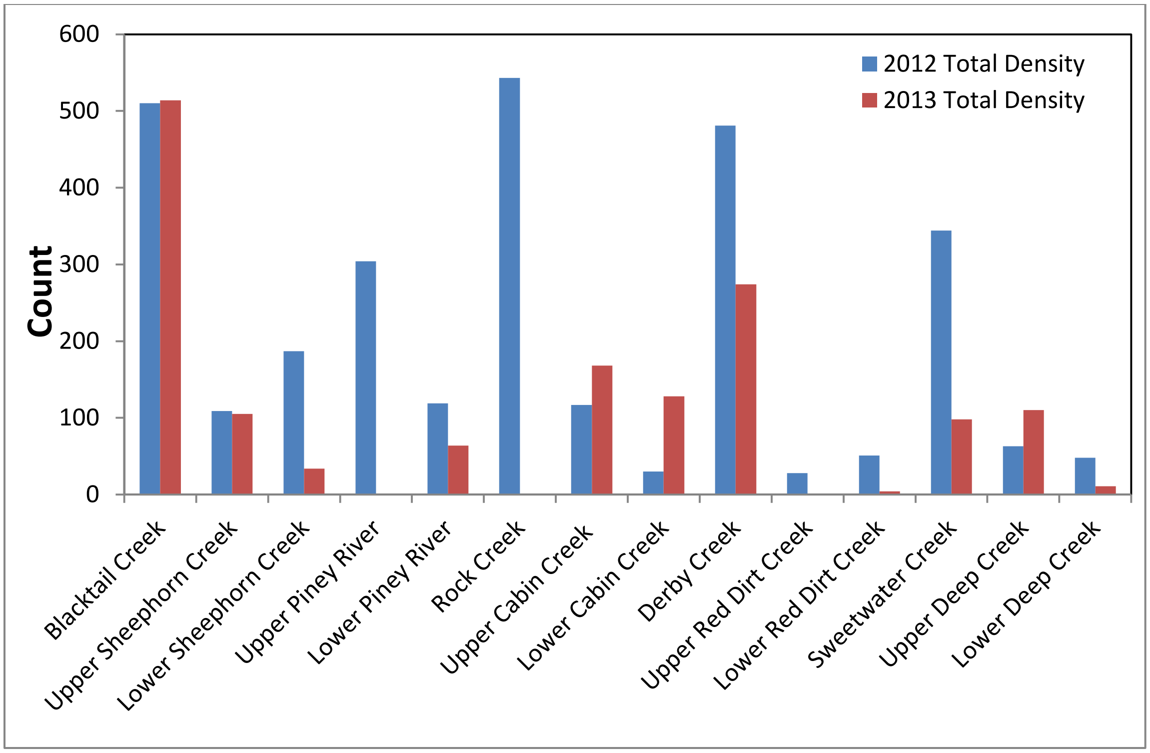


Figure 3.100 – Total macroinvertebrate density in the tributaries.

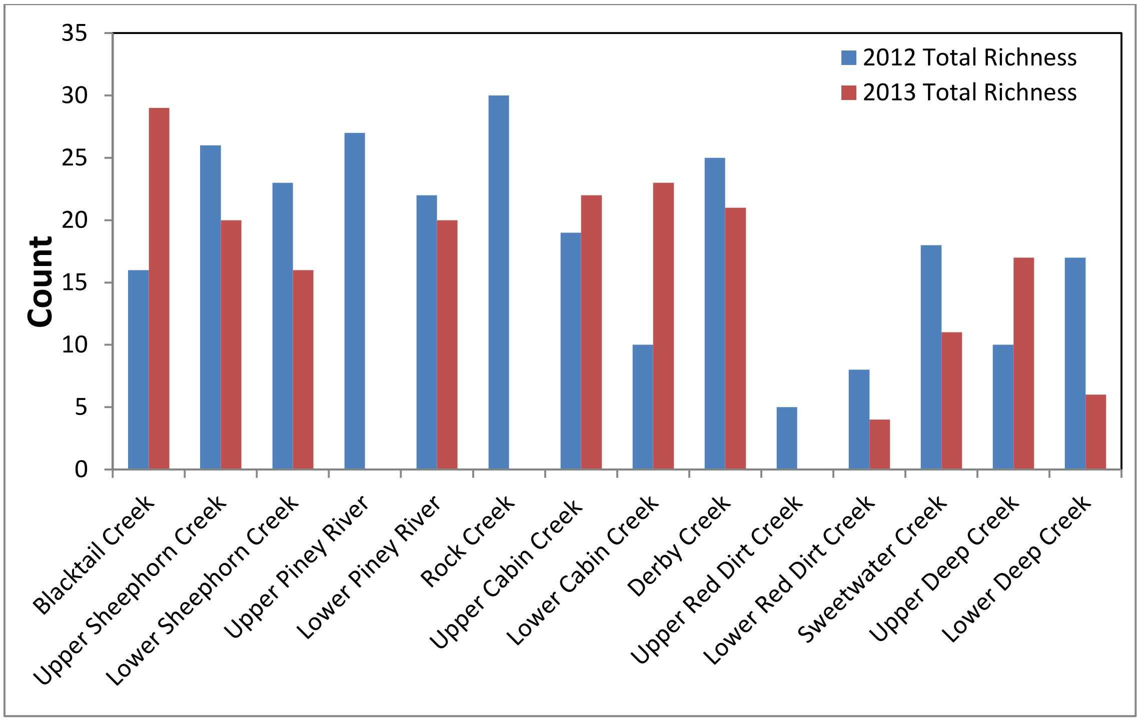


Figure 3.101 – Total macroinvertebrate richness in the tributaries.

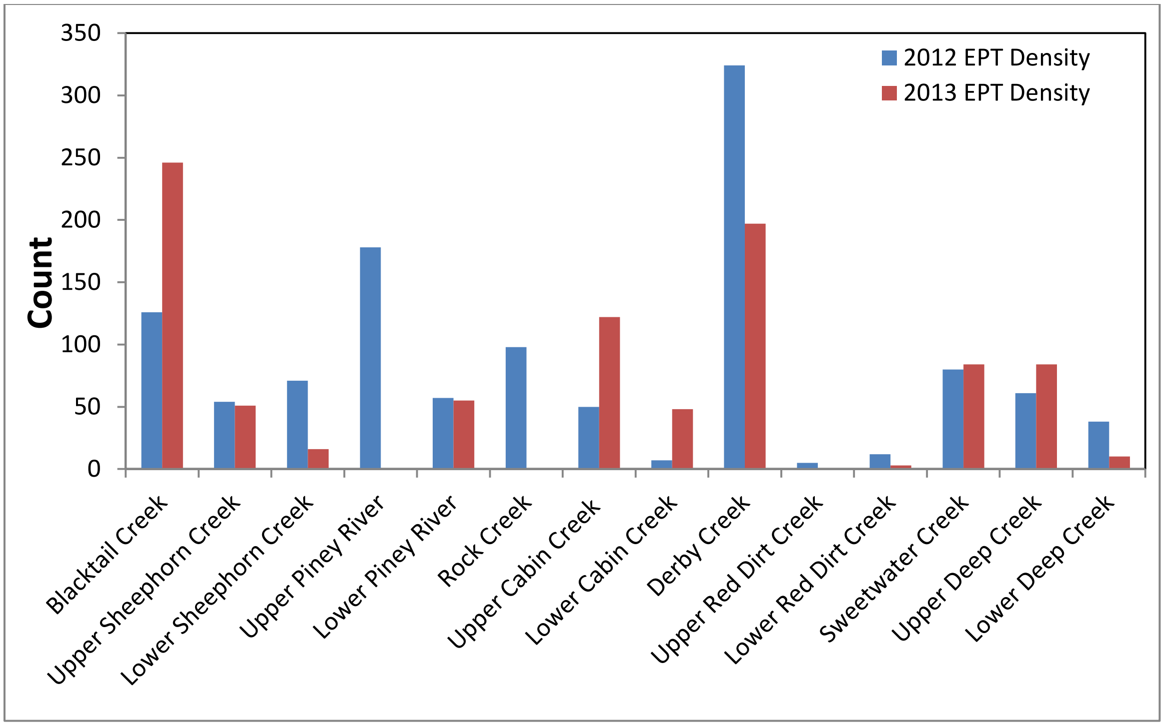


Figure 3.102 – Total EPT density in the tributaries.

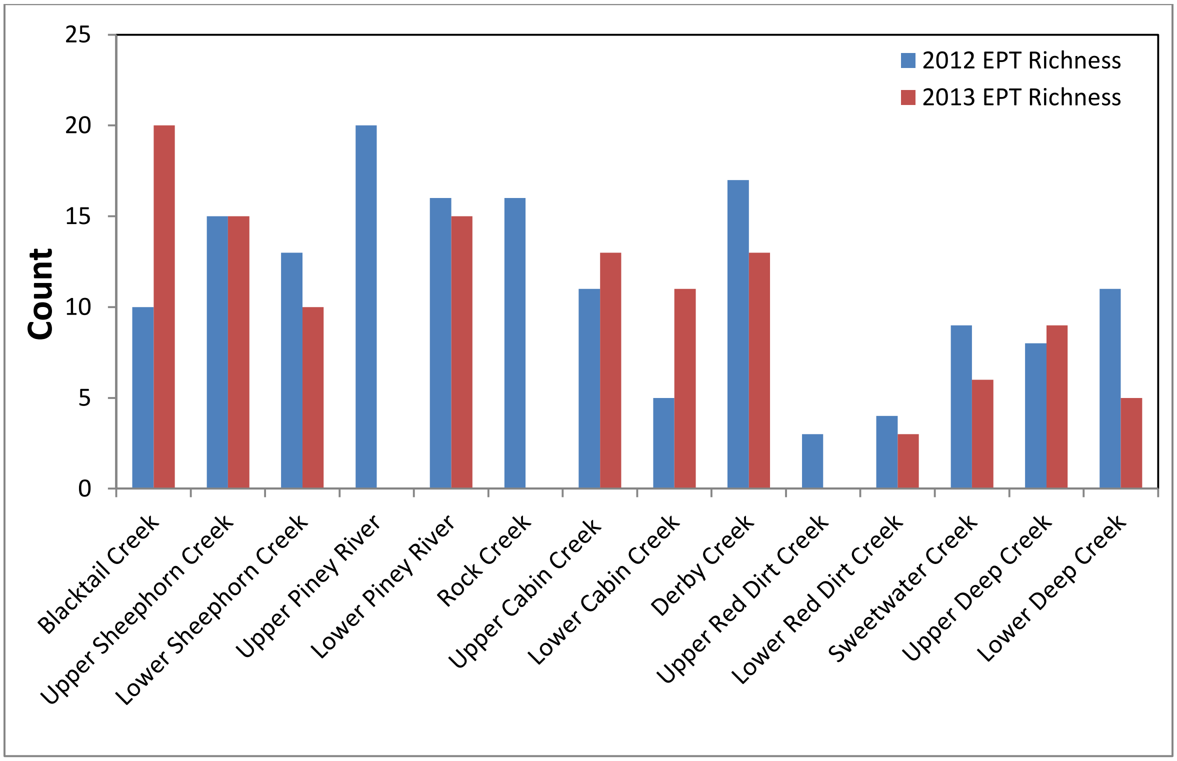


Figure 3.103 – Total EPT richness in the tributaries.

3.8.1 Macroinvertebrate Multi-metric Index Scores

CDPHE WQCC uses the Multi-metric Index (MMI) to assess attainment of aquatic life use standards as required by the Colorado Water Act and defined in the 2010 *Aquatic Life Use Attainment* (CDPHE WQCC, 2010) methodology. The MMI combines results from several weighted indices to produce a standardized score from 0 to 100, comparing results from site samples to healthy un-impacted 'reference' streams across the state in similar biotypes. All samples in the project area fell within the Transitional biotype, Biotype 2. In this biotype, scores above 52 are attaining aquatic life use standards, while sites scoring below 42 are considered impaired. If a sample scores between this interval, two additional metrics determine the final attainment status. Researchers sampled 24 total sites in 2013 and 2014; 24 on the main stem and 14 on tributaries. Streamflow variability prevented re-sampling of all sites in both years. In addition, low densities at some sites, and low numbers in certain operation taxonomic units prevented MMI calculation for some samples. The MMI was successfully calculated for 16 sites on the Colorado River and 6 tributary sites.

All sites attained state standards in 2012 and 2013, except the 2012 Blacktail Creek sample (Figure 3.104, Blacktail data point is presented in red for emphasis). This site produced a high score the next year, indicating either a wide natural variability to the creek, or potentially some introduced sampling error or outlier condition in the first year. Scores appeared to indicate a slight upward trend from Pumphouse to Dotsero on the main stem, although this was not statistically tested. As compared to state standards, generalized metrics for community assemblages appeared healthy in the project area.

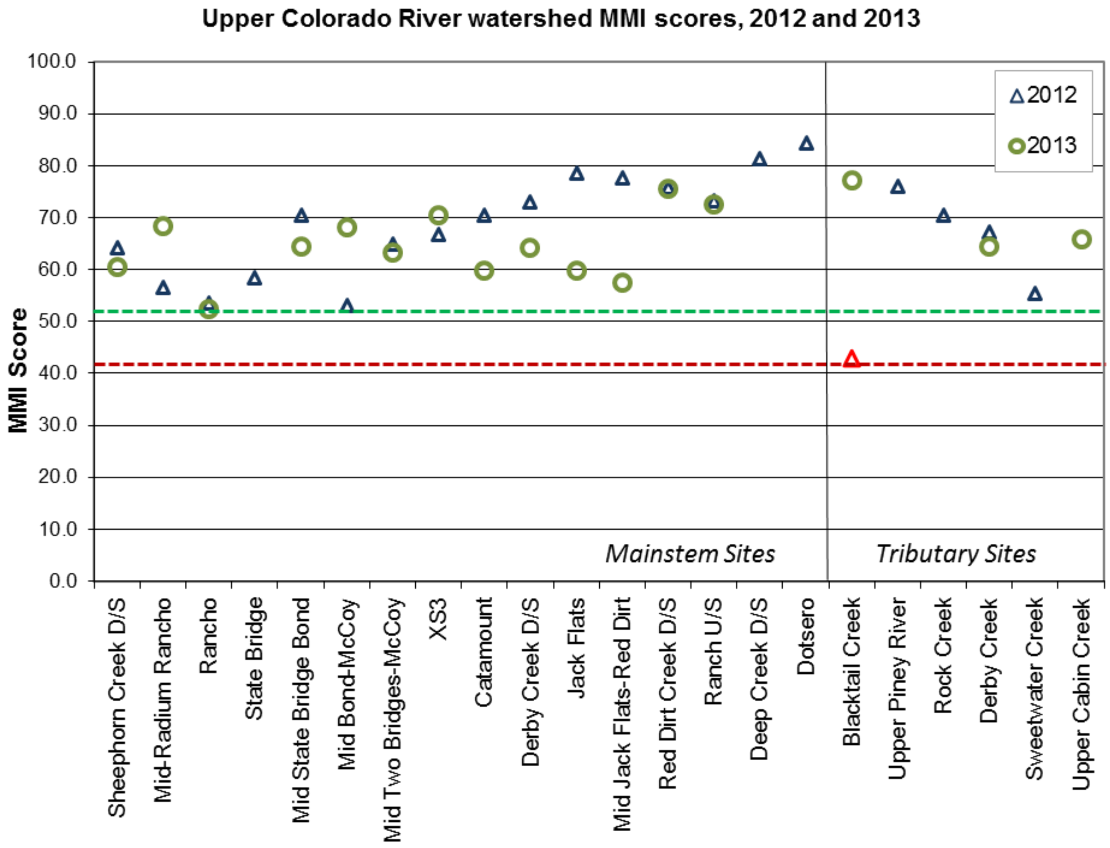


Figure 3.104 – MMI scores for main stem and tributary sites, 2012 and 2013.

MMI results appear to parallel the previously-reported trends in Total Richness and EPT Richness, which increased slightly in a downstream direction within the project area. Samples from perennial tributaries exhibit an apparent decreasing trend in the downstream direction, although again this was not statistically tested due to the low sample population. Perennial tributaries in the project area generally feature undeveloped or slightly-impacted headwater reaches, which then flow through areas of diversions and increased ranching including irrigated pasture and hay production, before joining the Colorado. The lower reaches of these creeks tend to have the available bottomland for agricultural use, small residential development, or access road alignment and thus the most potential for stream impacts in terms of dewatering, grazing impacts, and physical alteration. In general, MMI scores indicate the lower reaches of perennial streams are attaining CDPHE WQCC aquatic life use standards, although continued lower-frequency monitoring at a smaller subset of locations may help detect impacts of land use or changing climate/runoff regimes in the region to aquatic communities.

3.9 Fishes

Between Pumphouse and Radium, the river is designated as a wild reproducing brown trout fishery. Rainbow trout are present but the population is much smaller than the brown trout.

Electrofishing data from 2010-2012 indicate that brown trout biomass is approximately 5 to 14 times greater than rainbow trout (Ewert and Bakich, 2014) (Figure 3.105). Mountain whitefish were also caught in substantial numbers during those years, but electrofishing for this species is difficult due to recapture rates. All fish were determined to be in good condition due partially to abundant *Pteronarcys californica* larvae as a food source (Ewert, 2013).

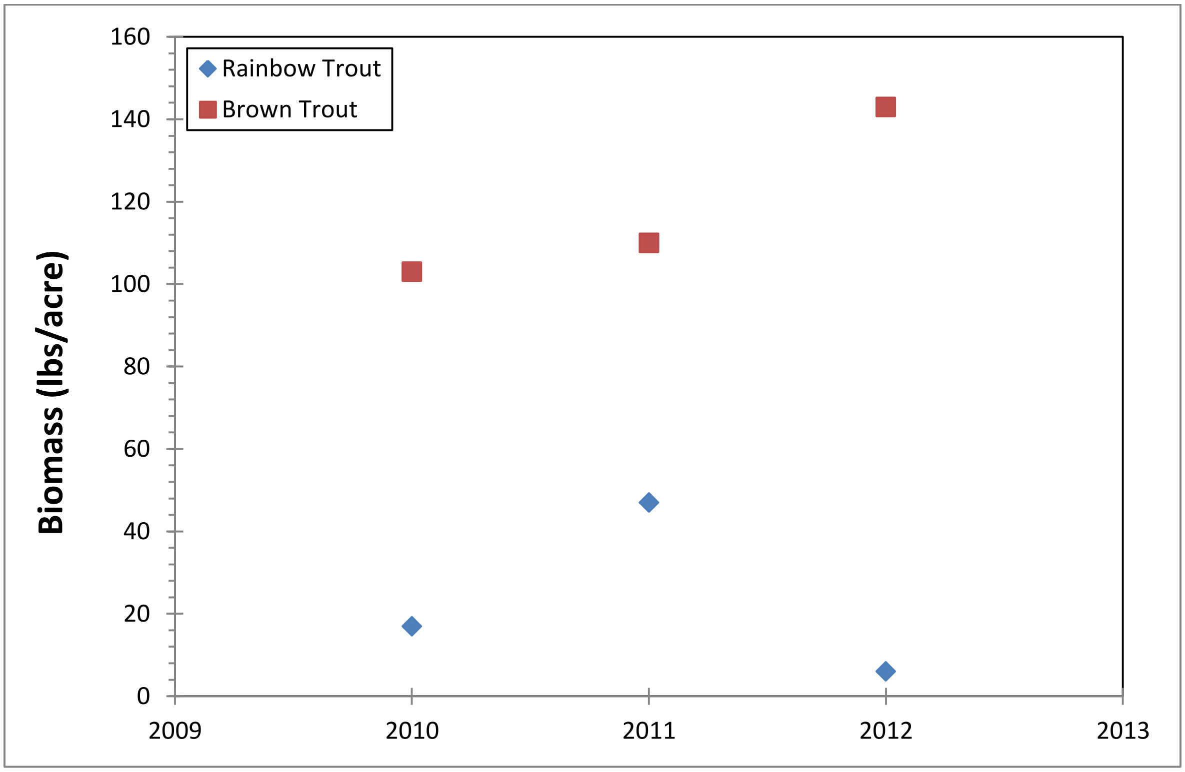


Figure 3.105 – Estimated brown and rainbow trout biomass from 2010 to 2012 between Pumphouse and Radium.

Electrofishing data from the CPW indicate that brown trout biomass decreases moving downstream. Between 2008 and 2013, the highest biomass occurred at Radium and it decreased at each site downstream (Figure 3.106). The very low biomass at Lyons Gulch in 2013 was a product of the Sweetwater Creek flood and resulting fish kill on the main stem. Local fishing guides anecdotally reported based on their experience on the river that trout become fewer and smaller downstream of Catamount.

Electrofishing surveys indicate a transition from a trout-dominated to sucker and chub-dominated water seems to occur downstream of Catamount. Fish count data in 2009 and 2010 indicate that although trout are still established downstream of Catamount, the sucker and chub populations become more prevalent (Figure 3.107). This shift in fish assemblages is likely caused by many factors including increases in water temperature, sediment deposition, and a greater prevalence of homogeneous run and glide habitat compared to upstream of Catamount.

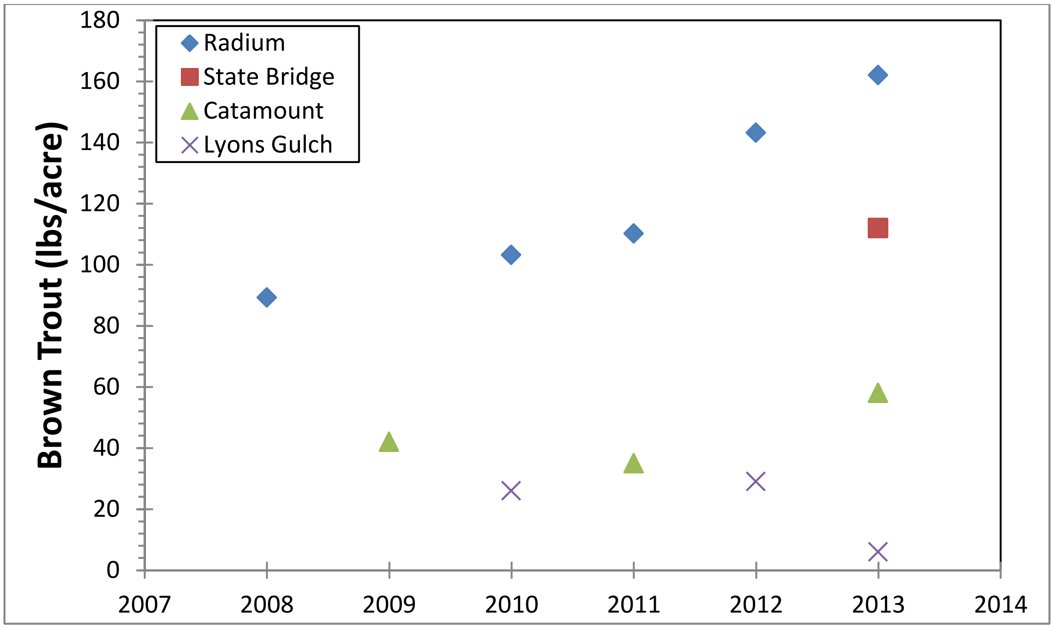


Figure 3.106 – Brown trout biomass at four locations within the study area.

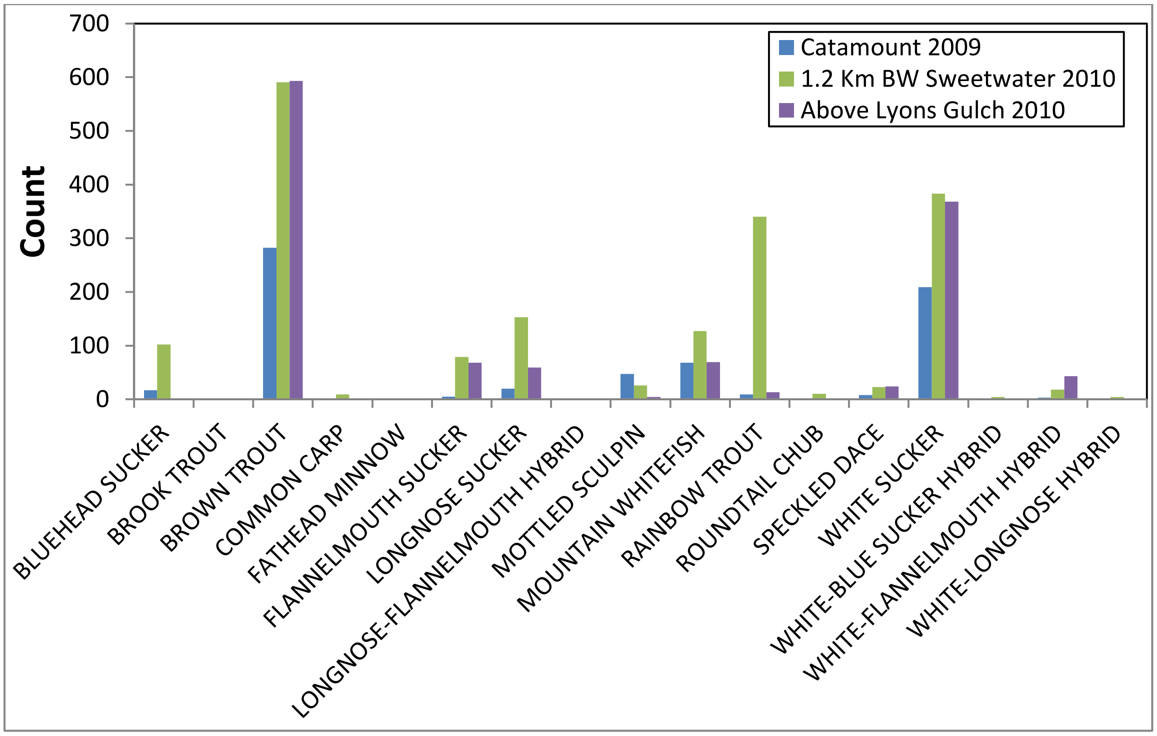


Figure 3.107 – Fish count data below Catamount from 2009 and 2010.

3.10 Flushing Flows

The importance of moderate to high streamflows in maintaining aquatic and riparian ecosystems is widely recognized (Poff *et al*., 1997; Bunn and Arthington, 2002; Annear *et al*., 2004; Poff and Zimmerman, 2010). Moderate to high flows in Rocky Mountain snowmelt rivers provide several types of amenities, physical processes, and ecological functions. Whiting (2002) summarized eight types of management objectives associated with environmental flows in these systems:

1) maintain recreation and aesthetics,
2) maintain sediment sizes on the bed and their mobility,
3) channel maintenance flows,
4) maintain longitudinal continuity of the channel,
5) maintain features and habitat,
6) floodplain maintenance,
7) hyporheic zone maintenance, and
8) maintain riparian vegetation.

Streamflow depletions in the Colorado River watershed have increased the risk of habitat degradation associated with sediment deposition and clogging of the river bed. In addition to adequate streamflows, spawning fish and aquatic invertebrates depend on open interstices in the river bed. Fine sediment deposition can reduce or eliminate this habitat (Waters, 1995). For example, fish eggs deposited within the river bed require interstitial space for oxygenation and fry emergence (Reiser *et al*., 1990). Excessive loading of fine sediments can also impair growth and survival of juvenile salmonids (Suttle *et al*., 2004).

A flushing flow analysis was performed on the main stem Colorado River to provide a preliminary estimate of flows needed to mobilize the median grain size bed material and surficial deposits of fine sediment at cross sections along the Colorado River through the study area. Methods for the flushing flow analysis are presented in detail in Appendix F. A brief overview of the field methods are provided below followed by the results. Sites were chosen along the Colorado River to be representative of a larger portion of the river, yet had to be to allow for data collection across the entire channel. Due to the size and limited wadeability of the Colorado River through the study area, only five sites were chosen as representative and accessible (Figure 3.108). At each site, total station surveys of cross sections and longitudinal profiles of bed slope, existing water-surface slope, and bankfull water-surface slope were conducted between November 27 and December 14, 2012 (Table 3.14). Cross sections were plotted for these five representative sites and are presented in Appendix G.

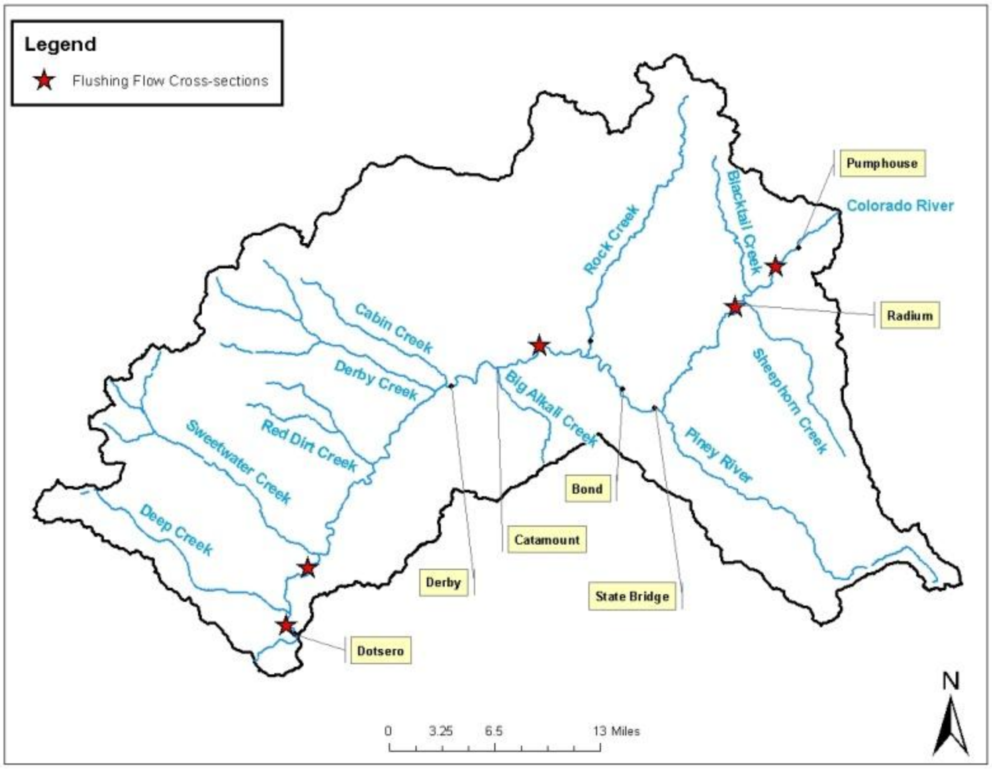


Figure 3.108 – Cross-section locations used in the flushing flow analysis.

Table 3.14 – Dates that substrate; percent embeddedness; and percent fines, coarse, and algae were sampled.

Cross Section	Sampling Dates Pre-runoff	Post-runoff
Pumphouse	12/14/2012	7/3/2013
Radium	11/28/2012	7/3/2013
Above Catamount	11/28/2012	7/3/2013
Below Sweetwater	11/27/2012	7/3/2013
Above Dotsero	11/28/2012	7/3/2013

A systematic point grid frame method was used in combination with a gravelometer to collect substrate data at each site along transects spanning the bankfull channel (Bunte and Abt, 2001) (Figure 3.109). The systematic point grid frame method was used to obtain over 300 pebble count observations with the gravelometer. Transects were placed in riffles as these areas are commonly used to assess the condition of aquatic ecosystems within gravel-bed streams. Substrate samples were taken pre- and post-runoff to quantify changes in bed material composition as a result of the magnitude and duration characteristics of the 2013 snowmelt hydrograph. Resulting grain-size distributions taken pre-runoff were truncated at 2 mm to estimate the d_{50} used in the flushing flow analysis (grain-size distributions are found in Appendix H). The substrate data collected before runoff was deemed a more accurate representation of what would possibly be flushed during runoff.

Figure 3.109 – A systematic point grid frame method was used in combination with a gravelometer to collect substrate data.

The point grid frame method was also used in conjunction with a bucket viewer to collect presence of fines, algae, and coarse substrate data. Embeddedness data were collected at each site by measuring the average depth of the largest substrate above and below the layer of fine material surrounding the rock. Fifteen rocks within the wetted boundary were measured at each site. Both embeddedness and presence of fines data were also collected pre- and post-runoff.

A peak flow of 1,750 cfs occurred at Kremmling on May 18, 2013 (Figure 3.110). Flows remained above 1,500 cfs for 3 days. The Colorado River at Dotsero, above the confluence with the Eagle River, also peaked on May 18 at 3,660 cfs. Flows remained above 2,870 cfs for 3 days. The Kremmling hydrograph applies to the Pumphouse and Radium cross sections. The Below Sweetwater and Above Dotsero cross sections are represented by the Dotsero hydrograph. For Above Catamount, the peak flow also occurred on May 18 and was 3,031 cfs. Flows remained above 1,966 cfs for 3 days. Results from the field collection and analysis are presented below (Table 3.15, Table 3.16, Table 3.17, and Table 3.18). Changes in substrate as a result of these flows will be discussed later in the in this section.

Studies on several gravel-bed rivers in the western United States have found that in river systems with slopes less than 1%, bankfull dimensionless shear stresses typically range from 0.02 to 0.06. Lower dimensionless shear stress values perform more of a surface flushing of veneers, while the incipient motion of coarse armor beds occurs at higher values (Table 3.19) (Milhous, 2000, 2003, 2009; Parker, 2008; Wilcock, 1998). A detailed description of the flushing flow results at each site follows.

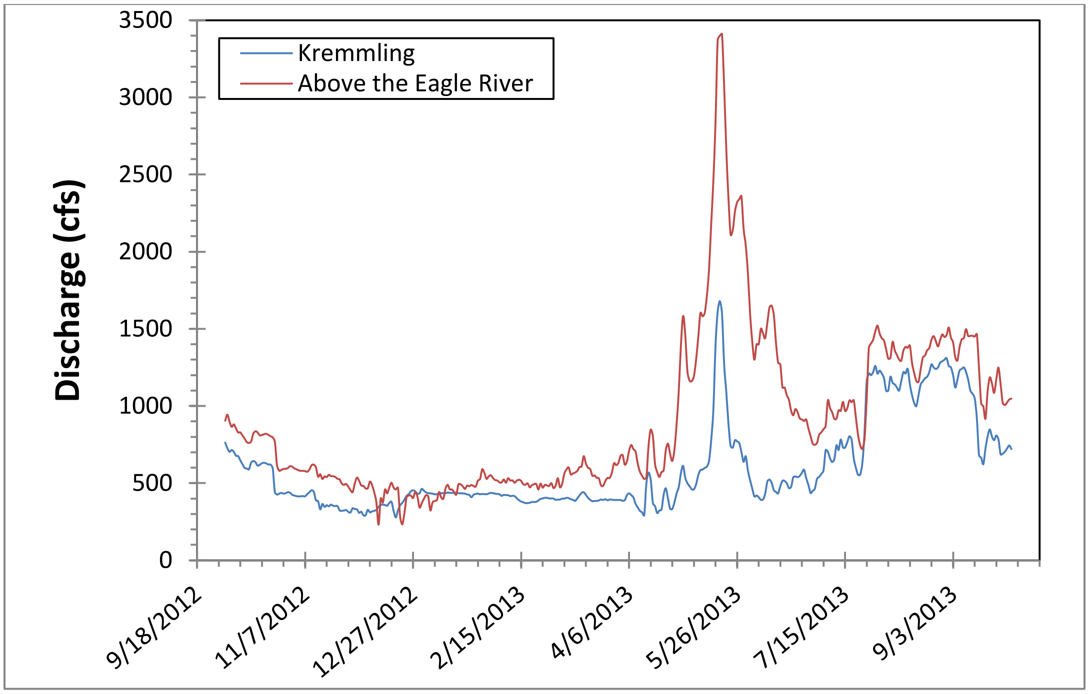


Figure 3.110 – Water year 2013 snowmelt hydrograph for the Colorado River at Kremmling and above the confluence with the Eagle River.

Table 3.15 – Cross-sectional and longitudinal characteristics of each site.

Site	$w = aQ^b$ (ft)	Post Diversion $Q_{1.5}$ (cfs)	n-value	Standard Deviation n-value	Bankfull Water Slope	SD Bankfull Water Slope	Bed Slope	d_{50} (mm)
Pumphouse	$13.285Q^{0.304}$	2050	0.035	0.00185	0.0029	0.00015	0.0029	102
Radium	$8.054Q^{0.355}$	2050	0.030	0.0015	0.0019	0.00009	0.0027	70
Above Catamount	$45.602Q^{0.183}$	2050	0.035	0.00185	0.0023	0.00012	0.0034	94
Below Sweetwater	$26.296Q^{0.220}$	3590	0.024	0.0012	0.0011	0.00006	0.0021	107
Above Dotsero	$7.385Q^{0.380}$	3590	0.030	0.0015	0.0038	0.00019	0.0049	77

Where a and b = constants; d_{50} = median diameter of bed material; n = Manning roughness coefficient; Q = volumetric flow rate; $Q_{1.5}$ = peak discharge with a return period of 1.5 years in the annual maximum series; w = effective channel width; and SD = standard deviation.

Table 3.16 – Percent embeddedness results for each cross section pre- and post-runoff.

Percent Embeddedness		
Cross Section	**Pre-runoff**	**Post-runoff**
Pumphouse	50	9
Radium	30	44
Above Catamount	32	37
Below Sweetwater	52	42
Above Dotsero	46	51

Table 3.17 – Percent fines, algae, and coarse material at each cross section pre- and post-runoff.

	Pre-runoff			Post-runoff		
Cross Section	**Fines Present**	**Algae Present**	**Coarse Present**	**Fines Present**	**Algae Present**	**Coarse Present**
Pumphouse	12	55	33	1	69	30
Radium	28	26	46	11	63	25
Above Catamount	8	65	27	2	75	24
Below Sweetwater	8	26	67	14	22	65
Above Dotsero	15	58	27	19	71	10

Table 3.18 – Interpretation of dimensionless shear stress values in terms of states of fine sediment flushing and coarse substrate mobilization at sites with slopes less than approximately 1% (Milhous, 2000, 2003, 2009; Parker, 2008; Wilcock, 1998).

	Dimensionless Shear Stress Referenced to d_{50}	
Sediment Movement State	**Lower Bound**	**Upper Bound**
Fines and sand are stored or in partial motion	-	0.021
Surface Cleaning	0.021	0.035
Movement of coarse armor	0.035	0.06-0.084

Table 3.19 – Flushing flow values for different critical shear stresses (referenced to the d_{50}) at each site in the study area.

Site Name	Critical Dimensionless Shear Stress (τ_*) Referenced to the d_{50}	Pre-runoff <2 mm		
		Median (cfs)	25th Percentile	75th Percentile
Pumphouse	0.021	5251	4574	6026
Pumphouse	0.030	11275	10255	12433
Pumphouse	0.035	15665	14237	17246
Pumphouse	0.040	20843	18957	22953
Pumphouse	0.045	26804	24355	29504
Radium	0.021	3224	2738	3793
Radium	0.030	7980	7174	8901
Radium	0.035	11839	10602	13215
Radium	0.040	16596	14911	18530
Radium	0.045	22396	20077	25026
Above Catamount	0.021	7420	6590	8307
Above Catamount	0.030	14262	13270	15331
Above Catamount	0.035	18949	17637	20360
Above Catamount	0.040	24187	22526	26065
Above Catamount	0.045	30031	27975	32301
Below Sweetwater	0.021	22897	20278	25816
Below Sweetwater	0.030	48102	44661	51776
Below Sweetwater	0.035	66144	61413	71235
Below Sweetwater	0.040	87015	80813	93520
Below Sweetwater	0.045	110685	102720	119285
Above Dotsero	0.021	5584	4970	6275
Above Dotsero	0.030	10398	9588	11244
Above Dotsero	0.035	13542	12540	14658
Above Dotsero	0.040	17044	15768	18463
Above Dotsero	0.045	20971	19331	22691

3.10.1 Pumphouse

Results from the flushing flow analysis show that possible coarse bed material mobilization at Pumphouse (Figure 3.111) occurs above 15,600 cfs (τ_* = 0.035). Removal of veneers of surface fines may occur at flows above 5,200 cfs (τ_* = 0.021) (Table 3.19). The peak flow in 2013 at Pumphouse was only 1,750 cfs which would indicate that flushing flows were highly improbable. Observed physical data are mostly in agreement. Pebble counts conducted pre- and post-runoff show that the percent of bed material ≤8 mm increased after runoff (Figure

3.112). The percent fines, algae, and coarse data show that more algae were present post-runoff (Figure 3.113) (Table 3.17). These can both be possible indications that flushing flows did not occur at Pumphouse; however, percent embeddedness data dropped from 50% pre-runoff to 9% post-runoff (Table 3.16). It is important to remember that percent fines are based on point samples of the uppermost layer of the bed and not an indication of the depth of the fines associated with the embeddedness data. Sampling methodology for embeddedness is far from standardized potentially making the data relatively imprecise compared to the other measures. However, these results show that removal of some of the finer material occurred in some areas of the channel. General observations of the bed material post-runoff indicate that surficial deposits appeared to be partially removed in the middle of the channel where shear stresses are highest, but were still present in appreciable amounts in high stress zones. Less removal of surficial fines occurred along the channel margins. Movement of larger bed material appeared to not occur based on the increased presence of algae and the bed remaining armored post-runoff.

Figure 3.111 – Pumphouse cross-section location.

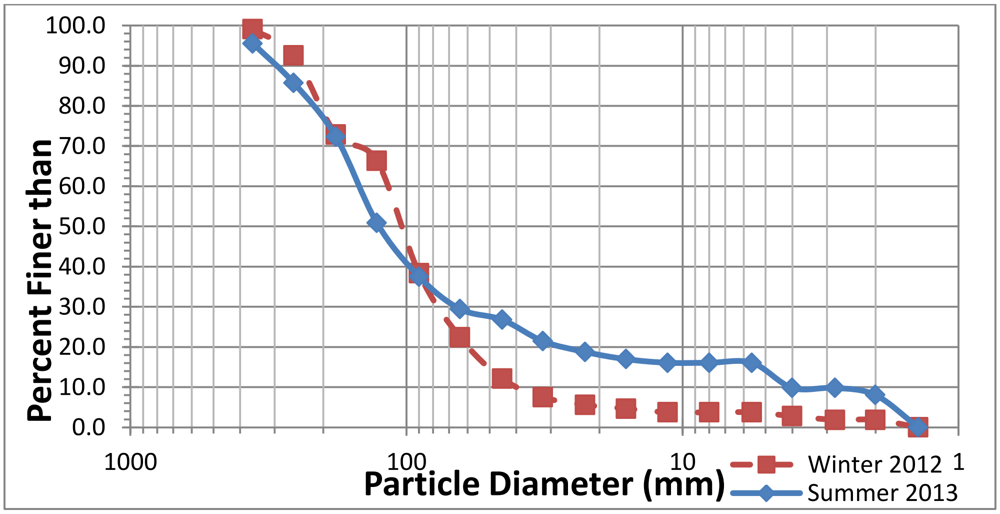


Figure 3.112 – Grain-size distribution at the Pumphouse cross section. Sampling occurred on 12/13/2012 and 7/2/2013.

Figure 3.113 – Green filamentous algae covered most of the post-runoff stream bed at Pumphouse.

Pumphouse is uniquely set at the bottom of Gore Canyon where the channel slope rapidly decreases. The bed material here consists of large boulders and cobbles with smaller substrate mixed in. The coarsest materials were most likely deposited during very large pre-diversion peak flows. The resulting high flushing flow values are realistic due to the large bed material and flatter slope. However, some visual observations indicate the removal of surface veneers appeared to possibly occur in certain channel areas at flows lower than 5,000 cfs.

3.10.2 Radium

Flushing flow analysis results suggest that flows above 11,800 cfs (τ_* = 0.035) may move coarse bed material. Flows above 3,200 cfs (τ_* = 0.021) would possibly provide some removal of surface veneers of fines (Table 3.19). The peak flow in 2013 reached 1,750 cfs, indicating that such removal was highly unlikely. The physical data also show that the bed material did not flush at Radium (Figure 3.114). Pebble count data after runoff indicate that the percent of bed material ≤8 mm increased (Figure 3.115). Algae also increased substantially (Table 3.17). The percent embeddedness at Radium increased from 30 to 44% (Table 3.16). These results all indicate that bed material flushing did not occur at Radium.

Figure 3.114 – Radium cross-section location at River Mile 7.2.

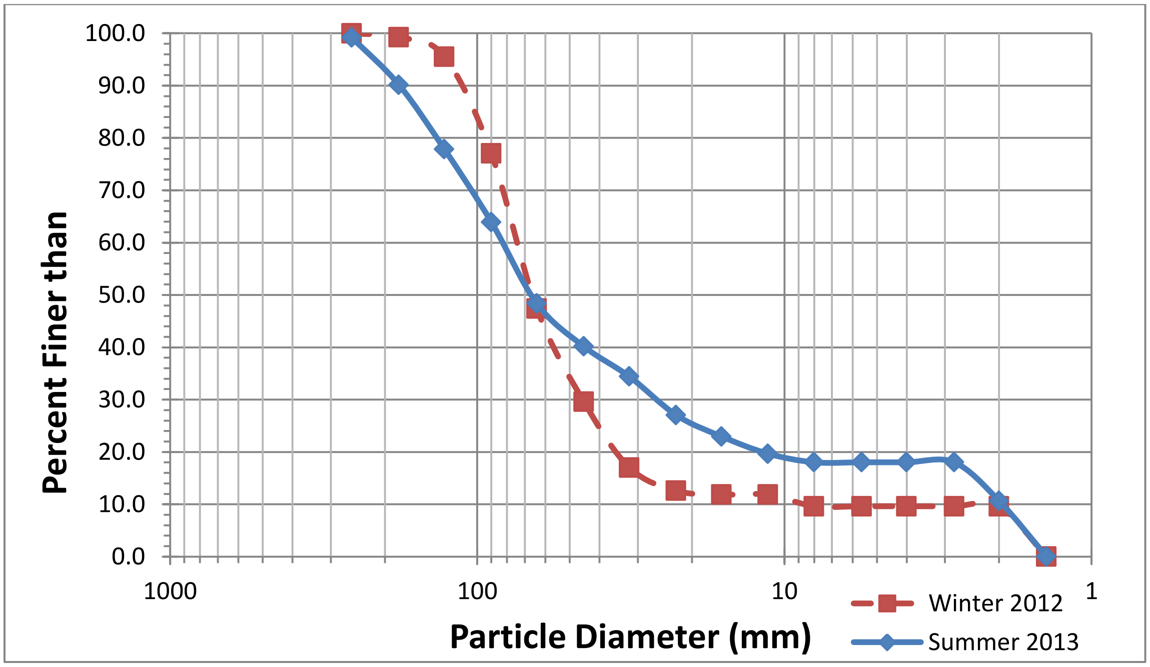


Figure 3.115 – Grain-size distribution at the Radium cross section. Sampling occurred on 11/27/2012 and 7/2/2013.

3.10.3 Above Catamount

At the Above Catamount site (Figure 3.116), flows above 18,900 cfs (τ_* = 0.035) are likely to mobilize coarse bed material. Flows above 7,400 cfs (τ_* = 0.021) are likely to remove surface veneers of fine material (Table 3.19). However, with enough sediment supply the surface veneer can be replaced on the falling limb of the peak runoff. With a 2013 peak flow of 3,031 cfs, flushing is unlikely at this site. The physical data also indicate that flushing did not occur and that the percent material ≤8 mm increased post-runoff (Figure 3.117). The percentage of algae increased (Table 3.17) and percent embeddedness increased from 32 to 37% (Table 3.16). Post-runoff, the bed appeared to be more inundated by veneers of fine gravel and sand. Green filamentous algae increased post-runoff and were densely covering the entire study riffle (Figure 3.118). It appears that no removal of surface fines occurred.

Figure 3.116 – Above Catamount cross-section location at River Mile 27.4.

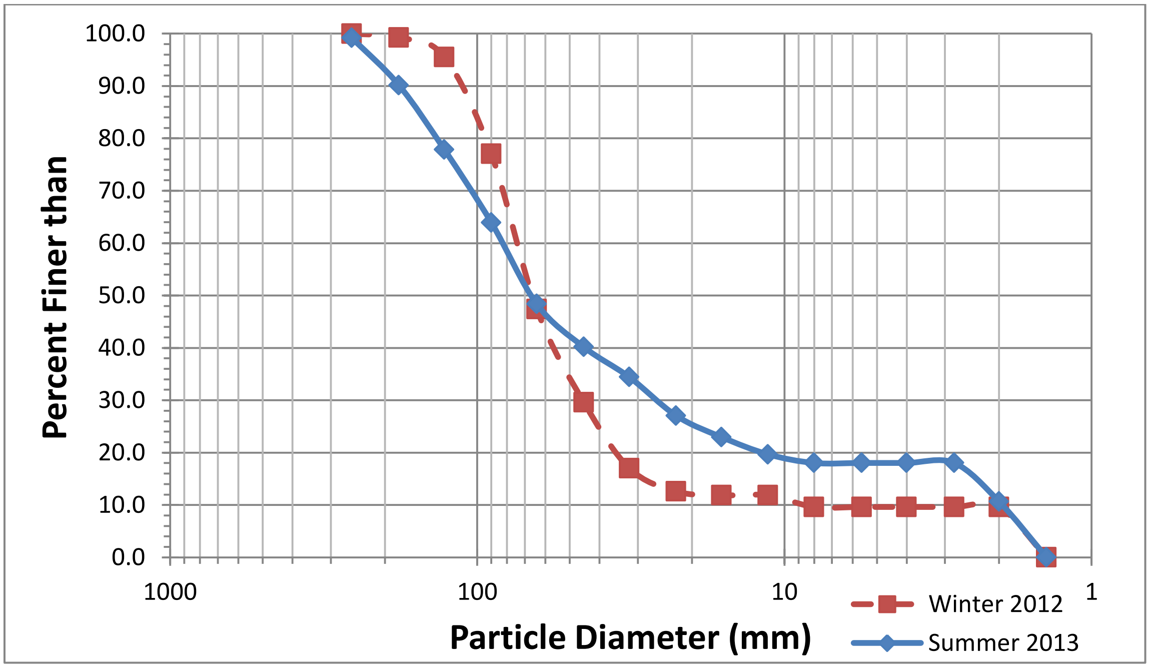


Figure 3.117 – Grain-size distribution at the Above Catamount cross section. Sampling occurred on 11/27/2012 and 7/2/2013.

Figure 3.118 – Green filamentous algae were covering the entire riffle at Above Catamount post-runoff.

3.10.4 Below Sweetwater

Flushing flows results for Below Sweetwater (Figure 3.119) were substantially higher than for other cross sections. This reflects the low slope and large bed material present. Flushing flows were above 66,000 cfs (τ_* = 0.035) for mobilization of coarse material and 22,900 cfs (τ_* = 0.021) for removal of surface fines (Table 3.19). The peak flow in 2013 only reached 3,660 cfs; thus, the shear stress analysis would predict that flushing is highly improbable. Pebble count data show that the percent of bed material ≤8 mm increased slightly (Figure 3.120). The amount of algae increased and the percent of fines also increased slightly (Figure 3.121 and Table 3.17). However, the embeddedness slightly decreased from 52 to 42% (Table 3.16), although the bed remained highly embedded with sand and fines. It appeared that no substantial change had occurred in the bed material and that no apparent mobilization of coarse material or removal of surface fines had occurred. The decrease in embeddedness could be due to inherent error and imprecision relative to the other measures.

Figure 3.119 – Below Sweetwater Creek cross section located at River Mile 54.1.

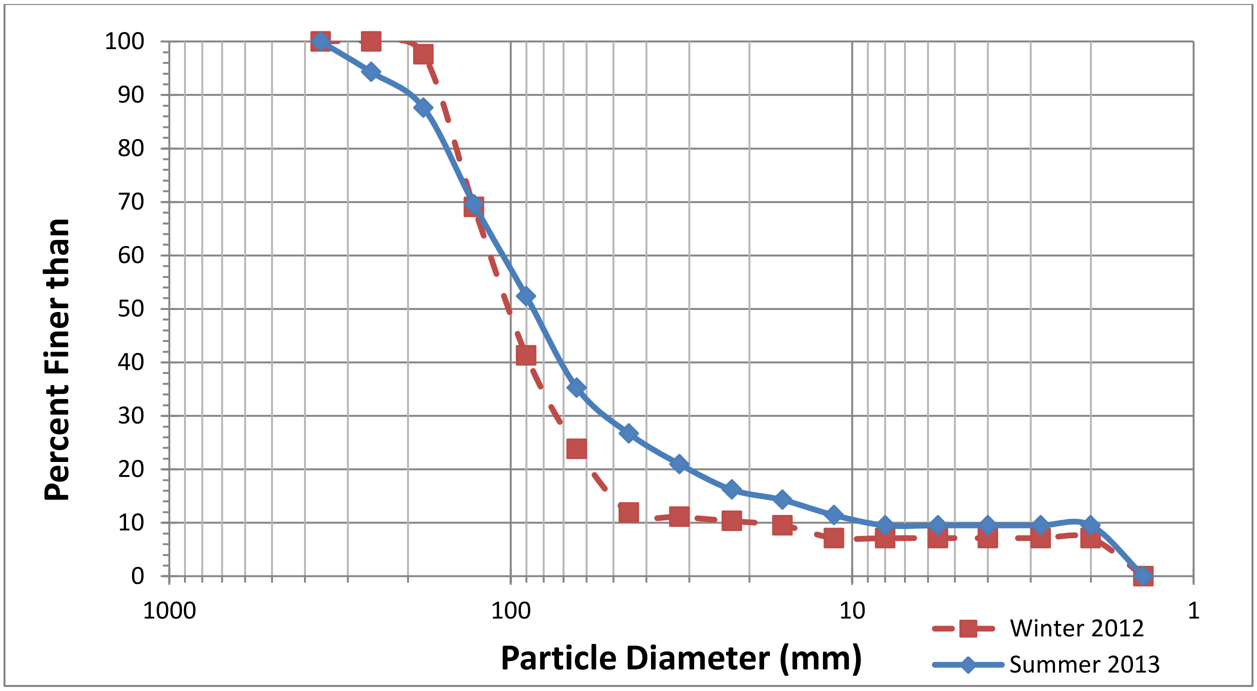


Figure 3.120 – Grain-size distribution at a cross section downstream of Sweetwater Creek. Sampling occurred on 11/28/2012 and 7/2/2013.

Figure 3.121 – Algae covered most of the bed material within the riffle Below Sweetwater post-runoff.

3.10.5 Above Dotsero

Flushing flow values for Above Dotsero (Figure 3.122) were above 13,500 cfs ($\tau_* = 0.035$) for coarse bed mobilization and above 5,500 cfs ($\tau_* = 0.021$) for surface sweeping (Table 3.19). Peak flows in 2013 only reached 3,660 cfs so no flushing would be expected based on shear stress analysis. The physical observations confirm this. Pebble counts show that the percent of substrate ≤8 mm substantially increased post-runoff (Figure 3.123). The embeddedness slightly increased and both fines and algae presence increased (Figure 3.124 and Figure 3.125, respectively) (Table 3.17 and Table 3.16). It appeared that the riffle had more fine sediment present than before runoff. Clouds of turbid water rose behind us with each step in the riffle (Figure 3.126). Overall, the Above Dotsero site showed no evidence of coarse substrate mobilization or removal of surface fines.

Figure 3.122 – Above Dotsero cross-section location.

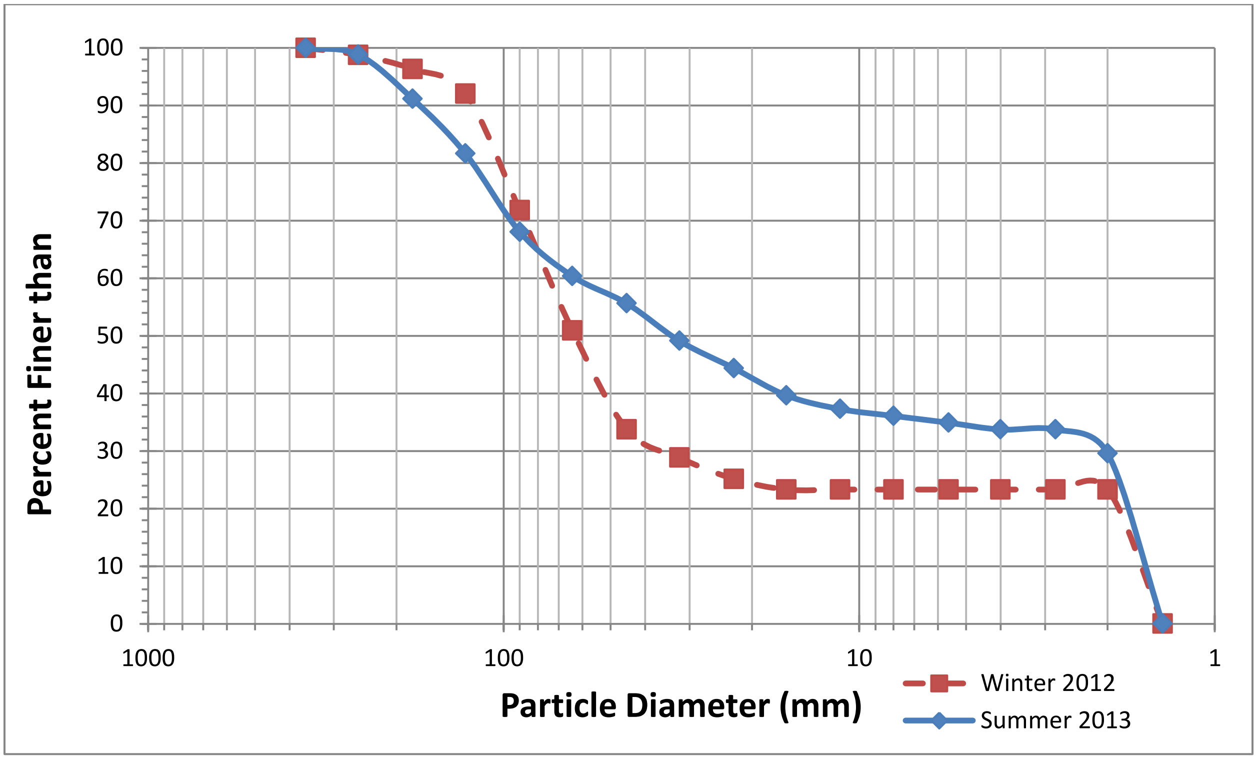


Figure 3.123 – Grain-size distribution at a cross section downstream of Deep Creek. Sampling occurred on 11/28/2012 and 7/2/2013.

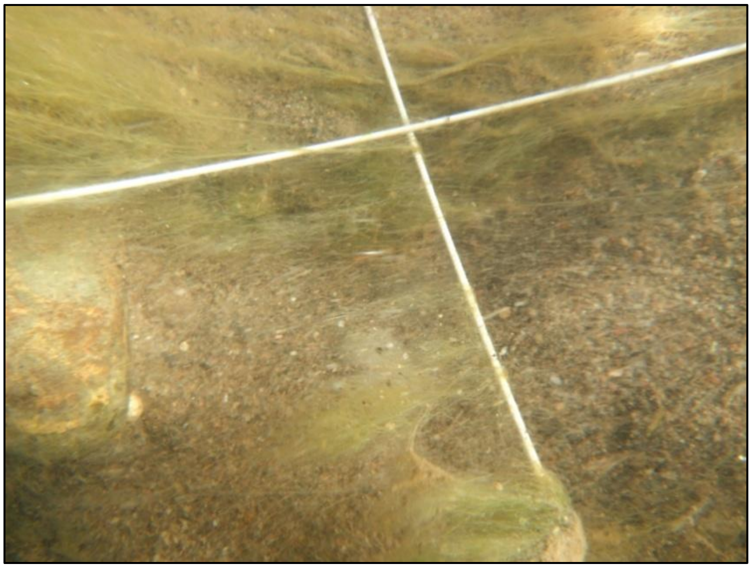


Figure 3.124 – Small gravel, sand, and fines were filling in interstitial spaces within the large bed material at Above Dotsero post-runoff.

Figure 3.125 – Green filamentous algae were blanketing much of the river bed at Above Dotsero post-runoff.

Figure 3.126 – With each step clouds of fines would appear downstream at Above Dotsero post-runoff.

3.10.6 Conclusions – Flushing Flows

The peak flows in 2013 did not mobilize coarse sediment at any of the study sites. Marginal removal of surface veneers of fines from the channel center may have occurred at two sites but did not occur at the other three study locations. Estimates of flushing flow magnitudes required for substrate mobilization may appear high, but it is important to consider these values in the context of historical peak flows. Flow records between 1904 and 1916 at Kremmling show the highest peak flow recorded was 21,500 cfs and the $Q_{1.5}$ was 8,410 cfs (Table 3.20). The flow values for the $Q_{1.5}$ might be slightly exaggerated due to the short period of record and wet period occurring in the early 20th century. From 1962 to 2013, the highest peak flow recorded was 13,600 cfs and the $Q_{1.5}$ was 2,050 cfs. It is also important to note that there were still some diversions occurring on the Colorado River during 1904 to 1916 so these values may not be fully representative of native flows. However, these historic flows can at least provide a glimpse of what peak flows for the upper half of the study area may have been like before diversions. Historic peak flows at Dotsero would have been even approximately doubled compared to Kremmling. Therefore, the resulting flushing flow estimates from this analysis appear to be plausible when considered in the context of historical flows. Overall, the large variability seen in the resulting flushing flow values through the study area do not allow for any flushing flow recommendations to be given. Further study of substrate mobilization, with a greater density of sites if possible, is encouraged to narrow down flow values that may result in substrate mobilization and flushing of surface fines throughout most of the study area.

Table 3.20 – Peak flow data for at Kremmling and Dotsero above the confluence with the Eagle River. The period at Kremmling from 1904-1916 is approximates pre-development conditions although some water was already being moved transmountain.

	Kremmling		
	Maximum Peak Flow (cfs)	$Q_{1.5}$	Q_2
1904 – 1916	21,500	8,410	
1962 – Present	13,600	2,050	3,100

	Dotsero		
	Maximum Peak Flow (cfs)	**$Q_{1.5}$**	**Q_2**
1962 – Present	15,180	3,590	5,050

A previous study by Miller Ecological Consultants, Inc. (Miller and Swaim, 2011) provided estimates of peak flows required to maintain fish habitat in its current state. However, the study did not have the same objectives and the estimated peak flows were not based on an actual analysis of substrate mobility. Therefore, they are not directly comparable with our findings.

Projects and Strategies for Conservation

This chapter reviews potential short- and long-term conservation work in the Eagle County sections of the Upper Colorado watershed.[1] Research conducted for the CRIA revealed that riparian and near-stream terrestrial ecosystems are largely intact and functional due to lower-intensity land uses and overall lack of development. In some locations, railroad placement and private land management practices such as mowing and hay growing interrupt vegetative cover near the river. The extent of these impacts does not appear to significantly affect water quality in the Colorado River, although impacts do become more pronounced on smaller perennial tributaries. The primary issue on the Colorado River in the project area is the significantly altered hydrologic regime from upstream diversions and reservoir operations. These upstream activities diminish seasonal high flows that maintain physical channel characteristics important to the region's aquatic life, and may expose those stream communities to high summer temperatures. Warmer temperatures between Catamount and Dotsero more frequently approach and cross critical thresholds for cold-water fisheries. In addition, fine sediment loading may produce negative effects on spawning habitat and food source abundance. Beyond the issues of the main stem Colorado, other existing unique assets and conservation values within the Eagle County river corridor deserve attention. Targeted projects surrounding these assets may generate positive stream health and social benefits to the greater watershed community.

This chapter is organized in a hierarchy that begins with the ecosystem-scale issue of flow alteration, then moves to regional-scale issues surrounding native fish and tributary watershed conditions, and finishes with local level reach-scale options for conservation work. Flow alteration is a legally and politically difficult issue to navigate, and fundamental changes will be driven by policy solutions and stakeholder collaboration at the regional-to-state level. Due to current activity surrounding the State Water Plan, an important timing window for action may be pressing. Additional scientific information may be needed before water resource managers can fully incorporate channel maintenance flows and temperature mitigation

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[1] This chapter was primarily authored by Lotic Hydrologic.

successfully into existing or new water-management arrangements. Invasive plant species management and native fish conservation are regional-scale issues in the project area. Native fish conservation in the Eagle County portions of the Upper Colorado watershed has both local and statewide importance; this segment outlines a potential long-term strategy for improving conditions for these increasingly threatened species. At the local level, reach-scale projects such as riparian improvement and recreational visitor portal enhancement may not generate large water-quality benefits to the main stem Colorado, but function to acknowledge the multitude of other conservation values held by the Eagle County and greater river user communities. They can also serve as important times and places for community outreach.

4.1 Ecosystem-scale Projects

4.1.1 Environemental Flow Management in the Upper Colorado River

Aquatic life communities and terrestrial riparian communities in the Upper Colorado River corridor have developed life-history strategies built around the natural flow regime of a snow-fed, mountain river system. Alterations of the timing and magnitude of key hydrologic events (especially peak runoff and flow recession) by water-management activities outside the project area produce important changes to the river corridor. Unmitigated sedimentation degrades aquatic habitat conditions in the lower reaches, and high summertime temperature regimes potentially affect cold-water stream communities. The state's Water Court decreed minimum in-stream flow (ISF) rights for the project reach in 2013, providing some amount of protection to the Upper Colorado ecosystem against management-driven extreme low-flow events in summer and fall. While minimum flow protection supplies an important component of environmental flows in the Upper Colorado, habitat maintenance flows are an equally important component.

Available fishery and macroinvertebrate data indicate aquatic life community health changes in a downstream direction, with a decrease in sediment-intolerant taxa and an increase in sediment-tolerant taxa. Analyses and empirical evidence provided by the CRIA identifies fine sedimentation and temperature as two primary influences on aquatic conditions. The river is unable to frequently provide habitat maintenance flows that flush accumulated fine sediment downstream due to man-made changes in the flow regime, and reservoir management may exacerbate summertime temperature concerns. Coordinated diversion and reservoir release actions by upstream water resource managers hold the potential to alleviate these ecosystem stressors in the project area. However, numerous existing and potential water-management agreements create a difficult political and regulatory arena in which to effect these vital restoration actions. Future storage and water-management activities in the Colorado Basin currently identified in the State Water Plan hold potential to further exacerbate the altered flow regime issues within the project area. For example, increased diversions from the Fraser River as part of the Moffat Firming Project and potential changes in release schedules tied to a proposed Wolcott Reservoir could both have direct and negative implications for flushing flows in the Upper Colorado area.

The CRIA provides preliminary flushing flow (habitat maintenance flows) estimates for the project reach from Pumphouse to Dotsero using five cross sections. Establishing additional cross sections, especially in the region from Catamount down, will refine these estimates. Additional substrate sampling before and after different spring runoff volumes can provide empirical evidence to support these estimates and reduce potential error. Flushing flow estimates may serve as the basis for flow regime targets for regional water managers, providing the scientific foundation for negotiation of coordinated reservoir actions upstream. A rational future goal would be to include a periodic flushing flow regime in statewide water-management agreements between Colorado River stakeholders to properly sustain ecosystem processes in the river reaches between Kremmling and Glenwood Canyon. The Upper Colorado W&S Stakeholder Group maintains a Channel Maintenance Work Group that is currently working towards consensus on this important issue. It is recommended that ERWC establish and promote a partnership with this Work Group for future monitoring and policy implementation activities surrounding flushing flows in the project area. Table 4.1 outlines goals, tasks, and initiation time frames for flushing flow activities; and Table 4.2 lists recommended flushing flow monitoring and additional sites.

Table 4.1 – Flushing flow activities.

Goal	Task	Time Frame to Initiate
Provide empirical evidence of flushing flows.	• Re-sample substrate data after 2014 runoff and additional flow years for evidence of substrate mobilization.	• Immediate; post-runoff 2014 (2014 is currently a high-runoff year)
Close estimation error on flushing flow estimates throughout project reach.	• Establish additional cross sections and substrate monitoring sites, especially between Catamount and Sweetwater Creek.	• Low flow • Late summer/fall 2014 – 2015
Institutionalize flushing flows within the policy framework for river management.	• Using best available scientific evidence, convene appropriate stakeholders (water rights holders, State Engineer, transmountain diversion (TMD) operators, reservoir operators, etc.) for collaborative negotiation of flow regime targets. • Write flushing flow schedules into operational policies and compacts that determine Upper Colorado flow regimes. Language used in the 2014 *Grand County Mitigation and Enhancement Coordination Plan* (Grand County, 2014) can serve as a template.	• After appropriate evidence and analysis is complete • 2015+

Table 4.2 – Recommended flushing flow monitoring and additional sites.

Cross Sections and Substrate Monitoring Sites		Task/Status
Current sites:	Pumphouse	Re-sample substrate in 2014
	Radium	Re-sample substrate in 2014
	Above Catamount	Re-sample substrate in 2014
	Above Sweetwater	Re-sample substrate in 2014
	Above Dotsero	Re-sample substrate in 2014

Additional recommended sites (approximate locations):	State Bridge area	Establish cross section, sample substrate, and model flows
	Derby Creek area	Establish cross section, sample substrate, and model flows
	Red Dirt Creek area	Establish cross section, sample substrate, and model flows

4.1.2 Temperature Management

CPW, BLM, and the W&S Stakeholder Group all conduct stream temperature monitoring on the Upper Colorado. Analysis in the CRIA of publicly-available data from the GCWIN identified exceedances of CDPHE WQCC temperature standards for the river above Dotsero in 2012 and 2013, and near Red Dirt Creek in 2013. This preliminary analysis suggests that temperature issues for the lower project reach may be a consistent issue and warrant continued monitoring and investigation. The W&S Stakeholder Group Monitoring Work Group and Trout Unlimited (TU) identified these issues in 2013 as well, pursuing voluntary stakeholder-initiated mitigation activities with water managers to alleviate late-summer temperature increases. Additional temperature monitoring over a range of water years at existing or additional sites will provide a fuller picture of the geographical and temporal nature of temperature issues in the project area. Continued exceedances may indicate a designation of 303(d) impairment for the reach is appropriate; however, such a designation warrants careful consideration, as it may either help or hinder negotiation of management alternatives among stakeholders and resource managers.

Future flow depletions and/or climate change will potentially exacerbate summer temperature extremes in the Upper Colorado River corridor. Since elevated temperatures appear to be controlled by interactions with major tributaries and reservoirs in the upstream watershed, it is recommended that future water-management decisions upstream of the study area be considered in terms of potential system-level temperature effects. It is strongly recommended that the influence of water management and reservoir operations on downstream temperatures be explicitly included in management agreements between Colorado River stakeholders to conserve critical ecosystem processes in the river reaches between Kremmling and Glenwood Canyon. The Upper Colorado W&S Stakeholder Group maintains a Monitoring Work Group that is currently working towards consensus on managing this important issue. ERWC should establish and promote a closer working partnership with this group for future monitoring and policy implementation activities surrounding temperature issues in the project area.

4.2 Regional-scale Projects

4.2.1 Invasive Species

Tamarisk occurs along the river corridor in sparse amounts, making it an ideal candidate for eradication before further establishment (Figure 2.41). Concerted efforts to cut and spray tamarisk communities from Bond to Dotsero will hinder the ability of communities to continue further upstream or entrench at existing locations. As this area is likely approaching the natural climate boundary for most tamarisk species, the probability of success is positively weighted. Invasive species is a programmatic mandate for BLM resource managers as well as county governments in Colorado; this situation should streamline planning and approval for these activities on BLM-managed land within the river corridor. An agency partnership with the ERWC on this effort will both strengthen stakeholder relations and serve as a nexus for short-term community volunteer engagement. Russian olive also occurs downstream of Bond, however, the degree of community establishment is much greater than tamarisk and will likely prove harder to manage. Russian olive is notoriously difficult to remove, often involving mechanical extraction of the entire root system with large equipment. Russian olive in areas with multiple or high conservation values may still be worthy to consider for control or removal. Current contact information for invasive plant management is reported in Table 4.3.

Table 4.3 – Area contacts for invasive plant management.

Agency	Contact Information
BLM	Project area: State Bridge – Dotsero Hydrologist/Geologist: Pauline Adams Colorado River Valley Field Office Telephone: (970) 876-9071 E-mail: padams@blm.gov
Eagle County	Scott Griffin Eagle County Noxious Weed Control Telephone: (970) 328-3553 Fax: (970) 328-8788

4.2.2 Native Fish Conservation and Reclamation Strategy

Colorado River cutthroat trout (Blue Lineage) and as-yet-to-be-named Green Lineage cutthroat trout exist in a small number of perennial tributaries to the main stem Colorado River in the project area. The Blue Lineage cutthroat is a species of special concern in the state and a BLM, State of Colorado, and USFS Region 2 sensitive species. Green Lineage cutthroats are currently treated as federally threatened, although recent genetic research in the state has initiated a review of species status and management. Regardless of current uncertainties surrounding Green Lineage fish, populations as a whole occupy a fraction of historical range and face the same difficult pressures as Blue Lineage fish. The last century has brought large reductions in overall habitat range and loss of genetics through hybridization with non-native trout species. Non-natives introduced for sport aggressively out-compete cutthroats for habitat in the limited number of suitable Colorado streams, threatening viability statewide and throughout the central Rocky Mountains.

Out of hundreds of miles of perennial streams in the project area, including tributaries to the Piney River, only six streams are currently known to support native cutthroat (WRNF, 2014). Other tributaries may still hold populations of indeterminate lineage and purity. Taken together, these subwatersheds of the Upper Colorado represent a potentially viable sanctuary region for cutthroat conservation and preservation; a region of headwater streams with some agricultural pressure; but partly free of heavy development, habitat loss, and legacy impacts from forestry, mining, and urbanization that degrade other watersheds in the Colorado River basin. These fisheries represent a unique, under-appreciated, and under-valued asset of the Upper Colorado region. A locally-pushed, unified strategy for their protection and enhancement could help ensure a sustainable and resilient stronghold for these populations in the face of statewide human and natural pressures that increasingly threaten their long-term survival prospects.

In 2006, the state wildlife agencies of Colorado, Utah, and Wyoming adopted a joint *Conservation Strategy for Colorado River Cutthroat Trout* (CRCT) to address threats to the species and preemptively avoid a potential Endangered Species Act listing (CRCT Coordination Team, 2006). The CRIA project area nests within the Colorado Headwaters Geographic Management Unit for that document. One significant tributary hosts a conservation population of Green Lineage fish and has already received limited attention by WRNF and EWRC for habitat improvement projects. Conservation populations are "*naturally reproducing and recruiting populations of native cutthroat trout that managed to preserve the historical genome and/or unique genetic, ecological, and/or behavioral characteristics*;" in general, they are more than 90% genetically pure (CRCT Coordination Team, 2006).

Populations of Green lineage in nearest-neighbor stream systems in Upper Colorado perennial tributaries could potentially qualify as 'metapopulations' under the interstate/interagency management strategy, although more data may be necessary to fully understand regional population genetics. Metapopulations are "*geographically distinct yet genetically interconnected. If individual localized populations go extinct, they can be refounded by surrounding populations*" (CRCT Coordination Team, 2006). A unified strategy for protection, habitat improvement, and stream range reclamation in the Upper Colorado region could proactively protect broodstocks, small populations, and spawning fish, creating a sustainable genetic sanctuary for cutthroat in the Pumphouse-Dotsero region.

This report does not recommend a single project, but rather, suggests investing in the development of a unified conservation strategy among local area partners including ERWC, CPW, WRNF, Colorado River Valley Field Office (CRVFO) / Kremmling Field Office (KFO) BLM, local hunting/fishing outfitters, and other potential partnerships such as Colorado Headwaters Chapter of Trout Unlimited (CO TU), Colorado Mountain Club (CMC), Walking Mountains, etc. At its core, this unified conservation strategy could be a down-scaled version of the interstate/interagency framework laid out in the 2006 Conservation Strategy. It would nest within the greater multi-agency/multi-state effort, but be guided by local-to-regional organizational partnerships (Table 4.4). Strategy implementation could utilize a suite of stream and reach-specific tools including habitat protection and enhancement (both riparian and in stream); non-native species removal; physical migration barriers and other engineered solutions; ISF and water rights acquisition; and where both appropriate and having a high probability of success, reclamation (re-introduction). Implementation strategies would vary reach to reach based on feasibility, probability of success, and land ownership situations.

Table 4.4 – Native fish conservation goals and tasks.

Goals	Tasks	Time Frame
Gage interest and coalition building.	• **Concept development.** Stakeholder engagement (ERWC, CPW, WRNF, BLM, other nongovernmental organizations (NGOs), and appropriate private parties).	2014
Identify available conservation options.	• **Feasibility assessment.** Fully review available fishery data, identify inter-agency management goals, objectives, and responsibilities. Determine property ownership and access status, initiate National Environmental Policy Act (NEPA), and other agency-required processes.	Fall 2014 – 2015
Begin active strategy implementation and fieldwork.	• **Strategy implementation.** Utilize suite of available tools to actively protect and enhance cutthroat in Upper Colorado region.	2015 – 2025

4.3 Local-scale Projects

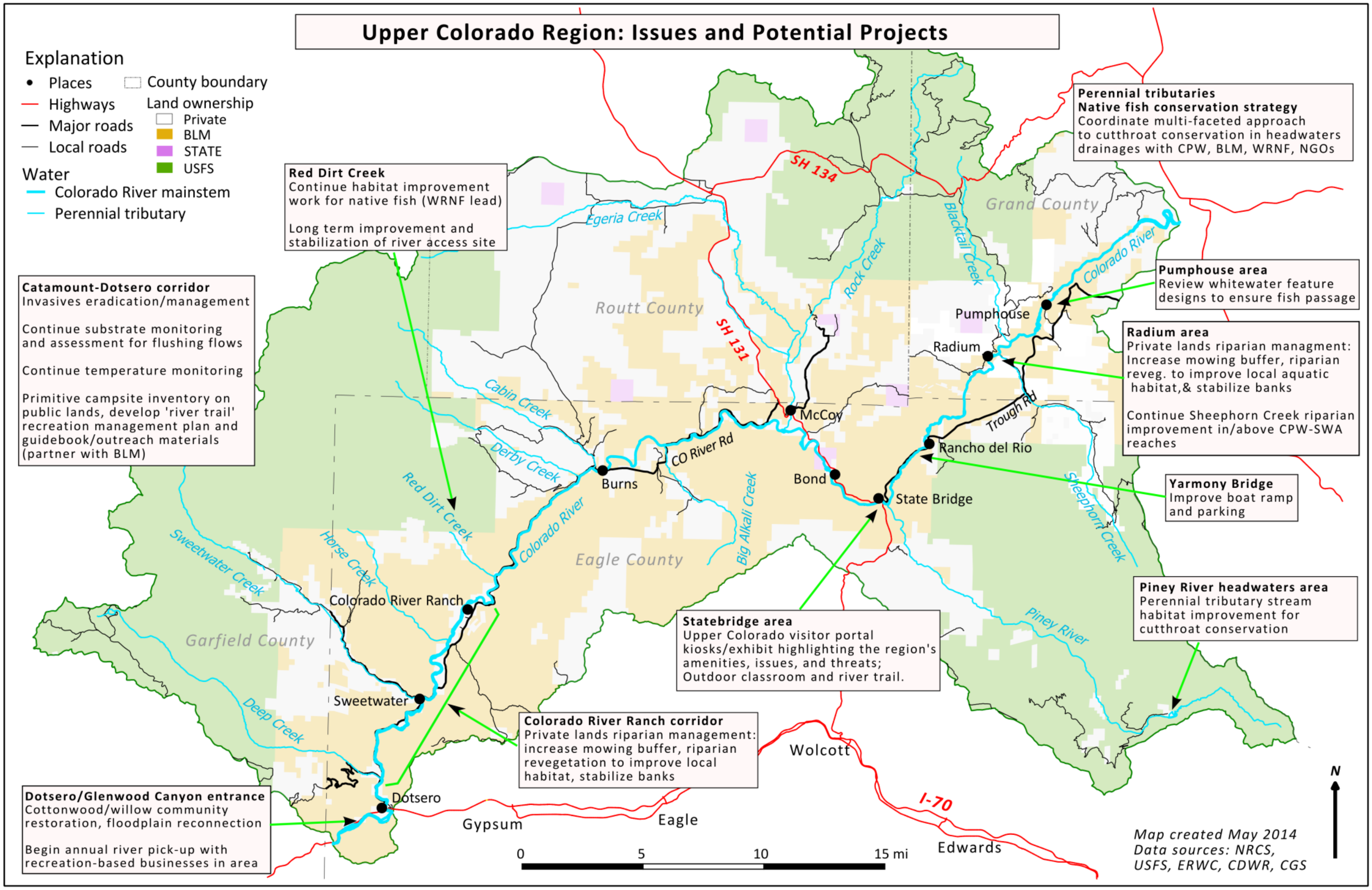
4.3.1 Riparian Buffer and Plantings

Functional riparian buffers generally persist in the project area, except where interrupted by localized land-management activities such as agricultural and residential mowing, or removed by significant physical alteration such as railroad construction directly bordering the river. For the main stem Colorado River, work conducted for the CRIA indicates that hydrologic alteration and localized sedimentation driven by water-management activities outside the project area are the primary controllers of aquatic ecosystem conditions. In general, actions targeting riparian improvement are unlikely to provide significant changes or improvements to main stem water-quality condition and aquatic communities. Where riparian improvement activities coincide with additional conservation values or special areas of concern, revegetation projects may still prove worthwhile due to the other resource values they support. Examples include river parcels with identified conservation easements, or segments with identified habitats for species of concern such as river otter. In general, short-scale reaches with outstanding wildlife, recreational, or other conservation values may be well-served by vegetation-oriented projects. In certain cases, landowners engaged in riparian restoration on Sage grouse habitat may receive certain technical assistance, planning, and other benefits from the Natural Resources Conservation Service (NRCS). Sage grouse habitat mapped by the NRCS tends to concentrate in northern Eagle County, on the south side of the river above Burns in the Big Alkali Creek watershed, and to a limited degree in the upper Cabin Creek watershed. Conservation-minded riparian management practices in these areas may have synergistic benefits for both native fish in perennial streams and landowner credits for grouse habitat preservation.

Tributaries. In select perennial tributaries with existing valuable native fish populations, additional riparian improvement projects can provide measureable benefits to aquatic habitat in the project area. One example is Red Dirt Creek, where existing vegetation and road-corridor work by the ERWC, WRNF, and CPW has sought to improve conditions for the conservation population of cutthroat, and potentially decrease sediment load to the Colorado River. Potential locations for reach-scale riparian improvement projects include the Colorado River Ranch, Red Dirt Creek, high-visibility recreational visitor ‘portals’ like the boat ramps and picnic areas at Lyons Gulch, Cottonwood, and Catamount. Sheephorn Creek has already been the focus of previous restoration; in 2001 NRCS initiated a bank-stability project on Piney Peak Ranch, in the lower reaches which border the Radium State Wildlife Area (SWA). As these downstream reaches are CPW-administered, publicly-accessible fishing segments, additional attention to stream stability, temperatures, and sediment delivery from upstream land use may be a worthwhile endeavor to ensure a sustainable and productive sport fishery in this high-use area.

Private lands. Private lands with degraded riparian conditions on the main stem tend to concentrate in the Bond-McCoy and Red Dirt Creek-Dotsero reaches (Figure 4.1), although the aerial extent of mowing and hayfield encroachment, and grazing impacts comprises only 4.1% of the 62-mi project area. A limited education/outreach campaign with landowners may generate voluntary efforts to refrain from mowing or otherwise developing riparian zones further. Emphasis for property owners could be placed on the improved bank stability and sediment retention characteristics of native vegetation over shallow turf grasses, in order to increase stakeholder buy-in to riparian projects on private lands. Geographic emphasis can be placed on corridors that are anticipated to receive more public use in the near future, such as the area near the Colorado River Ranch and downstream to other large parcels like the Roundup River Ranch (Figure 4.2). New and improved public river access at locations like Red Dirt Creek and Horse Creek are anticipated to increase recreational float boating and fishing use in these areas. Improving riparian conditions can provide examples of model land stewardship, as well as provide localized improvements to streamside habitat such as increased bank complexity, woody debris, and thermal refugia for aquatic life. Before implementing riparian improvement strategies in these areas, additional landowner education and outreach is necessary to generate support and local buy-in/ownership of conservation issues by residents, and to avoid the perception by landowners that unnecessary conservation projects are thrust upon them by top-down management planning.

Figure 4.1 – In the corridor from Red Dirt Creek to Dotsero, many private lands maintain little or no riparian buffer, potentially exacerbating bank erosion and limiting local-scale habitat for animal communities dependent on the riparian zone. An outreach campaign and guidance/support on riparian stewardship for riverside landowners can help improve this issue in the reach, which is experiencing increased recreational use from float boaters and fishermen due to access improvements by Eagle County.



Upper Colorado Region: Issues and Potential Projects

Red Dirt Creek
Continue habitat improvement work for native fish (WRNF lead)

Long term improvement and stabilization of river access site

Perennial tributaries
Native fish conservation strategy
Coordinate multi-faceted approach to cutthroat conservation in headwaters drainages with CPW, BLM, WRNF, NGOs

Catamount-Dotsero corridor
Invasives eradication/management

Continue substrate monitoring and assessment for flushing flows

Continue temperature monitoring

Primitive campsite inventory on public lands, develop 'river trail' recreation management plan and guidebook/outreach materials (partner with BLM)

Pumphouse area
Review whitewater feature designs to ensure fish passage

Radium area
Private lands riparian managment: Increase mowing buffer, riparian reveg. to improve local aquatic habitat,& stabilize banks

Continue Sheephorn Creek riparian improvement in/above CPW-SWA reaches

Yarmony Bridge
Improve boat ramp and parking

Piney River headwaters area
Perennial tributary stream habitat improvement for cutthroat conservation

Statebridge area
Upper Colorado visitor portal kiosks/exhibit highlighting the region's amenities, issues, and threats; Outdoor classroom and river trail.

Colorado River Ranch corridor
Private lands riparian management: increase mowing buffer, riparian revegetation to improve local habitat, stabilize banks

Dotsero/Glenwood Canyon entrance
Cottonwood/willow community restoration, floodplain reconnection

Begin annual river pick-up with recreation-based businesses in area

Map created May 2014
Data sources: NRCS, USFS, ERWC, CDWR, CGS

Figure 4.2 – Upper Colorado region issues and potential projects.

Agency lands. BLM staff at the CRVFO has identified the Colorado River at the entrance to Glenwood Canyon as a location of interest for larger-scale riparian restoration, including reconnection of the river to floodplain areas and re-establishing of cottonwood-willow communities (Table 4.5). Increased water-based recreational use between the Dotsero put-in and Bair Ranch rest area by tubers and standup paddleboarders has produced a large jump in visitor use and social impacts to the river corridor in the last 5+ years. This area is also potentially degraded from past land use management activities, legacy impacts from highway construction, and hydrologic impacts of Shoshone Dam downstream including delta formation and sedimentation in the reservoir backwaters. Bank and floodplain re-contouring and other localized physical improvements, followed by revegetation to reestablish healthy and functional riparian communities such as willow-cottonwood to this high-visibility portal to Glenwood Canyon and the Upper Colorado area surrounding Dotsero. Table 4.6 outlines goals, tasks, and initiation time frames for riparian improvement. Current contact information for riparian projects is reported in Table 4.7.

Table 4.5 – Local riparian improvement opportunities.

Site	Project
Colorado River Ranch-Dotsero corridor	Riparian improvement, private lands
Radium area	Riparian improvement, private lands
Glenwood Canyon entrance	Floodplain reconnection, revegetation, and willow-cottonwood restoration

Table 4.6 – Riparian improvement goals and tasks.

Goal	Task	Time Frame to Initiate
Generate landowner buy-in to riparian stewardship and improvement.	• Focused landowner outreach and education campaign to avoid the perception of an outsider-imposed conservation mandate. • Determine interest level, cooperative partners, and available locations	2014 – 2015
Identify priority improvement areas within Red Dirt Creek-Dotsero corridor.	• Prioritize areas by landowner access, riparian condition, and revegetation feasibility. • Produce a planning or guidance document.	2014 – 2015
Partner with residents, Eagle County, and relevant agencies to implement riparian improvement.	• Help landowners design and implement BMPs for riparian buffering and mowing/grazing restrictions on streambanks. • Utilize volunteer base and partnerships to re-vegetate impacted areas.	2015+

Table 4.7 – Area contacts for riparian projects.

Agency	Contact Information
BLM	Hydrologist/Geologist: Pauline Adams Colorado River Valley Field Office Telephone: (970) 876-9071 E-mail: padams@blm.gov
Eagle County Conservation District	District Manager: Audra Meyers PO Box 360 Eagle, CO 81631 Telephone: (970) 230-0844
Colorado NRCS	District Conservationist: Derek Wiley Glenwood Springs Field Office (Eagle County) 258 Center Drive Glenwood Springs, CO 81601-2539 Telephone: (970) 945-5494 Fax: (970) 945-0837

4.3.2 Visitor Portal Enhancement

Physical improvement or maintenance of high-use visitor portals addresses recreational values in the project area (Table 4.8). These can include improving boat ramp conditions for sustainable long-term use; or other engineering projects around these areas involving re-grading, drainage work, and revegetation and visitor use pattern management.

Table 4.8 – Visitor portal improvement projects.

Location	Work Needed	Purpose	Operator
Red Dirt Creek	Continued stabilization of boating access point and vehicle access road.	Long-term physical site stability	Eagle County Open Space
Yarmony Bridge	Used as unofficial put-in below Rancho del Rio, eroding ramp and parking issues.	High visibility/recreation value and visitor portal	None currently
Others as needed	Update inventory on existing status, user numbers, and work needed at multi-agency boat ramps and riverside recreational amenities.	Various	BLM, Eagle County, CPW

4.3.3 Education and Outreach Projects

State Bridge river access: Outdoor classroom and interpretive station. In addition to research and projects, ERWC is mandated to advocate for the health of the Eagle and Upper Colorado Rivers via public education and outreach. The State Bridge area is a key access to the Upper Colorado River corridor for thousands of local and out-of-area visitors yearly, arriving both by I-70/Wolcott, the Steamboat area to the north, and Grand County via the Trough Road. Eagle County invested significant resources in improved river access here in 2012, and the State Bridge music center and BLM campground continue to serve as a social focal point for thousands of recreational users including float boaters, fishermen, and others. This portal is a high-visibility, high-use, and high-quality location for public engagement by ERWC and organizational partners like Walking Mountains Science Center, Eagle County, and BLM. A small river interpretive station at the access site can provide visitors a welcoming overview of the Upper Colorado region, including conservation issues and threats, recreation amenities, and wildlife resources. In addition to these river access site items, coupling additional amenities such as a short interpretive trail/walking classroom towards the Piney River confluence (below the existing road cut) and a small outdoor classroom or primitive amphitheater seating setup, could provide the physical setting for reoccurring outreach/education activities by ERWC and partners like Walking Mountains Science Center.

Dotsero-Glenwood area river cleanup. In recent years, the advent of several commercial tubing businesses in the Vail and Glenwood area and the large increase in Stand Up Paddleboarding (SUPing) on state rivers have both significantly increased recreational river use on the reach from Dotsero landing to Bair Ranch. The river is generally calm, deeper, and devoid of major rapids through this area, making it ideal for these uses. With increased social use comes increased resource pressure, as well as a desire for a clean natural setting for optimum visitor experiences. Large metal debris from legacy land uses, as well as occasional litter from recreational users, currently detract from scenic values on this reach and could be addressed with a minimum amount of work. A partnership between ERWC and area businesses that utilize this stretch for a yearly, bi-yearly, or as-needed cleanup effort would ensure the resource retains the high-quality experience that visitors to the area expect, and that underpins the region's tourism and recreation-based economy.

Chapter 5

Conclusions

When considering the results from the inventory and assessment of the Eagle County portion of the Colorado River corridor, there appear to be certain factors that control the ecological condition of the river corridor. Generally speaking, land use within the river corridor has changed modestly since the first arrival of European settlers. Homes have been built and irrigated hay fields have been established along areas with wider floodplains, but the lack of mineral and oil or gas resources have kept hydrologic and water-quality impacts from local land use change to a minimum. Future land use change is likely to remain minimal due to the arid and steep setting of the river corridor. However, rehabilitation of the riparian area along these private lands could provide localized ecological benefit to the river corridor.

The railroad and road are the two biggest encroachments upon the river corridor. Paralleling the river throughout the entire study area, the railroad and road have impacted the river corridor by: reducing riparian habitat, disrupting connectivity between surrounding terrestrial habitats and the river for wildlife, acting as a pathway for invasive species, reducing wood inputs to the river, and replacing natural banks with riprap that remain sparsely vegetated. However, the removal of either the road and/or railroad from the river corridor is impractical and socially unacceptable. Despite this, sections of the river corridor still harbor one of the most intact riparian areas on the Colorado River within the state including rare plant assemblages. Future threats to the riparian area include greater establishment of invasive species, future hypothetical high-speed rail plans which may further encroach upon the river, and decreased frequency and duration of flows inundating the riparian area to maintain ecological health.

Overall, the most significant current threats to the ecological condition of the Colorado River are elevated water temperatures above the known thermal tolerance of trout, and interactions between fine sediment loading and the available environmental maintenance flows. All of these issues can be attributed to water quantity and flow regime. Beyond the water rights held by the Shoshone Water Plant and Cameo Call group downstream, the magnitude, frequency, and duration of environmental flows are controlled completely by the upstream watershed. Given uncertainty in future water demands and climate, ensuring the provision of future flows necessary to keep water temperatures below critical levels, flush deposited fine sediments, and mobilize the substrate for rejuvenation of habitats in the river bed becomes the utmost priority. Water-management decisions in the upstream watershed may directly affect the Eagle County portion of the Colorado River and should be monitored closely. Preliminary estimates of flushing flows necessary for coarse substrate mobilization at a few accessible riffles generally exceed 12,000 cfs. Preliminary analyses also suggest that removal of surficial veneers of fine sediment could potentially be achievable at flows in the vicinity of 4000-8000 cfs, especially in the upstream reaches of the study area. Continued monitoring of the capacity of the current flow regime to flush the system is recommended to allow water managers to make informed decisions in the future. Finally, it is important to manage this portion of the Colorado River as an inseparable unit of the entire upstream watershed system that ultimately determines its fate.

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Appendix A – Upstream Watershed Descriptions

A.1 Willow Creek

Willow Creek watershed (Figure A.1) drains approximately 142 mi^2 of mountainous terrain ranging in elevation from 12,320 to 7,930 ft (Figure A.2). The mean basin elevation is 9,440 ft. The dominant land covers are 74% evergreen forest in the higher elevations, and 11% shrub/scrub and 7% hay/pasture in the lower elevations (Figure A.3). Mean annual precipitation for the watershed is 24 inches. Median SWE for Willow Creek Pass (9,540 ft) peaks at 14.5 inches (1981-2010) (Figure A.4). Willow Creek Reservoir impounds the creek a few miles upstream from its confluence with the Colorado River. Water is eventually diverted from Willow Creek to the East Slope. The average annual hydrograph for Willow Creek below Willow Creek Reservoir shows a snowmelt-generated peak runoff usually occurs mid to late-May (Figure A.5).

Figure A.1 – Willow Creek below Willow Creek Reservoir.

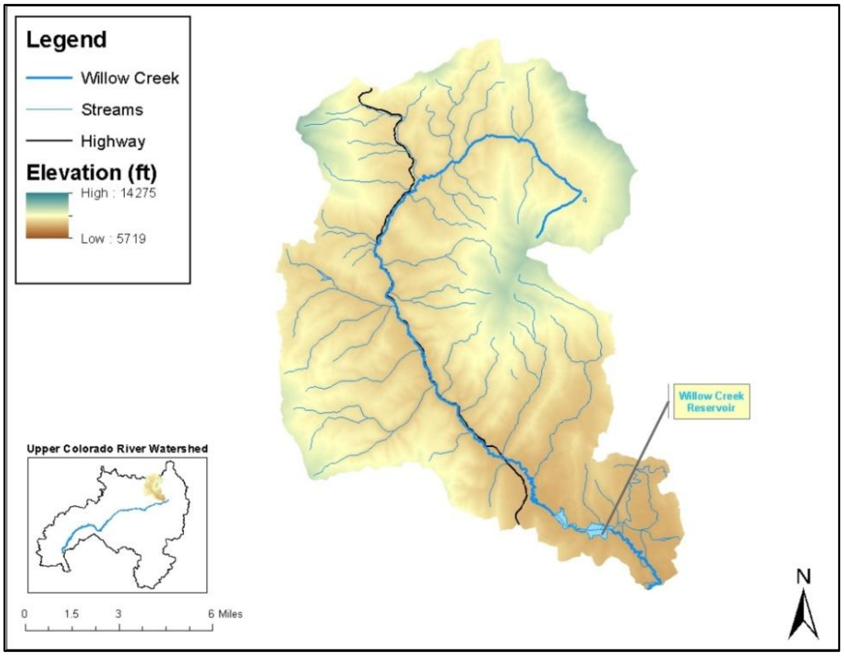


Figure A.2 – Willow Creek watershed elevation profile.

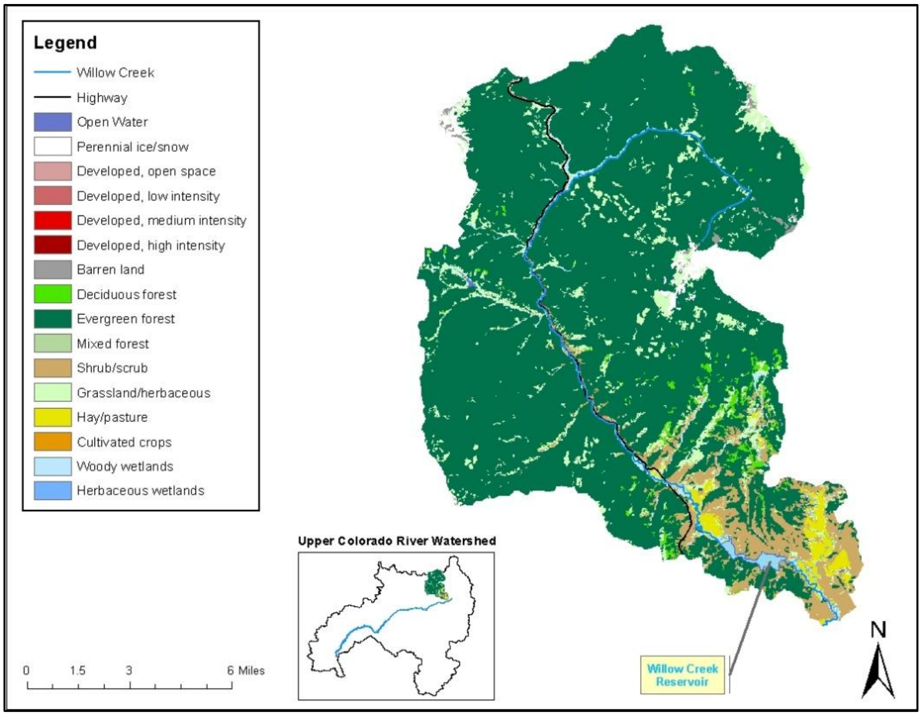


Figure A.3 – Willow Creek watershed land cover.

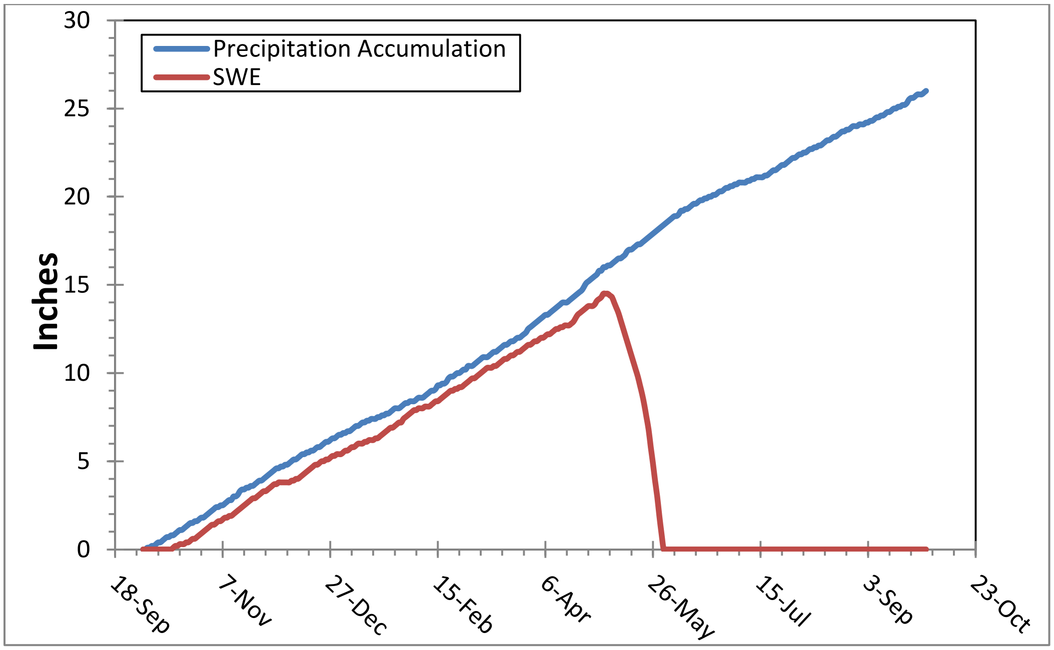


Figure A.4 – Average SWE and precipitation accumulation for Willow Creek Pass (1981-2010).

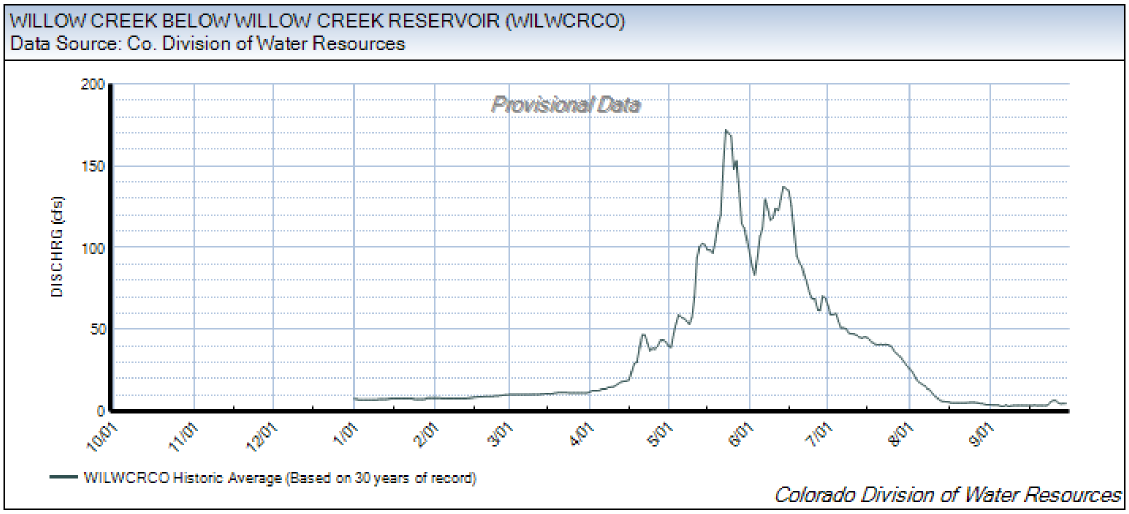


Figure A.5 – Average annual hydrograph for Willow Creek below Willow Creek Reservoir based on 30 years of record.

A.2 Fraser River

The Fraser River (Figure A.6) is one of the larger tributaries to the Colorado River and usually contributes more flow at their confluence. No reservoirs are in place on the Fraser River, but multiple diversions transfer water to the East Slope. The watershed drains a 302 mi^2 area of mountainous terrain ranging from 12,320 to 7,930 ft (Figure A.7). The mean basin elevation is 9,730 ft. Municipalities located within the watershed include: Winter Park, Fraser, Tabernash, and Granby. Evergreen forest covers 64% of the land, mostly in the higher elevations. The lower elevations consist of 9% grassland/herbaceous and 8% shrub/scrub (Figure A.8). Mean annual precipitation for the watershed is 26 inches. Berthoud Pass Summit (11,300 ft) located at the top of the watershed has a median peak SWE of 21.4 inches (1981-2010) (Figure A.9). The average peak flow (1999-2013) for the Fraser River below Crooked Creek (USGS 09033300) is approximately 892 cfs and usually occurs from mid to late-June (1998-2013) (Figure A.10).

Figure A.6 – Fraser River near Granby, Colorado (http://donaldsfishinjournal.blogspot.com/).

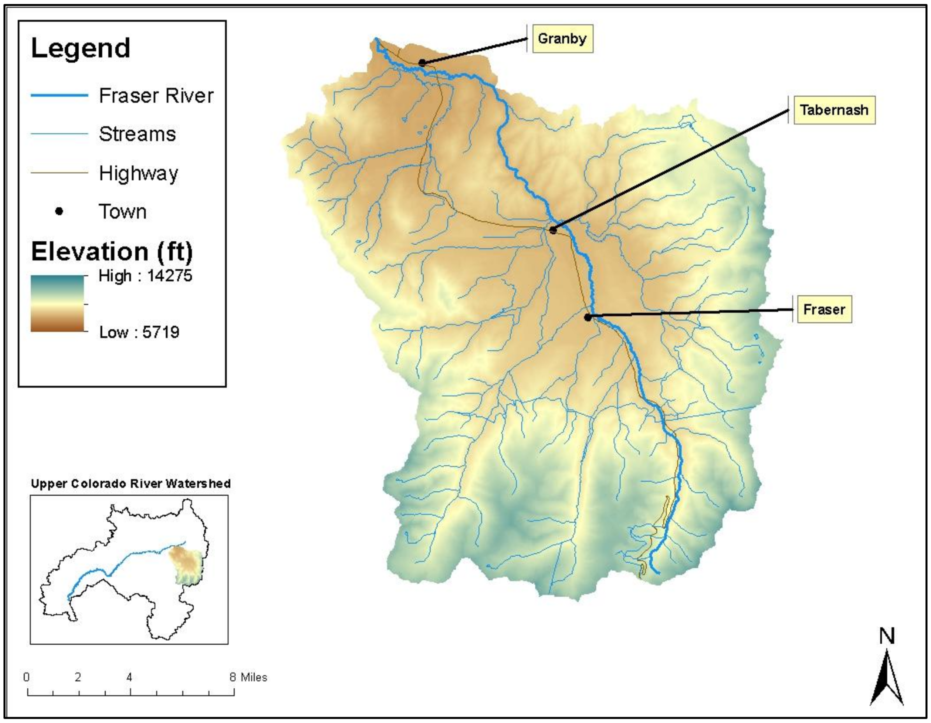


Figure A.7 – Fraser River watershed elevations.

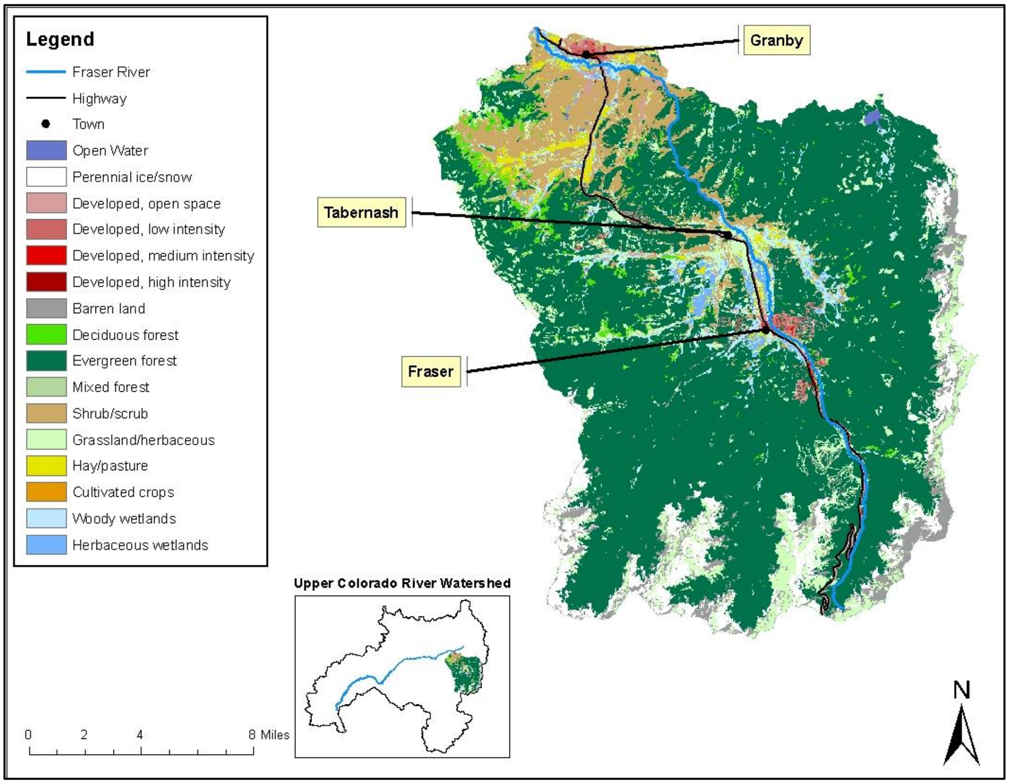


Figure A.8 – Fraser River watershed land cover.

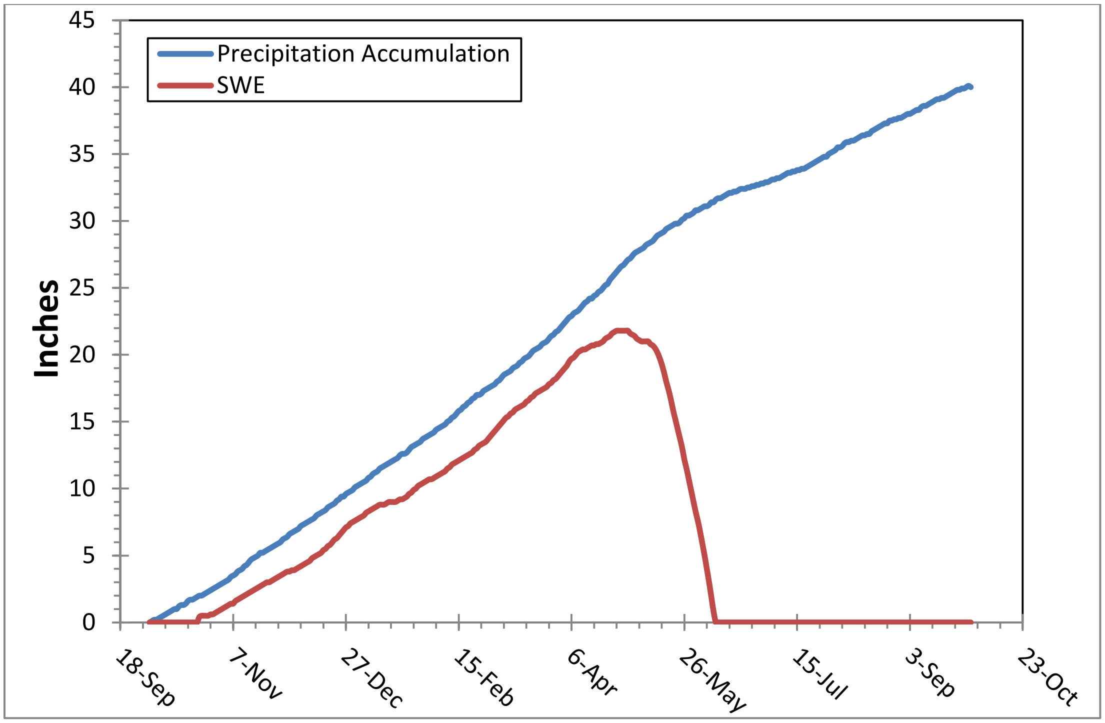


Figure A.9 – Median SWE and average precipitation accumulation (1981-2010) for Berthoud Pass Summit.

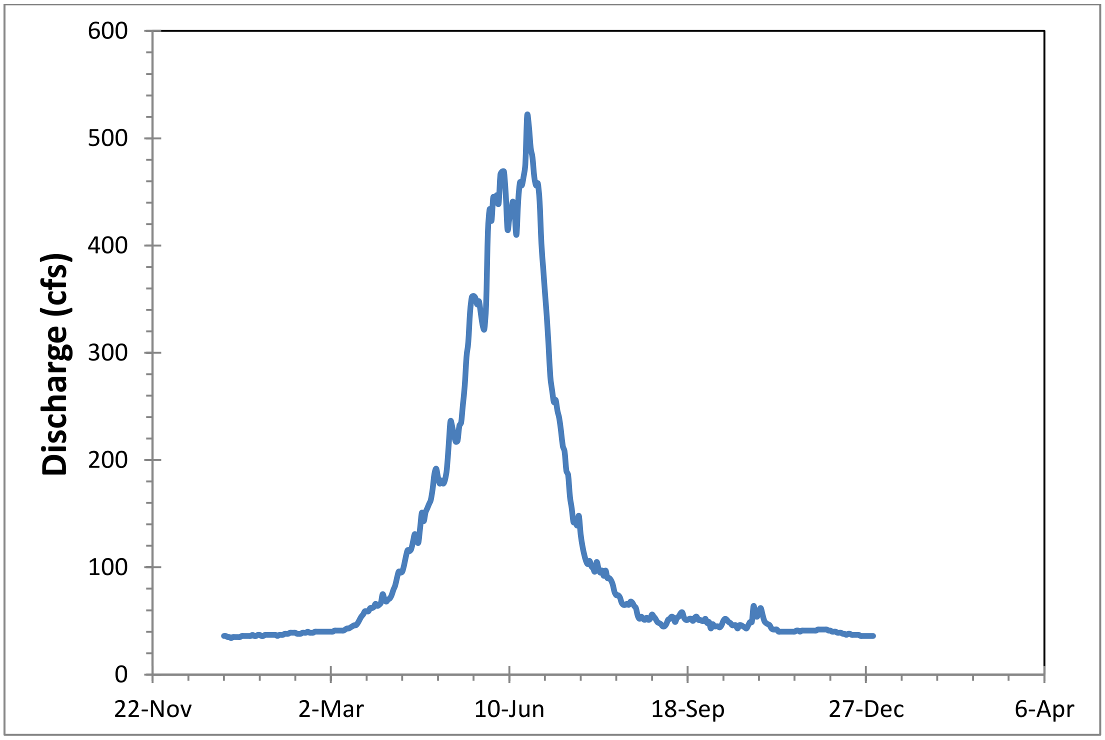


Figure A.10 – Average annual hydrograph (1998-2013) for the Fraser River below Crooked Creek (USGS 09033300).

A.3 Williams Fork

The Williams Fork watershed (Figure A.11) drains 232 mi^2 of mountainous terrain ranging from 13,460 to 7,484 ft with a mean basin elevation of 9,800 ft (Figure A.12). Evergreen forest covers 56% of the land, while shrub/scrub and grassland/herbaceous cover 15% and 8%, respectively (Figure A.13). Mean annual precipitation for the watershed is 23 inches. Middle Fork Camp SNOTEL site (8,940 ft) has a median peak SWE of 11.5 inches (2001-2010) (Figure A.14). The Williams Fork Reservoir is owned and operated by Denver Water to use as a substitute for water being diverted to the East Slope farther upstream. The average peak flow (1949-2012) for the Williams Fork below Williams Fork Reservoir is approximately 610 cfs and usually occurs mid to late-June (1998-2013) (Figure A.15).

Figure A.11 – Williams Fork River below Williams Fork Reservoir (http://www.intheriffle.com/destinations).

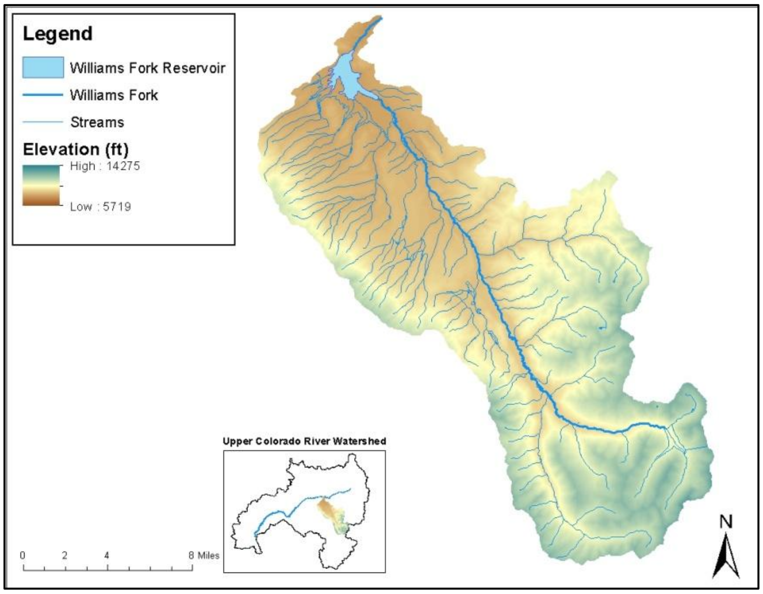


Figure A.12 – Williams Fork watershed elevations.

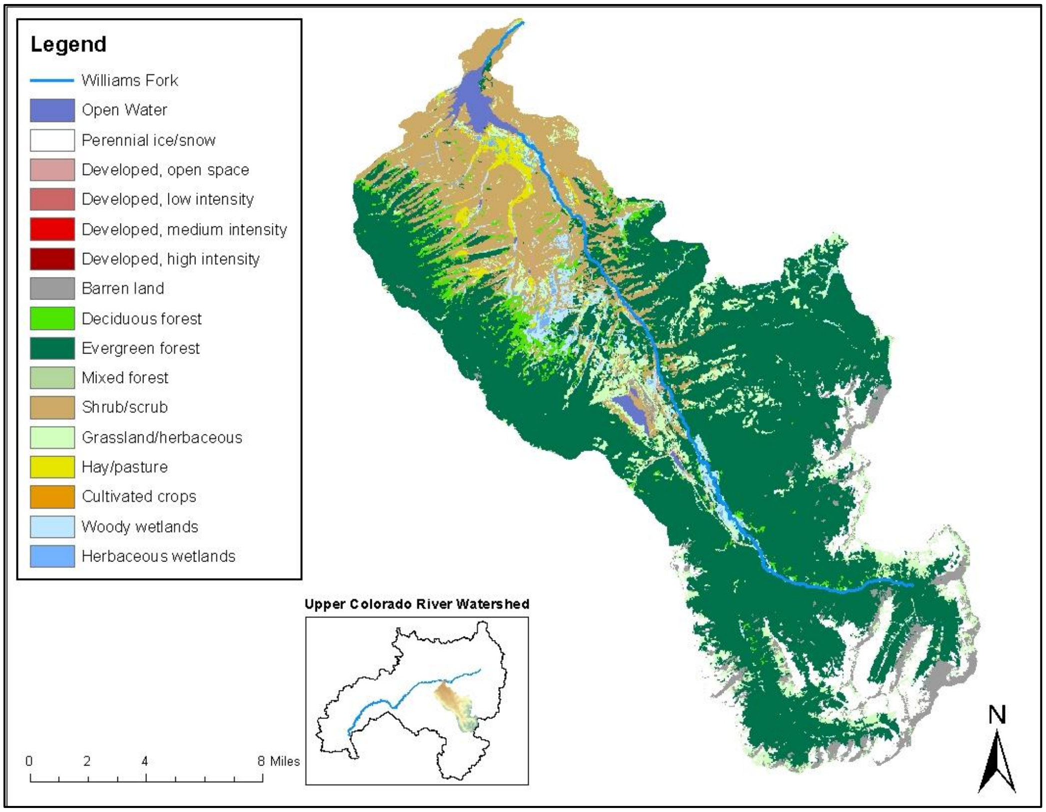


Figure A.13 – Williams Fork watershed land cover.

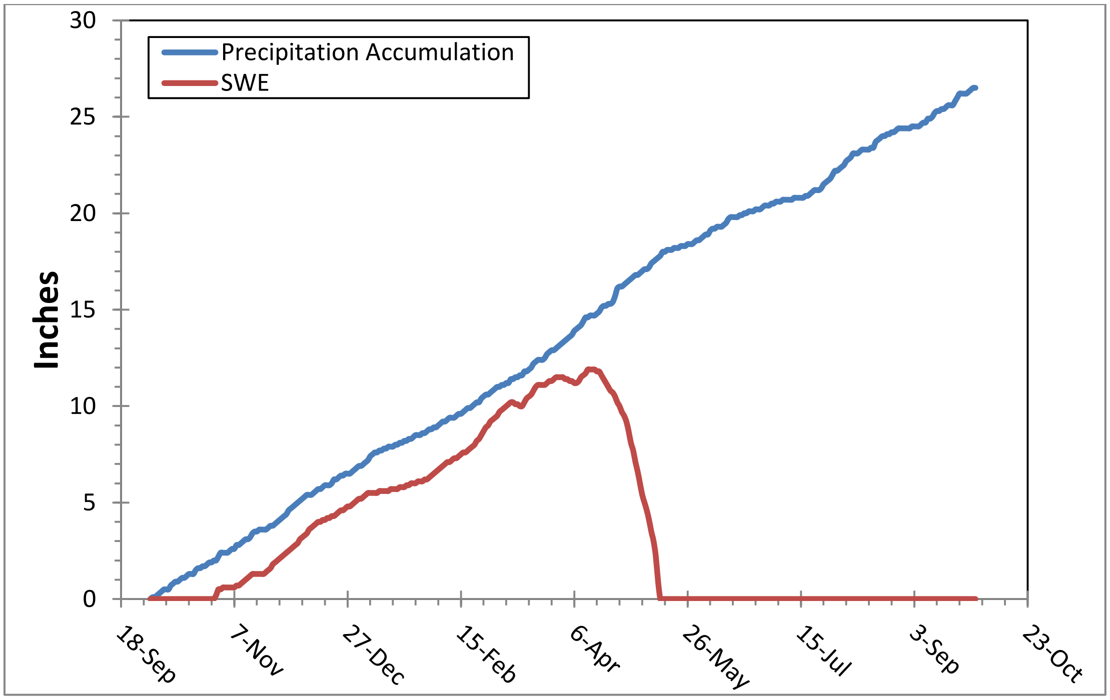


Figure A.14 – Median SWE and average precipitation accumulation (2001-2010) for Middle Fork Camp SNOTEL site.

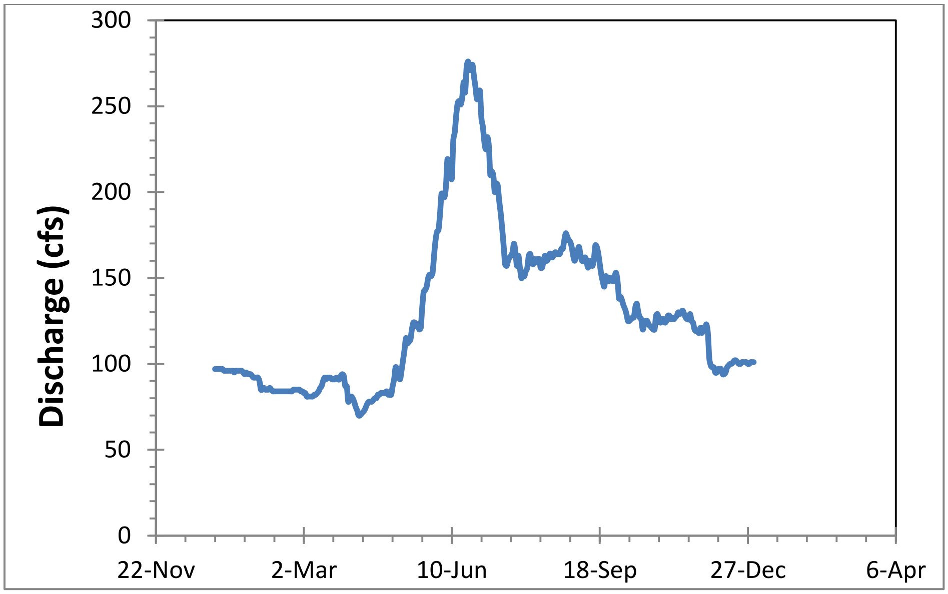


Figure A.15 – Average annual hydrograph (1998-2013) for the Williams Fork below Williams Fork Reservoir (USGS 09038500).

A.4 Muddy Creek

The Muddy Creek watershed (Figure A.16) drains a 294 mi^2 area of mountainous terrain ranging from 10,935 to 7,283 ft (Figure A.17). The mean basin elevation is 8,540 ft. The largest percent land covers within the watershed are 45% shrub/scrub, 24% evergreen forest, and 12% grassland/herbaceous (Figure A.18). It is the only upstream watershed not dominated by evergreen forest. Mean annual precipitation for the watershed is 22 inches. Arapahoe Ridge SNOTEL site (10,960 ft) is located along the border of the watershed and has a median peak SWE of 22.3 inches (2001-2010) (Figure A.19). Wolford Mountain Reservoir was built on Muddy Creek to provide water for the West Slope and allow East Slope water users to purchase water to substitute for water diverted elsewhere within the Colorado River basin. The average peak flow (1999-2013) for Muddy Creek below Wolford Mountain Reservoir is approximately 617 cfs and usually occurs mid to late-June (1998-2013) (Figure A.20).

Figure A.16 – Muddy Creek below Wolford Mountain Reservoir (http://www.coloradofishing.net/ft_muddy.htm).

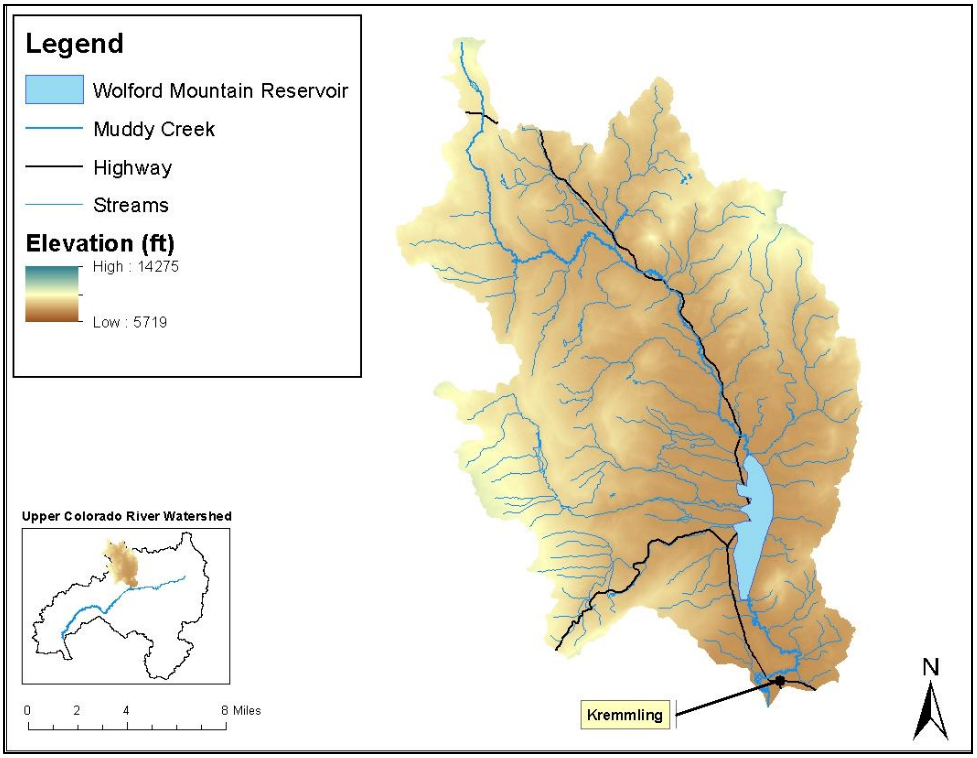


Figure A.17 – Muddy Creek watershed elevations.

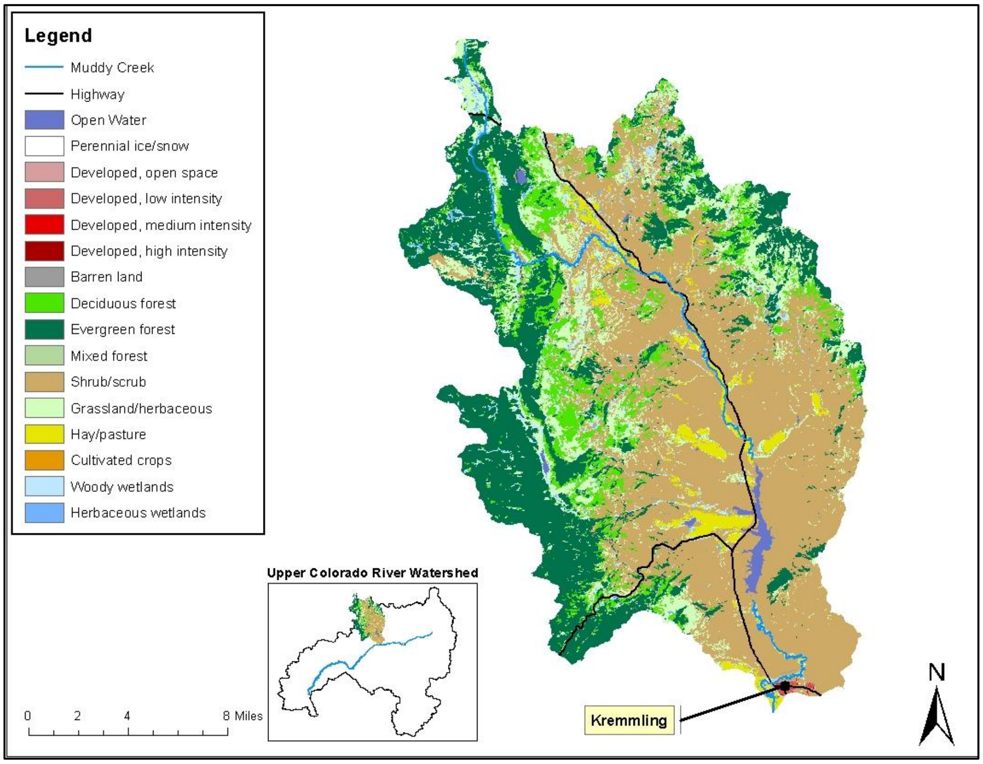


Figure A.18 – Muddy Creek watershed land cover.

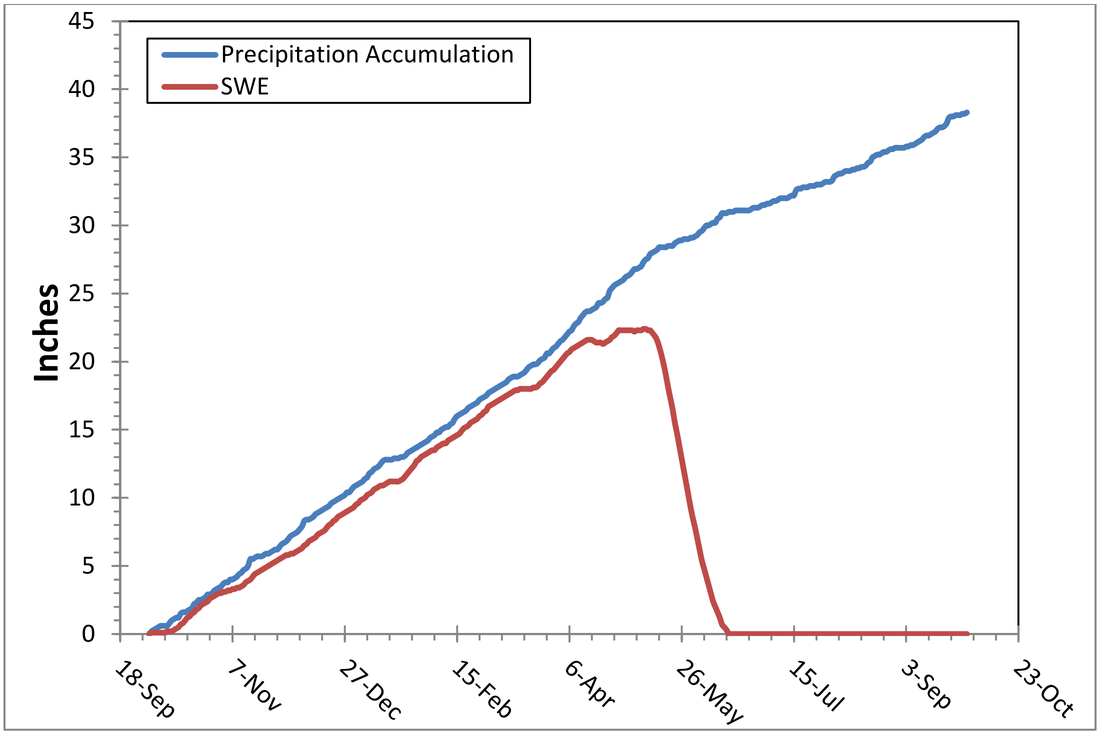


Figure A.19 – Median SWE and average precipitation accumulation (2001-2010) for Arapahoe Ridge SNOTEL site.

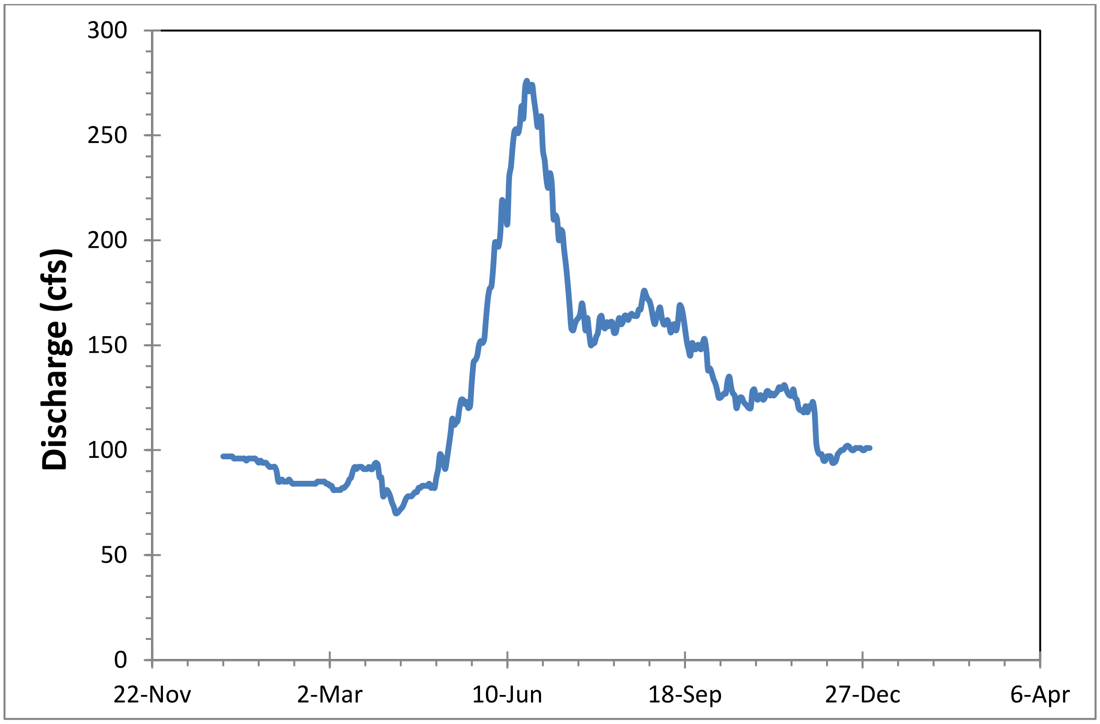


Figure A.20 – Average annual hydrograph (1998-2013) for Muddy Creek below Wolford Mountain Reservoir (USGS 09041400).

A.5 Blue River

Two reservoirs impound the Blue River. Dillon Reservoir upstream diverts water to the East Slope. Downstream, Green Mountain Reservoir is used to substitute for water diverted upstream within the watershed. The Blue River watershed (Figure A.21) drains 683 mi^2 of mountainous terrain ranging from 14,275 to 7,329 ft (Figure A.22) with a mean basin elevation of 10,300 ft. Larger municipalities located within the watershed are Dillon, Silverthorne, and Breckenridge. Evergreen forest covers 44% of the land, while grassland/herbaceous and shrub/scrub cover 17% and 13%, respectively (Figure A.23). Mean annual precipitation for the watershed is 25 inches. Hoosier Pass SNOTEL site (11,400 ft) is located at the top of the watershed and has a median peak SWE of 16.6 inches (1981-2010) (Figure A.24). The average peak flow (1938-2013) for the Blue River below Green Mountain Reservoir is approximately 1,878 cfs and usually occurs in mid to late-June (1938-2013) (Figure A.25).

Figure A.21 – The Blue River just upstream from the confluence with the Colorado River.

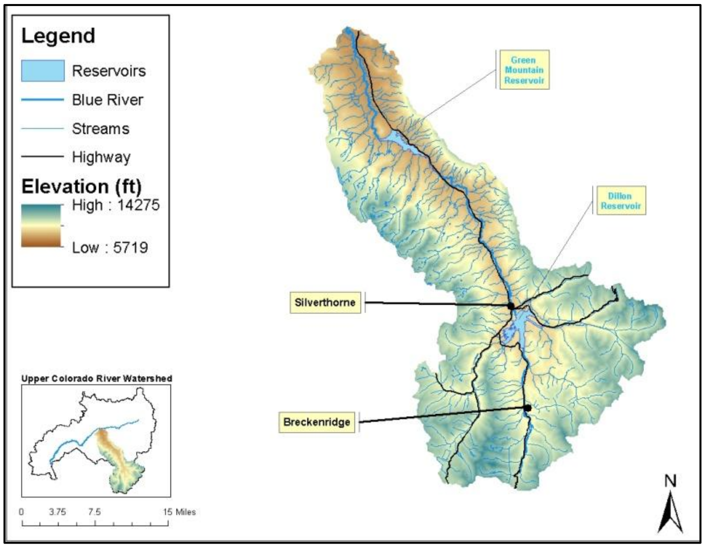


Figure A.22 – Blue River watershed elevations.

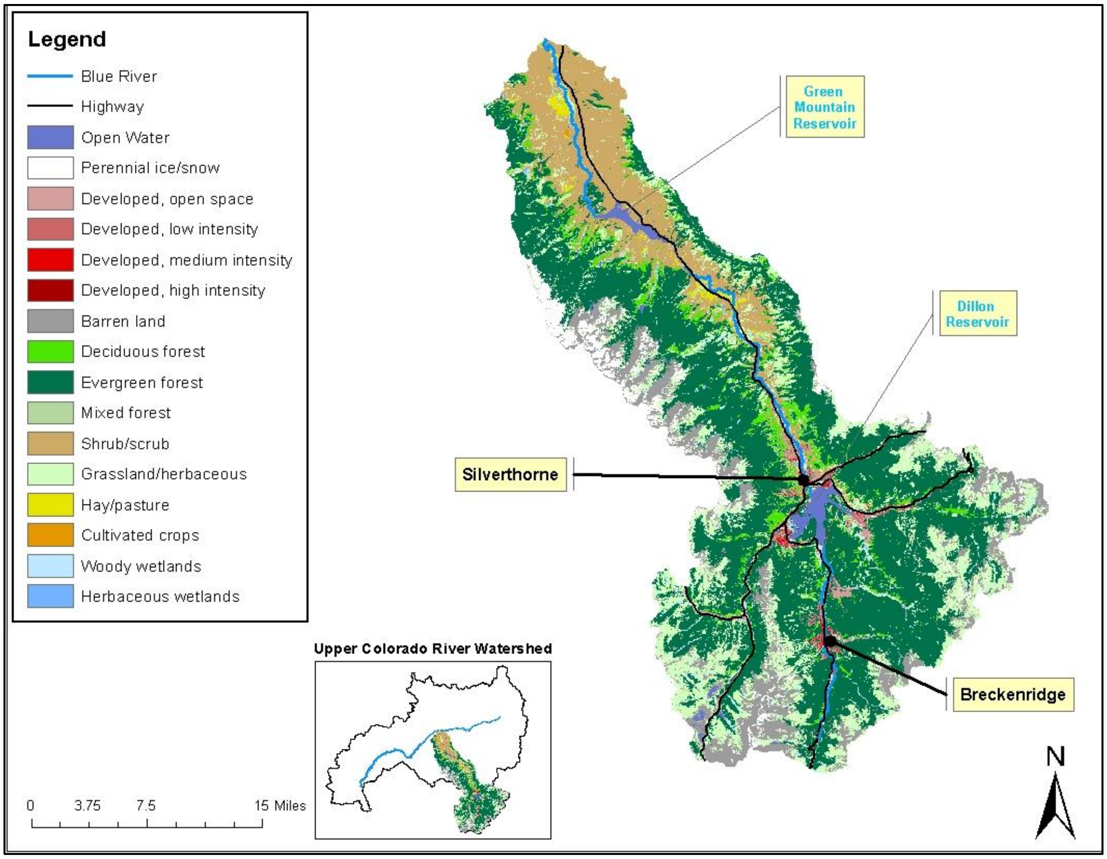


Figure A.23 – Blue River watershed land cover.

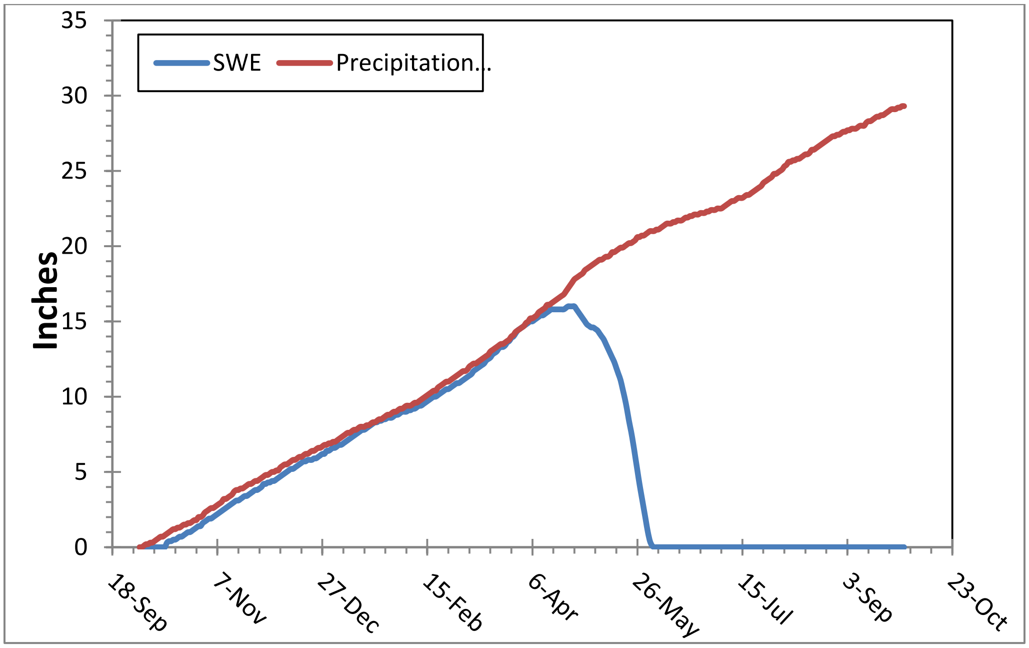


Figure A.24 – Median SWE and average precipitation accumulation (1981-2010) for Hoosier Pass SNOTEL site.

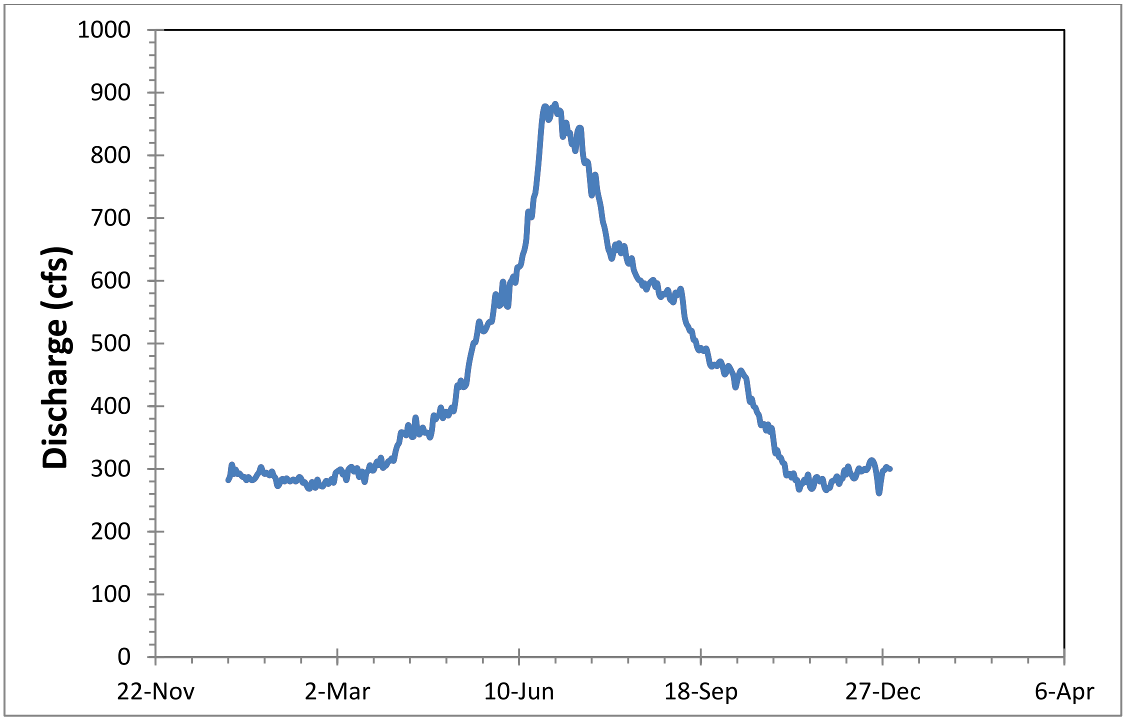


Figure A.25 – Average annual hydrograph (1938-2013) for the Blue River below Green Mountain Reservoir (USGS 09057500).

Appendix B – Upstream Reservoir Descriptions

Shadow Mountain Reservoir was built between 1944 and 1946 by the BOR and is operated by the NCWCD. It is located downstream of Grand Lake and acts as a conduit between Grand Lake and Lake Granby. The North Fork of the Colorado River drains into the southwest side of the reservoir. It has a maximum capacity of 17,354 AF (Figure B.1).

Figure B.1 – Grand Lake is the foreground with Shadow Mountain Reservoir behind it http://grandlakechamber.com/wp-content/uploads/2013/03/Shadow_Mountain_Fire_lookout.jpg).

The Colorado River drains out of Shadow Mountain Reservoir and flows into Lake Granby (Figure B.2). Lake Granby was constructed between 1942 and 1949 by the BOR and is operated by the NCWCD. The main purpose of the reservoir is to store water to be sent over to the East Slope. The maximum capacity of Lake Granby is 539,758 AF.

Figure B.2 – Lake Granby dams up the Colorado River downstream of Shadow Mountain Reservoir (http://www.allwinterpark.com/lakes_rivers_falls/lake_granby.php).

Willow Creek Reservoir captures water from Willow Creek, a tributary to the Colorado River (Figure B.3). It was built between 1951 and 1953 by the BOR and is operated by the NCWCD. Water from the reservoir is eventually diverted to the East Slope. The maximum capacity of Willow Creek Reservoir is 10,600 AF.

Figure B.3 – Willow Creek Reservoir (http://www.northernwater.org/WaterProjects/WillowCreek.aspx).

Williams Fork Reservoir dams up the Williams Fork of the Colorado River (Figure B.4). It was completed in 1959 by Denver Water who still operates it today. Water from the reservoir is diverted to the East Slope to be used by the City of Denver. The maximum capacity is 96,882 AF.

Figure B.4 – Williams Fork Reservoir (http://www.applegategroup.com/publications/applegate-calendars/2011-calendar).

Wolford Mountain Reservoir dams up Muddy Creek, a tributary to the Colorado River (Figure B.5). Construction was completed in 1996. The reservoir is operated by the Colorado River District to provide storage benefits for the West and East Slopes. The West Slope receives 66,00 AF of storage but Denver Water can use up to 40% of the water in exchange for financial support.

Figure B.5 – Wolford Mountain Reservoir (http://www.applegategroup.com/Publications/Applegate%20Calendars/2013%20Calendar).

Dillon Reservoir, the farthest upstream reservoir on the Blue River, was completed in 1963 (Figure B.6). The reservoir is owned and operated by Denver Water. The maximum capacity is 257,304 AF. Water from the reservoir is diverted to the East Slope.

Figure B.6 – Dillon Reservoir (http://www.upthecreek.org/calendar-2012.htm).

Farther downstream on the Blue River is Green Mountain Reservoir (Figure B.7). The reservoir was built between 1938 and 1943 by the BOR and is still operated by them today. Water from the reservoir is used to compensate the West Slope for water being diverted to the East Slope from other reservoirs. The maximum capacity is 153,000 AF. An agreement between Denver Water and the Colorado River District allows Denver Water to substitute for water that does not make it to Green Mountain Reservoir from Dillon Reservoir with water from Wolford Mountain Reservoir.

Figure B.7 – Green Mountain Reservoir (http://www.northernwater.org/WaterProjects/GreenMountainReservoir.aspxa).

Appendix C – Water-quality Data

Table C.1 – Water-quality point samples taken between September 26 and October 2, 2012 on the main stem Colorado River and Blue River.

Location	Date	Time	Turbidity (NTU)	pH	Conductivity (µS/cm)	Temperature (°F)	Dissolved Oxygen (mg/L)	Oxygen Reduction Potential (Volts)	Notes
Blue River above junction w/ Colorado	10/2/2012	3:21:00 PM	3.2	8.64	185.10	59.62	9.03	0.14	
Colorado River above Kremmling	10/2/2012	3:44:47 PM	1.7	8.41	151.64	56.74	10.37	0.14	
Pumphouse	9/26/2012	1:03:53 PM	5.8	7.62	286.54	57.03	9.29	0.24	recent rain
Un-named Trib U/S	9/26/2012	2:56:57 PM	4.8	8.59	291.32	58.28	9.42	0.21	
Un-named Trib D/S	9/26/2012	3:05:25 PM	4.8	8.65	292.22	58.39	9.44	0.20	
Blacktail Creek D/S	9/26/2012	4:09:34 PM	4.7	8.16	292.27	58.73	9.30	0.21	
Sheephorn Creek D/S	9/26/2012	5:25:06 PM	4.8	6.75	293.45	58.98	9.24	0.24	
Midpoint 2 Radium-Rancho	9/27/2012	10:22:55 AM	7.4	5.66	280.39	55.61	8.45	0.29	rain last night
Rancho del Rio	9/27/2012	11:46:32 AM	6.3	6.78	283.86	56.28	8.46	0.24	
Midpoint 3 Rancho-Piney	9/27/2012	1:36:35 PM	5.8	6.32	288.59	57.56	8.53	0.23	
Piney River U/S	9/27/2012	2:50:22 PM	6.4	6.19	290.36	58.25	9.02	0.25	
Piney River D/S	9/27/2012	3:23:20 PM	5.6	8.10	291.94	58.53	9.03	0.22	
Midpoint 4 State Bridge-Bond	9/28/2012	11:08:49 AM	6.9	7.89	282.23	54.53	8.71	0.19	
Bond	9/28/2012	11:45:20 AM	6.1	7.51	287.39	55.86	9.53	0.14	
Midpoint 5 Two Bridges-McCoy #1	9/28/2012	12:46:31 PM	5.5	7.26	290.32	56.73	9.63	0.14	
Rock Creek D/S Two Bridges-McCoy #2	9/28/2012	2:18:40 PM	5.0	8.48	299.07	58.95	10.49	0.09	
Midpoint 6 XS3	9/28/2012	3:40:40 PM	4.5	8.62	306.12	60.74	10.65	0.08	
Big Alkali Creek D/S	9/29/2012	9:26:18 AM	5.5	8.09	280.58	54.45	8.33	0.07	
Midpoint 7 Catamount-Burns	9/29/2012	10:45:15 AM	5.6	7.84	282.52	55.09	8.82	0.11	
Derby Creek D/S	9/29/2012	1:04:21 PM	5.8	8.31	290.84	56.44	8.92	0.13	
Red Dirt Creek U/S	9/29/2012	2:30:59 PM	6.6	8.43	292.73	56.97	9.17	0.14	
Mid Jack Flats Red Dirt	9/29/2012	3:31:07 PM	6.4	8.46	295.30	57.32	9.02	0.14	
Red Dirt Creek D/S	9/29/2012	4:22:21 PM	7.3	8.52	293.90	57.51	8.87	0.16	
Ranch U/S	9/29/2012	4:59:44 PM	7.0	8.50	295.77	57.68	8.86	0.15	
Midpoint 10 - Poison Cr	9/30/2012	10:44:51 AM	9.6	8.56	296.68	55.68	8.54	0.10	
Sweetwater Creek D/S	9/30/2012	1:09:30 PM	14.7	8.46	314.66	58.19	8.88	0.14	
Lyons Gulch	9/30/2012	2:49:43 PM	13.3	8.50	320.13	59.41	8.83	0.15	
Above Dotsero Cross Section	10/1/2012	11:43:56 AM	9.3	8.39	334.19	55.65	8.77	0.14	
Dotsero	10/1/2012	12:43:06 PM	9.0	8.52	374.74	56.80	8.82	0.09	

Table C.2 – Water-quality point samples taken between September 26 and October 2, 2012 on tributaries of Colorado River within the study area.

Location	Date	Time	Turbidity (NTU)	pH	Conductivity (μS/cm)	Temperature (°F)	Dissolved Oxygen (mg/L)	Oxygen Reduction Potential (Volts)	Notes
Un-named Trib directly U/S Blacktail	9/26/2012	2:46:47 PM	8.2	8.05	404.15	50.86	8.91	0.23	recent rain
Blacktail Creek	9/26/2012	3:59:56 PM	1.1	6.79	191.38	56.09	8.02	0.24	recent rain
Upper Sheephorn Creek	10/2/2012	2:19:07 PM	9.2	8.44	408.53	57.82	8.23	0.12	
Sheephorn Creek	9/26/2012	4:59:30 PM	17.8	6.37	432.17	60.02	7.93	0.25	recent rain
Upper Piney River	10/2/2012	1:20:25 PM	1.4	8.36	251.00	53.03	9.08	0.12	
Piney River	9/27/2012	2:38:42 PM	2.2	6.25	262.41	56.82	8.95	0.25	rained the night before
Rock Creek	9/28/2012	1:58:39 PM	3.9	7.85	308.80	57.20	9.42	0.12	
Big Alkali Creek	9/28/2012	5:26:51 PM	206.0	7.10	1504.70	57.16	8.15	0.13	
Upper Cabin Creek	10/2/2012	11:49:35 AM	9.3	8.43	347.52	48.20	9.28	0.13	
Cabin Creek	9/29/2012	11:32:19 AM	9.1	8.37	360.26	48.64	9.32	0.10	
Derby Creek	9/29/2012	12:40:18 PM	8.9	8.39	275.58	51.30	9.26	0.13	
Upper Red Dirt Creek	10/2/2012	10:41:44 AM	36.5	8.16	101.34	42.43	9.92	0.14	
Red Dirt Creek	9/29/2012	3:56:40 PM	21.5	8.30	120.13	51.58	8.94	0.16	
Sweetwater Creek	9/30/2012	12:40:33 PM	157.9	8.52	359.68	55.38	8.42	0.13	
Upper Deep Creek	10/2/2012	8:47:52 AM	3.2	8.49	205.30	43.69	10.00	0.14	
Deep Creek	10/1/2012	11:12:17 AM	28.4	8.40	485.57	48.28	9.61	0.15	
Return Flow Culvert	10/1/2012	12:10:18 PM	15.7	8.56	264.03	51.98	9.08	0.12	
Hot Spring	10/1/2012	12:28:57 PM	-0.4	6.54	26201.44	94.14	0.84	0.14	

Table C.3 – Water-quality point samples taken between October 1 and October 4, 2013 on the main stem Colorado River.

Location	Date	Time	Turbidity (NTU)	Nitrate (mV)	Ammonium (mg/L-N)	pH	Conductivity (µS/cm)	Temperature (°F)	Dissolved Oxygen (mg/L)	Total Dissolved Solids (g/L)	Salinity (ppt)	Oxygen Reduction Potential (Volts)	Notes
Pumphouse	10/1/2013	1:00:00 PM	0.7	164.8	0.12	8.77	184.5	51.2	8.94	0.1181	0.08	0.269	
Un-named Trib D/S	10/1/2013	1:50:00 PM	0.3	170.3	0.12	9.01	185.2	53.2	9.03	0.1186	0.08	0.279	
Blacktail Creek D/S	10/1/2013	2:05:00 PM	0.1	157.5	0.10	9.10	185.6	53.3	8.88	0.1190	0.08	0.298	
Sheephorn Creek D/S	10/1/2013	3:15:00 PM	0.1	166.0	0.11	8.92	184.6	53.9	9.13	0.1184	0.08	0.353	
Midpoint 2 Radium-Rancho	10/1/2013	4:00:00 PM	0.2	165.4	0.10	9.17	188.5	55.6	8.93	0.1207	0.09	0.365	
Rancho del Rio	10/1/2013	4:30:00 PM		161.2	0.10	9.18	188.2	55.8	9.24	0.1204	0.09	0.374	
Midpoint 3 Rancho-Piney	10/1/2013	5:30:00 PM	0.1	163.8	0.10	9.10	188.2	55.7	9.19	0.1205	0.09	0.329	
Piney River U/S	10/4/2013	1:30:00 PM	0.8	132.5	0.04	8.81	191.2	48.6	8.62	0.1223	0.09	0.315	
Piney River D/S	10/1/2013	6:30:00 PM	0.0	160.0	0.08	9.13	202.4	54.5	8.28	0.1294	0.09	0.345	
Midpoint 4 State Bridge-Bond	10/2/2013	10:00:00 AM	0.0	152.4	0.06	8.80	195.1	50.5	8.24	0.1248	0.09	0.346	
Bond	10/2/2013	11:00:00 AM	0.0	156.8	0.06	9.00	195.2	51.5	8.59	0.1252	0.09	0.317	
Midpoint 5 Two Bridges-McCoy #1	10/2/2013	12:00:00 PM	0.0	150.2	0.06	9.00	195.8	52.4	8.66	0.1253	0.09	0.341	
Rock Creek D/S Two Bridges-McCoy #2	10/2/2013	1:00:00 PM	0.0	140.3	0.06	9.09	196.6	53.3	8.84	0.1256	0.09	0.371	
Midpoint 6 XS3	10/2/2013	3:30:00 PM	0.0	154.4	0.08	8.96	202.7	55.0	8.80	0.1300	0.09	0.311	
Big Alkali Creek D/S	10/2/2013	4:00:00 PM	0.4	155.2	0.08	9.28	203.1	55.8	8.77	0.1299	0.09	0.381	
Midpoint 7 Catamount-Burns	10/2/2013	5:00:00 PM	5.0	143.3	0.08	9.41	205.9	56.4	8.81	0.1318	0.09	0.395	
Cabin Creek U/S	10/3/2013	10:00:00 AM	0.7	158.2	0.07	8.73	206.4	50.9	8.31	0.1325	0.10	0.323	
Derby Creek U/S	10/3/2013	12:00:00 PM	0.8	149.1	0.07	8.88	212.7	51.0	8.32	0.1363	0.10	0.338	
Derby Creek D/S	10/3/2013	1:00:00 PM	1.2	147.6	0.06	9.00	212.6	51.1	8.38	0.1360	0.10	0.35	
Pinball Point (rd u/S 13)	10/3/2013	2:00:00 PM	7.4	146.1	0.07	9.10	211.9	51.7	8.61	0.1357	0.10	0.368	
Jack flats	10/3/2013	2:30:00 PM	4.3	146.6	0.07	9.05	212.5	52.4	8.61	0.1360	0.10	0.378	
Red Dirt Creek U/S (MID JACK RED 13)	10/3/2013	3:15:00 PM	3.4	149.3	0.07	9.01	211.9	52.6	8.71	0.1356	0.10	0.398	
Red Dirt directly u/s	10/4/2013	11:30:00 PM	2.5	136.0	0.04	9.02	209.7	48.2	8.70	0.1344	0.10	0.358	snowmelt
Red Dirt Creek D/S	10/3/2013	4:30:00 PM	3.3	141.6	0.06	8.92	212.1	53.0	8.59	0.1358	0.10	0.406	
U/S of Poison Creek (ranch u/s)	10/3/2013	5:00:00 PM	3.6	150.5	0.07	9.30	213.0	53.4	8.62	0.1367	0.10	0.419	
Midpoint 10 - Poison Cr	10/3/2013	5:30:00 PM	4.0	144.6	0.07	8.94	214.1	53.7	8.62	0.1371	0.10	0.419	
Sweetwater Creek directly U/S	10/4/2013	11:00:00 PM		149.0	0.06	9.11	232.2	49.2	8.48	0.1485	0.11	0.373	snowmelt
Deep Creek directly u/s	10/4/2013	10:30:00 AM	7.1	137.1	0.06	8.92	292.0	48.3	8.41	0.1851	0.14	0.368	snowmelt
Deep Creek D/S XS5	10/4/2013	9:30:00 AM	7.4	133.1	0.06	8.77	291.5	48.2	8.42	0.1868	0.14	0.393	snowmelt
Dotsero	10/4/2013	9:00:00 AM	6.9	136.1	0.06	8.72	302.4	48.1	8.44	0.1936	0.15	0.396	snowmelt

Table C.4 – Water-quality point samples taken between October 1 and October 4, 2013 on tributaries of the Colorado River within the study area.

Location	Date	Time	Turbidity (NTU)	Nitrate (mV)	Ammonium (mg/L-N)	pH	Conductivity (µS/cm)	Temperature (°F)	Dissolved Oxygen (mg/L)	Total Dissolved Solids (g/L)	Salinity (ppt)	Oxygen Reduction Potential (Volts)	Notes
Blacktail Creek	10/1/2013	1:45:00 PM	0.0	166.2	0.10	8.65	250.2	52.5	8.06	0.1601	0.12	0.306	
Upper Sheephorn Creek	10/4/2013	2:30:00 PM	10.7	132.4	0.06	9.12	382.4	43.7	9.13	0.2447	0.19	0.398	snowmelt
Sheephorn Creek	10/1/2013	3:00:00 PM	8.8	169.0	0.14	8.76	396.9	56.9	7.82	0.2540	0.20	0.341	new beaver dam
Piney River	10/4/2013	2:00:00 PM	0.0	142.5	0.03	8.75	240.9	42.1	9.66	0.1541	0.11	0.338	snowmelt
Big Alkali Creek	10/4/2013	1:00:00 PM	87.7	137.1	0.13	8.10	1673.2	43.5	8.76	1.0708	0.89	0.24	
Upper Cabin Creek	10/4/2013	12:00:00 PM	1.1	150.0	0.07	9.10	688.1	44.7	9.00	0.4405	0.35	0.377	snowmelt
Cabin Creek	10/3/2013	11:00:00 AM	0.0	159.5	0.07	9.25	735.5	44.9	9.00	0.4710	0.38	0.325	
Derby Creek	10/3/2013	12:15:00 PM	0.0	159.7	0.03	9.08	173.6	44.5	9.20	0.1115	0.08	0.321	
Red Dirt Creek	10/3/2013	4:00:00 PM	21.9	138.6	0.06	8.71	166.7	49.1	8.53	0.1066	0.07	0.401	
Red Dirt Creek snowmelt	10/4/2013	12:00:00 PM	42.3	137.8	0.05	8.84	160.4	39.6	9.79	0.1030	0.07	0.351	snowmelt
Sweetwater Creek	10/4/2013	11:00:00 PM	27.5	151.2	0.05	9.28	453.5	44.4	9.16	0.2903	0.23	0.378	snowmelt
Upper Deep Creek	10/4/2013	10:00:00 AM	2.7	134.1	0.03	9.30	297.8	42.2	9.41	0.1904	0.14	0.382	snowmelt
Deep Creek	10/4/2013	10:30:00 AM	13.8	122.3	0.05	9.22	585.3	42.3	9.49	0.3745	0.30	0.363	snowmelt

Table C.5 – All the available water-quantity and water-quality data available for the Upper Colorado River.

		Flow Data		Temp Data	
Site Location	Site Operator	From	To	From	To
Colorado River downstream of Granby Reservoir	GCWIN			4/19/2007	3/24/2011
Colorado River below Lake Granby	USGS #9019000	10/1/1950	9/30/1982		
Colorado River downstream of YMCA flow gage	GCWIN/Northern	5/13/2003	11/16/2012	4/17/2007	3/24/2011
Colorado River Near Granby	USGS #9019500	1/1/1908	Present		
Willow Creek below Willow Creek Reservoir	USGS #9021000	10/1/1953	9/30/1982	4/17/2007	3/24/2011
Willow Creek downstream of Willow Creek Reservoir	GCWIN			4/17/2007	3/24/2011
Willow Creek Near Granby	CDWR	1/1/1935	12/31/1954		
Willow Creek below Willow Creek Reservoir	CDWR	1/1/1985	12/31/2010		
Willow Creek pump Canal	Northern	1/1/1986	Present		
Fraser River below Crooked Creek	GCWIN			7/23/2006	10/15/2006
Fraser River below Crooked Creek at Tabernash	USGS #9033300	10/1/1998	Present	6/7/2007	Present
Fraser River at Hwy 40 at Granby	GCWIN			7/13/2007	9/8/2012
Fraser River above Granby Sanitation District	GCWIN			7/28/2005	9/8/2012
Fraser River near Granby	Northern	10/16/2000	Present		
Fraser River at Granby	USGS #9034000	8/1/1904	12/31/1955		
Fraser River below Granby Sanitation District	GCWIN			7/3/2008	9/8/2012
Colorado River above Fraser River Confluence	GCWIN			7/26/2005	9/7/2005
Fraser River above Colorado River Confluence	GCWIN			7/26/2005	11/14/2005
Colorado River Upstream of Windy Gap	GCWIN			4/17/2007	11/3/2009
Colorado River at Windy Gap Bypass	GCWIN			4/17/2007	5/26/2011
Colorado River at confluence Windy Gap Spillway and Bypass	GCWIN			4/17/2007	3/23/2011
Colorado River at Windy Gap (Chinmney Rock)	Northen	4/25/2003	Present		
Colorado River at Windy Gap, near Granby	USGS #9034250	10/1/1981	Present	4/1/2008	Present
Colorado River below Windy Gap at Hitching post (abv 9034250)	GCWIN			7/26/2005	10/22/2012
Colorado River below Windy Gap	GCWIN			8/9/2007	9/30/2009
Colorado River 1 mi downstream of Windy Gap at USGS flow gage	GCWIN			4/17/2007	3/23/2011
Colorado River at Sheriff Ranch at Silver Doctor Cabin	GCWIN			6/24/2010	9/8/2012
Colorado River at Hot Sulphur Springs	USGS #9034500	10/1/1904	9/30/1994	10/1/1969	9/30/1993
Colorado River near Hot Sulphur Springs	Northern	7/5/2003	Present		
Colorado River above Hot Sulphur Springs Water Treatment Plant	GCWIN			7/29/2006	9/8/2012
Colorado River above Hot Sulphur Springs Resort	GCWIN			5/4/2008	9/8/2012
Colorado River below Byers Canyon	GCWIN			8/19/2008	9/8/2012
Colorado River at Lone Buck below CDOW Office	GCWIN			7/29/2006	9/8/2012
Williams Fork below Williams Fork Reservoir	USGS #9038500	10/1/1948	Present		
Colorado River near Parshall	Northern	4/23/2003	Present		
Colorado River above Kids Pond below Parshall	GCWIN			7/26/2005	9/8/2012
Colorado River at Public Access East of Con Ritschard	GCWIN			9/6/2006	9/8/2012
Colroado River at CR3 Bridge at Bar Lazy J Ranch	GCWIN			7/13/2007	9/8/2012
Colorado River at CR39 Bridge - KB Ditch	GCWIN			8/18/2007	9/8/2012
Colorado River below KB Ditch	Northern	4/23/2003	Present		
Colorado River above Hwy 9 Bridge at Kremmling	GCWIN			7/30/2006	11/5/2012
Blue River below Green Mountain Reservoir	USGS #9057500	10/1/1937	Present	10/12/1996	9/30/1999
Blue River at Yust Ranch 100 ft upstream of Trough Road Bridge	GCWIN			5/27/2010	9/8/2012
Muddy Creek below Wolford Mtn Reservoir near Kremmling	USGS #9041400	7/29/1995	Present	10/3/1995	Present
Muddy Creek below Cow Creek confluence	GCWIN			7/22/2010	9/8/2012
Muddy Creek at Kremmling	USGS #9041500	4/21/1982	9/30/1995		
Muddy Creek below Hwy 40 bridge	GCWIN			6/18/2008	9/7/2011
Muddy Creek below Kremmling Sanitation District	GCWIN			7/29/2008	11/12/2012
Colorado River near Kremmling	USGS #9058000	8/1/1904	Present	4/21/2006	Present
Colorado River below Gore Canyon above Pumphouse	GCWIN			7/30/2006	8/30/2011
Colorado River near Radium	USGS #9058030	8/20/1981	9/30/1990		
Piney River near State Bridge	USGS #9059500	6/1/1944	Present		
Colorado River near Dotsero	USGS #9070500	12/1/1940	Present	2/15/1980	9/15/1998
Eagle River below Gypsum	USGS #9070000	10/1/1946	Present	7/23/2002	12/31/2004

Appendix D – Macroinvertebrate Samples

Table D.1a – Macroinvertebrate sampling results from 9/26/2012 – 10/1/2012 for sites on the Colorado River main stem.

	Colorado River											
Location	**Pump-house**	**Black-tail D/S**	**Sheep-horn D/S**	**Mid Radium – Rancho**	**Rancho**	**Mid Rancho – Piney**	**State Bridge**	**Mid State Bridge – Bond**	**Mid Bond McCoy**	**Mid Two Bridges – McCoy #1**	**Rock Creek D/S**	**XS3**
Ephemeroptera												
Ameletus sp.												
Acentrella insignificans				1	5			1				
Baetis tricaudatus	41	67	114	24	42	9	151	49	93	91	183	42
Diphetor hageni												
Drunella coloradensis												
Drunella doddsii												
Drunella grandis		1										
Ephemerella sp.	2	13	37	23	34	25	15	11	12	35	126	24
Serratella sp.												
Cinygmula sp.												
Epeorus sp.	2		2	1	2							2
Heptagenia sp.										2	3	
Rhithrogena sp.			5	5		1		1	2	1	18	3
Paraleptophlebia sp.		1	13	4	9	1	1		2		5	8
Tricorythodes explicatus	1	1	3	4	27	22	6	2	1	13	18	15
Plecoptera												
Capnia sp.												
Capniidae												
Paracapnia angulata			1									
Chloroperlidae			1									
Sweltsa sp.												
Prostoia besemetsa												
Zapada cinctipes												
Zapada oregonensis group												
Pteronarcella badia											1	
Pteronarcys californica (Year 0+)			16									
Pteronarcys californica (Year 1+)			55	1								
Pteronarcys californica (Year 2+)		6		2			6				1	
Pteronarcys californica (Year 3+)		3		2				3	1	1		1
Taenionema sp.												
Claassenia sabulosa												
Hesperoperla pacifica												
Cultus sp.		2	6	5	2	2		1	1	2		
Diura knowltoni												
Isoperla fulva												
Isoperla sp.		1	3		5	2	4	2		1	3	
Megarcys signata												
Perlodidae												
Isogenoides sp.												
Skwala americana								1				
Trichoptera												
Brachycentrus americanus	3					1			1			
Brachycentrus occidentalis							6	3		6	2	1
Micrasema sp.												
Culoptila thoracica								1		1	2	5
Glossosoma sp.												
Helicopsyche borealis												
Arctopsyche grandis												
Cheumatopsyche sp.											2	2
Hydropsyche cockerelli			3	3		1	7	10	4	4	4	4
Hydropsyche occidentalis	12	10	7	12	1	3	34	16	26	20	22	3
Hydropsyche oslari		42	54	24	1	48	54	32	22	15	23	17
Hydroptila sp.											2	1
Lepidostoma sp.	6	5	17	4	1	2	2			1	1	
Oecetis sp.					1							
Psycomyia flavida						1						
Rhyacophila brunnea												
Rhyacophila coloradensis		1										
Rhyacophila sp.												
Oligophlebodes minutes												

Table D.1b – Continued macroinvertebrate sampling results from 9/26/2012 – 10/1/2012 for sites on the Colorado River main stem.

	Colorado River											
Location	**Pump-house**	**Black-tail D/S**	**Sheep-horn D/S**	**Mid Radium – Rancho**	**Rancho**	**Mid Rancho – Piney**	**State Bridge**	**Mid State Bridge – Bond**	**Mid Bond McCoy**	**Mid Two Bridges – McCoy #1**	**Rock Creek D/S**	**XS3**
Diptera												
Chironomidae												
Orthocladiinae	118	99	53	39	115	204	58	17	23	18	18	22
Tanypodinae	1			1	3					2	3	5
Tanytarsini												
Chironomini	1		1	2	16	19	1	1	3	4	2	2
Diamesinae	2				1		1			1		
Other Diptera												
Atherix pachypus	1	1	5	1		1	1	1		1		2
Ceratopogoninae					1							
Dixa sp.												
Hemerodromia sp.												
Chelifera/Neoplasta sp.												
Wiedemannia sp.												
Pericoma sp.												
Simulium sp.		41	51	27	19	104	155	158	307	111	152	124
Antocha sp.												
Dicranota sp.												
Hexatoma sp.											1	
Coleoptera												
Helichus striatus												
Heterlimnius corpulentus												
Microcylloepus sp.											23	
Optioservus sp.	29	5	178	20	11	1	24	3	6	8	6	32
Zaitzevia parvula			6			1	3	1	1		7	2
Odonata												
Ophiogomphus severus					2							
Hemiptera												
Trichocorixa sp.												
Lepidoptera												
Petrophila sp.												
Miscellaneous												
Atractides sp.												
Hygrobates sp.				18								
Lebertia sp.				3			1			1		
Protzia sp.												
Sperchon sp.	12	11	8	3	19	18		4	3	2	1	
Caecidotea sp.												
Crangonyx sp.												
Ferrissia sp.	1			1		2				1		1
Gyraulus sp.												
Lymnaeidae				1	1							
Physa sp.		2		2								
Dugesia sp.												
Polycelis coronata												
Erpobdellidae												
Enchytraeidae												
Lumbricidae												
Tubificidae (w/out hair chaetae)												
Nematoda		2	2	1	3	1	1	3	1		1	
Total:	**232**	**314**	**641**	**234**	**321**	**469**	**531**	**321**	**509**	**342**	**630**	**318**
Taxa Richness:	**15**	**20**	**24**	**28**	**23**	**22**	**20**	**22**	**18**	**24**	**27**	**22**
EPT Taxa:	**7**	**13**	**16**	**15**	**12**	**13**	**11**	**14**	**11**	**14**	**17**	**14**

Table D.1c – Continued macroinvertebrate sampling results from 9/26/2012 – 10/1/2012 for sites on the Colorado River main stem.

	Colorado River												
Location	Catamount	Mid Catamount – Burns	Derby Creek D/S	Red Dirt U/S	Jack Flats	Mid Jack – Red Dirt	Red Dirt D/S	Ranch U/S	Sweet-water D/S	Lyons Gulch	Deep Creek D/S	XS1	Dotsero
Ephemeroptera													
Ameletus sp.													
Acentrella insignificans						1	2						
Baetis tricaudatus	211	174	371	71	27	122	137	218	19	58	72	9	58
Diphetor hageni													
Drunella coloradensis													
Drunella doddsii													
Drunella grandis									2		1	3	
Ephemerella sp.	68	51	98	36	15	21	39	75	4	17	10		4
Serratella sp.													
Cinygmula sp.			1			1							
Epeorus sp.	5		1										
Heptagenia sp.	3		9	7			8	11		6	2		1
Rhithrogena sp.	3		21	3		1		7		2	1		1
Paraleptophlebia sp.	17	16	92	16	4	1	13	34	1	1	4		2
Tricorythodes explicatus	31	15	54	27	18	5	71	79	9	24	15		8
Plecoptera													
Capnia sp.													
Capniidae													
Paracapnia angulata													
Chloroperlidae							1						
Sweltsa sp.											1		
Prostoia besemetsa													
Zapada cinctipes													
Zapada oregonensis group													
Pteronarcella badia								1	2		1		1
Pteronarcys californica (Year 0+)													
Pteronarcys californica (Year 1+)													
Pteronarcys californica (Year 2+)						1							
Pteronarcys californica (Year 3+)													
Taenionema sp.													
Claassenia sabulosa		1	4	2	5	2	1	6	3	3		1	
Hesperoperla pacifica							1						1
Cultus sp.	2		14	1	3	3	2	3	1				1
Diura knowltoni													
Isoperla fulva													
Isoperla sp.	4		1	5	1	3	6	2		6	6	1	3
Megarcys signata													
Perlodidae													
Isogenoides sp.												1	1
Skwala americana			1										
Trichoptera													
Brachycentrus americanus	1		1										1
Brachycentrus occidentalis		1	3	3	6	10	5	3	7	1	7	1	3
Micrasema sp.													
Culoptila thoracica	8	21	70	59	9	4	9	51	2	46	17	2	9
Glossosoma sp.													
Helicopsyche borealis													
Arctopsyche grandis									2				
Cheumatopsyche sp.	6	5	16	2		11	2	3	2	6	12		4
Hydropsyche cockerelli	9	18		2	15	29	7	7	18	9	1	2	2
Hydropsyche occidentalis	17					19	5	6	26	14	54	4	41
Hydropsyche oslari	53	46	54	7	29	13	5	23	18	7	46	7	37
Hydroptila sp.	1		12	3	1	1	4	21		1	9		
Lepidostoma sp.	1						1			1			
Oecetis sp.		2	4				1	2	2	1	2	1	
Psycomyia flavida													
Rhyacophila brunnea													
Rhyacophila coloradensis	1										1		
Rhyacophila sp.													
Oligophlebodes minutes													

Table D.1d – Continued macroinvertebrate sampling results from 9/26/2012 – 10/1/2012 for sites on the Colorado River main stem.

	Colorado River												
Location	**Catamount**	**Mid Catamount – Burns**	**Derby Creek D/S**	**Red Dirt U/S**	**Jack Flats**	**Mid Jack – Red Dirt**	**Red Dirt D/S**	**Ranch U/S**	**Sweet-water D/S**	**Lyons Gulch**	**Deep Creek D/S**	**XS1**	**Dotsero**
Diptera													
Chironomidae													
Orthocladiinae	1	29	38	13	13	4	10	20	6	5	7		5
Tanypodinae	21	9	26	1	2	2	2	3	1	1	4		
Tanytarsini													
Chironomini	1	1	2	1	1			2		2			1
Diamesinae			1										
Other Diptera													
Atherix pachypus	3		17	7	2	2	2	1	1	7	12	6	4
Ceratopogoninae													
Dixa sp.													
Hemerodromia sp.					1				2				1
Chelifera/Neoplasta sp.													
Wiedemannia sp.													
Pericoma sp.													
Simulium sp.	105	171	137	26	1	38	33	43	3	4	20	1	5
Antocha sp.													
Dicranota sp.													
Hexatoma sp.		1	2		1	1				2			
Coleoptera													
Helichus striatus													
Heterlimnius corpulentus													
Microcylloepus sp.	1	10	1				1	1			38		2
Optioservus sp.	23	9	48	5	33	9	18	39	8	18	21	2	12
Zaitzevia parvula	8	3	5	7	1	5	8	9	2	5	11		4
Odonata													
Ophiogomphus severus			1										
Hemiptera													
Trichocorixa sp.													
Lepidoptera													
Petrophila sp.													
Miscellaneous													
Atractides sp.			1			1	1						
Hygrobates sp.							5	1		1	1		
Lebertia sp.			2								1		
Protzia sp.													
Sperchon sp.	4	2	10	8		6	3	3	1	1	6	1	1
Caecidotea sp.													
Crangonyx sp.													
Ferrissia sp.			1							1			
Gyraulus sp.													
Lymnaeidae													
Physa sp.	3												
Dugesia sp.											2		
Polycelis coronata													
Erpobdellidae						1							
Enchytraeidae			1										
Lumbricidae													
Tubificidae (w/out hair chaetae)													
Nematoda		1				1	1						1
Total:	**611**	**586**	**1120**	**312**	**188**	**318**	**404**	**674**	**142**	**250**	**385**	**42**	**214**
Taxa Richness:	**28**	**21**	**35**	**23**	**21**	**29**	**31**	**28**	**24**	**28**	**30**	**15**	**28**
EPT Taxa:	**18**	**11**	**19**	**15**	**12**	**18**	**20**	**18**	**16**	**17**	**19**	**11**	**18**

Table D.2a – Macroinvertebrate sampling results from 9/26/2012 – 10/1/2012 for sites on tributaries to the Colorado River main stem.

	Tributary														
Location	Black-tail Creek	Upper Sheep-horn Creek	Lower Sheep-horn Creek	Upper Piney River	Lower Piney River	Rock Creek	Upper Cabin Creek	Lower Cabin Creek	Derby Creek	Upper Red Dirt Creek	Lower Red Dirt Creek	Sweet-water Creek	Upper Deep Creek	Lower Deep Creek	Blue River
Ephemeroptera															
Ameletus sp.													1		
Acentrella insignificans															
Baetis tricaudatus	2		1	52	21	16	18	1	3	3	8	38	50	2	2
Diphetor hageni		1				2							1		
Drunella coloradensis															
Drunella doddsii														1	
Drunella grandis				1			1					2	1	9	
Ephemerella sp.		3		7	8	13	2	1	5	1	1	1	2		
Serratella sp.															
Cinygmula sp.														1	
Epeorus sp.	1			3		4			6						
Heptagenia sp.															
Rhithrogena sp.		4	2	3	1			1	3						
Paraleptophlebia sp.		1	1	11	1	20	2		6						2
Tricorythodes explicatus				1		13									
Plecoptera															
Capnia sp.															
Capniidae													1		
Paracapnia angulata															
Chloroperlidae		3	14	7		1	2		7						2
Sweltsa sp.						1			25			1	3	9	
Prostoia besemetsa											1				
Zapada cinctipes	3														
Zapada oregonensis group															
Pteronarcella badia		11	4	3	3		1		8			2			
Pteronarcys californica (Year 0+)				4	2										
Pteronarcys californica (Year 1+)				1	3										
Pteronarcys californica (Year 2+)				14	3										
Pteronarcys californica (Year 3+)				2											
Taenionema sp.															
Claassenia sabulosa			1	2	1				1			1			
Hesperoperla pacifica									9						
Cultus sp.															
Diura knowltoni															
Isoperla fulva	3	1							3					1	
Isoperla sp.						3	4								
Megarcys signata														1	
Perlodidae															
Isogenoides sp.		2	4												
Skwala americana					2	4			5						
Trichoptera															
Brachycentrus americanus	13	3	2		1		2	3	34					2	1
Brachycentrus occidentalis															
Micrasema sp.	1						1								
Culoptila thoracica				2		4									
Glossosoma sp.															
Helicopsyche borealis															
Arctopsyche grandis	2	1	3	4					1					5	
Cheumatopsyche sp.						2									
Hydropsyche cockerelli		10	8	20	3	2									
Hydropsyche occidentalis		1	24		1					1		4			1
Hydropsyche oslari	98	4	3	12	3	2	16	1	2			28			1
Hydroptila sp.															
Lepidostoma sp.	2	8	4	22	3	8			205			3			
Oecetis sp.		1				3									
Psycomyia flavida															
Rhyacophila brunnea							1						2	6	
Rhyacophila coloradensis	1													1	
Rhyacophila sp.					1				1		2				
Oligophlebodes minutes				7											

Table D.2b – Continued macroinvertebrate sampling results from 9/26/2012 – 10/1/2012 for sites on tributaries to the Colorado River main stem.

	Tributary														
Location	**Black-tail Creek**	**Upper Sheep-horn Creek**	**Lower Sheep-horn Creek**	**Upper Piney River**	**Lower Piney River**	**Rock Creek**	**Upper Cabin Creek**	**Lower Cabin Creek**	**Derby Creek**	**Upper Red Dirt Creek**	**Lower Red Dirt Creek**	**Sweet-water Creek**	**Upper Deep Creek**	**Lower Deep Creek**	**Blue River**
Diptera															
Chironomidae															
Orthocladiinae	343	1	4	56	38	32	22	13	103	7	17	104			3
Tanypodinae									2						3
Tanytarsini	1					1			2						
Chironomini		1				4						1			
Diamesinae	23														
Other Diptera															
Atherix pachypus		6	1	2											
Ceratopogoninae		2	1			10	1								
Dixa sp.		1													
Hemerodromia sp.												9			
Chelifera/Neoplasta sp.											1	1			
Wiedemannia sp.													1		
Pericoma sp.															
Simulium sp.	4	3	2	1	8	2	11	2	2	16	20	125		1	1
Antocha sp.	11			5					4		1				
Dicranota sp.															
Hexatoma sp.		1			2	11	1							1	
Coleoptera															
Helichus striatus														1	
Heterlimnius corpulentus														2	
Microcylloepus sp.						1	1								
Optioservus sp.	2	34	82	47	12	228	25	4	19			15	1	4	49
Zaitzevia parvula		3	17	11	1	2			14			3		1	1
Odonata															
Ophiogomphus severus															
Hemiptera															
Trichocorixa sp.															
Lepidoptera															
Petrophila sp.															
Miscellaneous															
Atractides sp.															
Hygrobates sp.															
Lebertia sp.			3			3									
Protzia sp.			1												
Sperchon sp.		2	4	4	1	7			11			5			
Caecidotea sp.															
Crangonyx sp.															1
Ferrissia sp.															
Gyraulus sp.												1			
Lymnaeidae															
Physa sp.		1				142	2	3							16
Dugesia sp.															
Polycelis coronata								1							
Erpobdellidae						1									
Enchytraeidae			1												
Lumbricidae						1	4								12
Tubificidae (w/out hair chaetae)															
Nematoda															
Total:	**510**	**109**	**187**	**304**	**119**	**543**	**117**	**30**	**481**	**28**	**51**	**344**	**63**	**48**	**95**
Taxa Richness:	**16**	**26**	**23**	**27**	**22**	**30**	**19**	**10**	**25**	**5**	**8**	**18**	**10**	**17**	**14**
EPT Taxa:	**10**	**15**	**13**	**20**	**16**	**16**	**11**	**5**	**17**	**3**	**4**	**9**	**8**	**11**	**6**

Table D.3a – Macroinvertebrate sampling results from 10/1/2013 – 10/4/2013 for sites on the Colorado River main stem.

	Colorado River											
Location	Pump-house	Black-tail U/S	Black-tail D/S	Sheep-horn D/S	Mid Radium – Rancho	Rancho	Mid Rancho – Piney	Mid State Bridge – Bond	Mid Bond McCoy	Mid Two Bridges – McCoy #1	Mid Two Bridges – McCoy #2	XS3
Ephemeroptera												
Ameletus sp.												
Acentrella insignificans			2	1	3		1		1			
Baetis tricaudatus	53	47	282	269	115	75	17	47	113	247	169	328
Diphetor hageni												
Drunella coloradensis												
Drunella doddsii												
Drunella grandis												
Ephemerella sp.		8	25	3	5	64	10	16	9	111	98	275
Serratella sp.			1									
Cinygmula sp.												
Epeorus sp.	2	4	7	10	1	1	2	1				1
Heptagenia sp.								2	2	1	1	1
Rhithrogena sp.		3	1	8	6	23	6	1	3	18	14	36
Paraleptophlebia sp.		3		1	2	17	5	10	2	20	12	16
Tricorythodes explicatus	2	1	10	1	1	123	4	8	3	18	17	3
Plecoptera												
Capnia sp.												
Capniidae												
Paracapnia angulata												
Chloroperlidae												
Sweltsa sp.												
Prostoia besemetsa												
Zapada cinctipes												
Zapada oregonensis group												
Pteronarcella badia												
Pteronarcys californica (Year 0+)		1			14		2	1		1	1	
Pteronarcys californica (Year 1+)	1	4	2	9	7		2					
Pteronarcys californica (Year 2+)	5	5		8	33	3	8	7	1	11		
Pteronarcys californica (Year 3+)	3	1			5	3	5	2	3	2	1	6
Taenionema sp.												
Claassenia sabulosa												1
Hesperoperla pacifica												
Cultus sp.		1	8	3	2	6	1			4	1	1
Diura knowltoni												
Isoperla fulva												
Isoperla sp.					1					5	3	3
Megarcys signata												
Perlodidae												
Isogenoides sp.												
Skwala americana												
Trichoptera												
Brachycentrus americanus	1									2		
Brachycentrus occidentalis								13	12	4		2
Micrasema sp.												
Culoptila thoracica			1	1				3		17	1	18
Glossosoma sp.		1										
Helicopsyche borealis												
Arctopsyche grandis				1					1			
Cheumatopsyche sp.							2			11	7	13
Hydropsyche cockerelli				3	5		1	8	3	8	4	9
Hydropsyche occidentalis	16	15	17	3	9	5		25	23	72	16	21
Hydropsyche oslari	2	15	21	17	14		3	9	23	12	9	14
Hydroptila sp.						1	1			1		2
Lepidostoma sp.	1	2	5	1								
Oecetis sp.			1						1	1		
Psycomyia flavida												
Rhyacophila brunnea												
Rhyacophila coloradensis												
Rhyacophila sp.												
Oligophlebodes minutes												

Table D.3b – Continued macroinvertebrate sampling results from 10/1/2013 – 10/4/2013 for sites on the Colorado River main stem.

	Colorado River											
Location	Pump-house	Black-tail U/S	Black-tail D/S	Sheep-horn D/S	Mid Radium – Rancho	Rancho	Mid Rancho – Piney	Mid State Bridge – Bond	Mid Bond McCoy	Mid Two Bridges – McCoy #1	Mid Two Bridges – McCoy #2	XS3
Diptera												
Chironomidae												
Orthocladiinae	4	3	13	17	8	23	8	2	13	43	20	15
Tanypodinae		4	1	1	1	8	2		1	6	7	2
Tanytarsini												
Chironomini	1		2			11						
Diamesinae												
Other Diptera												
Atherix pachypus		5	2		9		3	3	1	6	2	
Ceratopogoninae												
Dixa sp.												
Hemerodromia sp.									1	2		
Chelifera/Neoplasta sp.												
Wiedemannia sp.												
Pericoma sp.												
Simulium sp.			12	65	6	2		6	20	46	48	165
Antocha sp.			1									
Dicranota sp.												
Hexatoma sp.					1							
Coleoptera												
Helichus striatus												
Heterlimnius corpulentus												
Microcylloepus sp.											1	
Optioservus sp.	5	19	10	16	13	4	5	12	8	11	14	6
Zaitzevia parvula			1	3	3	1		4	3	2	4	3
Odonata												
Ophiogomphus severus							3					
Hemiptera												
Trichocorixa sp.												
Lepidoptera												
Petrophila sp.												1
Miscellaneous												
Atractides sp.												
Hygrobates sp.	11											
Lebertia sp.		1										
Protzia sp.												
Sperchon sp.	2	2	11	2	3	7	3	1	2	2	1	
Caecidotea sp.												
Crangonyx sp.												
Ferrissia sp.	1		1		1	10	3	1				
Gyraulus sp.												
Lymnaeidae												
Physa sp.						1						
Dugesia sp.												
Polycelis coronata												
Erpobdellidae												
Enchytraeidae												
Lumbricidae		1										
Tubificidae (w/out hair chaetae)												
Nematoda			1						1		1	
Total:	**110**	**146**	**438**	**443**	**268**	**388**	**97**	**182**	**250**	**684**	**452**	**942**
Total Taxa:	**16**	**22**	**25**	**22**	**25**	**20**	**23**	**22**	**24**	**28**	**24**	**24**
EPT Taxa:	**10**	**15**	**14**	**16**	**16**	**11**	**16**	**15**	**15**	**20**	**15**	**18**

Table D.3c – Continued macroinvertebrate sampling results from 10/1/2013 – 10/4/2013 for sites on the Colorado River main stem.

	Colorado River								
Location	**Catamount**	**Mid Catamount – Burns**	**Derby Creek D/S**	**Red Dirt U/S**	**Jack Flats**	**Mid Jack – Red Dirt**	**Red Dirt D/S**	**Ranch U/S**	**XS1**
Ephemeroptera									
Ameletus sp.									
Acentrella insignificans			1						
Baetis tricaudatus	266	202	123	42	212	73	86	114	40
Diphetor hageni									
Drunella coloradensis									
Drunella doddsii							1		
Drunella grandis									
Ephemerella sp.	136	124	44	17	91	86	51	39	6
Serratella sp.									
Cinygmula sp.									
Epeorus sp.								1	
Heptagenia sp.	1			4	15	5	3		1
Rhithrogena sp.	14	20	10	5	5	5	8	10	
Paraleptophlebia sp.	10	22	12		19	11	28	12	1
Tricorythodes explicatus	12	13	6	4	11	12	10	8	3
Plecoptera									
Capnia sp.									
Capniidae									
Paracapnia angulata									
Chloroperlidae									
Sweltsa sp.									
Prostoia besemetsa									
Zapada cinctipes									
Zapada oregonensis group									
Pteronarcella badia			1						
Pteronarcys californica (Year 0+)									
Pteronarcys californica (Year 1+)									
Pteronarcys californica (Year 2+)	2								
Pteronarcys californica (Year 3+)									
Taenionema sp.									
Claassenia sabulosa		1	5	2			4		1
Hesperoperla pacifica									
Cultus sp.			2			1	1	2	
Diura knowltoni									
Isoperla fulva									
Isoperla sp.	3		1					5	
Megarcys signata									
Perlodidae									
Isogenoides sp.					2				
Skwala americana				1					2
Trichoptera									
Brachycentrus americanus							1		
Brachycentrus occidentalis	4	8	1		13	27	13	2	4
Micrasema sp.									
Culoptila thoracica	25	11	7			10	32	7	
Glossosoma sp.									
Helicopsyche borealis				1					1
Arctopsyche grandis					2	1	3		
Cheumatopsyche sp.	16	35			8	2		4	
Hydropsyche cockerelli	1	3	10	1	1	1			1
Hydropsyche occidentalis	25	13	2	1	6	10	16	22	8
Hydropsyche oslari	26	23	3	4	8	2	2	3	7
Hydroptila sp.	30		16		14	65	20	5	2
Lepidostoma sp.									
Oecetis sp.		2							
Psycomyia flavida	1	1							
Rhyacophila brunnea									
Rhyacophila coloradensis									
Rhyacophila sp.									
Oligophlebodes minutes									

Table D.3d – Continued macroinvertebrate sampling results from 10/1/2013 – 10/4/2013 for sites on the Colorado River main stem.

	Colorado River								
Location	**Catamount**	**Mid Catamount – Burns**	**Derby Creek D/S**	**Red Dirt U/S**	**Jack Flats**	**Mid Jack – Red Dirt**	**Red Dirt D/S**	**Ranch U/S**	**XS1**
Diptera									
Chironomidae									
Orthocladiinae	11	11	11	3	1	4	12	9	4
Tanypodinae	1	3	1	1	1	1	2	1	
Tanytarsini									
Chironomini				1					
Diamesinae									
Other Diptera									
Atherix pachypus	2	2	6		8	12	10	3	3
Ceratopogoninae									
Dixa sp.									
Hemerodromia sp.							1		
Chelifera/Neoplasta sp.									
Wiedemannia sp.									
Pericoma sp.									
Simulium sp.	106	57	126	7	2	94	37	45	8
Antocha sp.									
Dicranota sp.									
Hexatoma sp.				1					
Coleoptera									
Helichus striatus									
Heterlimnius corpulentus									
Microcylloepus sp.	2					1		2	
Optioservus sp.	5	18	13	1	7	11	7	5	6
Zaitzevia parvula	8	15	8	3	4	6	21	4	4
Odonata									
Ophiogomphus severus			1						1
Hemiptera									
Trichocorixa sp.									
Lepidoptera									
Petrophila sp.									
Miscellaneous									
Atractides sp.									
Hygrobates sp.									
Lebertia sp.									
Protzia sp.									
Sperchon sp.	2				2	8	1	1	2
Caecidotea sp.									
Crangonyx sp.									
Ferrissia sp.	1	1	1						
Gyraulus sp.									
Lymnaeidae			1						
Physa sp.	1				3				
Dugesia sp.									
Polycelis coronata									
Erpobdellidae									
Enchytraeidae									
Lumbricidae									
Tubificidae (w/out hair chaetae)				5					
Nematoda			1			1			
Total:	**711**	**585**	**413**	**104**	**435**	**449**	**370**	**304**	**105**
Total Taxa:	**26**	**21**	**26**	**19**	**22**	**24**	**24**	**22**	**20**
EPT Taxa:	**16**	**14**	**16**	**11**	**14**	**15**	**16**	**14**	**13**

Table D.4a – Macroinvertebrate sampling results from 10/1/2013 – 10/4/2013 for sites on tributaries to the Colorado River main stem.

	Tributary										
Location	**Blacktail Creek**	**Upper Sheephorn Creek**	**Lower Sheephorn Creek**	**Lower Piney River**	**Upper Cabin Creek**	**Lower Cabin Creek**	**Derby Creek**	**Lower Red Dirt Creek**	**Sweet-water Creek**	**Upper Deep Creek**	**Lower Deep Creek**
Ephemeroptera											
Ameletus sp.											
Acentrella insignificans							1		1		
Baetis tricaudatus	7	11	1		29	22	6		69	52	
Diphetor hageni	8				1	2					
Drunella coloradensis										1	
Drunella doddsii											
Drunella grandis	1	1	1	1							1
Ephemerella sp.	8	6	1	3	3	2	10	1	5	5	
Serratella sp.											
Cinygmula sp.										3	
Epeorus sp.		2		1							
Heptagenia sp.			1				1		1		
Rhithrogena sp.	1									2	
Paraleptophlebia sp.	16	3	4	1	4	3	10				
Tricorythodes explicatus	1		1					1			
Plecoptera											
Capnia sp.	10										
Capniidae											
Paracapnia angulata											
Chloroperlidae			1				3				
Sweltsa sp.	1						3				
Prostoia besemetsa											
Zapada cinctipes	49										
Zapada oregonensis group										5	4
Pteronarcella badia		3		2	3		3		2		
Pteronarcys californica (Year 0+)											
Pteronarcys californica (Year 1+)				3							
Pteronarcys californica (Year 2+)				2							
Pteronarcys californica (Year 3+)		1		10							
Taenionema sp.										3	
Claassenia sabulosa		1		1							
Hesperoperla pacifica	1										
Cultus sp.			1								
Diura knowltoni	1										
Isoperla fulva	1				1						
Isoperla sp.		1			3	1	1				
Megarcys signata											1
Perlodidae											
Isogenoides sp.		1									
Skwala americana	1					6	5				
Trichoptera											
Brachycentrus americanus	10				22	6	31			12	
Brachycentrus occidentalis						1					
Micrasema sp.	1				3						
Culoptila thoracica											
Glossosoma sp.											
Helicopsyche borealis											
Arctopsyche grandis		3		8	6	1	1				1
Cheumatopsyche sp.											
Hydropsyche cockerelli		12		11							
Hydropsyche occidentalis				1		1			6		
Hydropsyche oslari	117	1		3	43	3				1	
Hydroptila sp.											
Lepidostoma sp.	10	4	4	6			122	1			
Oecetis sp.			1								
Psycomyia flavida											
Rhyacophila brunnea	1				3						3
Rhyacophila coloradensis	1	1			1						
Rhyacophila sp.											
Oligophlebodes minutes				2							

Table D.4b – Continued macroinvertebrate sampling results from 10/1/2013 – 10/4/2013 for sites on tributaries to the Colorado River main stem.

	Tributary										
Location	**Blacktail Creek**	**Upper Sheephorn Creek**	**Lower Sheephorn Creek**	**Lower Piney River**	**Upper Cabin Creek**	**Lower Cabin Creek**	**Derby Creek**	**Lower Red Dirt Creek**	**Sweet-water Creek**	**Upper Deep Creek**	**Lower Deep Creek**
Diptera											
Chironomidae											
Orthocladiinae	184				11	35	64		1	10	1
Tanypodinae											
Tanytarsini	1						2				
Chironomini										1	
Diamesinae											
Other Diptera											
Atherix pachypus		16	4	2		1			1		
Ceratopogoninae	1										
Dixa sp.											
Hemerodromia sp.					1	1					
Chelifera/Neoplasta sp.						1					
Wiedemannia sp.											
Pericoma sp.										1	
Simulium sp.					3	10	3		10	1	
Antocha sp.	2				1	1	1				
Dicranota sp.					1	5					
Hexatoma sp.	1						1				
Coleoptera											
Helichus striatus						1					
Heterlimnius corpulentus	2										
Microcylloepus sp.											
Optioservus sp.	72	26	6	4	26	19	1		1	1	
Zaitzevia parvula	3	9	2	1		3	2		1		
Odonata											
Ophiogomphus severus											
Hemiptera											
Trichocorixa sp.							3				
Lepidoptera											
Petrophila sp.											
Miscellaneous											
Atractides sp.											
Hygrobates sp.				1							
Lebertia sp.										1	
Protzia sp.											
Sperchon sp.	2	2	2		1			1			
Caecidotea sp.											
Crangonyx sp.											
Ferrissia sp.											
Gyraulus sp.											
Lymnaeidae											
Physa sp.			2	1	1	2					
Dugesia sp.											
Polycelis coronata										1	
Erpobdellidae											
Enchytraeidae										10	
Lumbricidae		1			1	1					
Tubificidae (w/out hair chaetae)			2								
Nematoda											
Total:	**514**	**105**	**34**	**64**	**168**	**128**	**274**	**4**	**98**	**110**	**11**
Total Taxa:	**29**	**20**	**16**	**20**	**22**	**23**	**21**	**4**	**11**	**17**	**6**
EPT Taxa:	**20**	**15**	**10**	**15**	**13**	**11**	**13**	**3**	**6**	**9**	**5**

Appendix E – Macroinvertebrate Sediment Tolerance

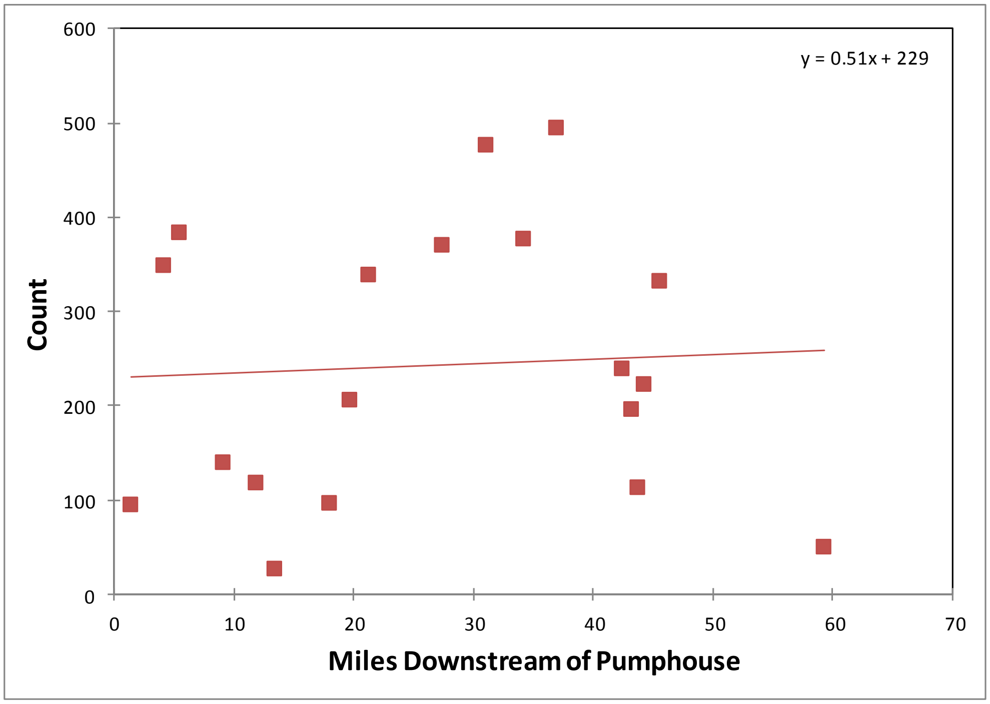


Figure E.1 – Sediment-tolerant *Baetis tricaudatus* density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

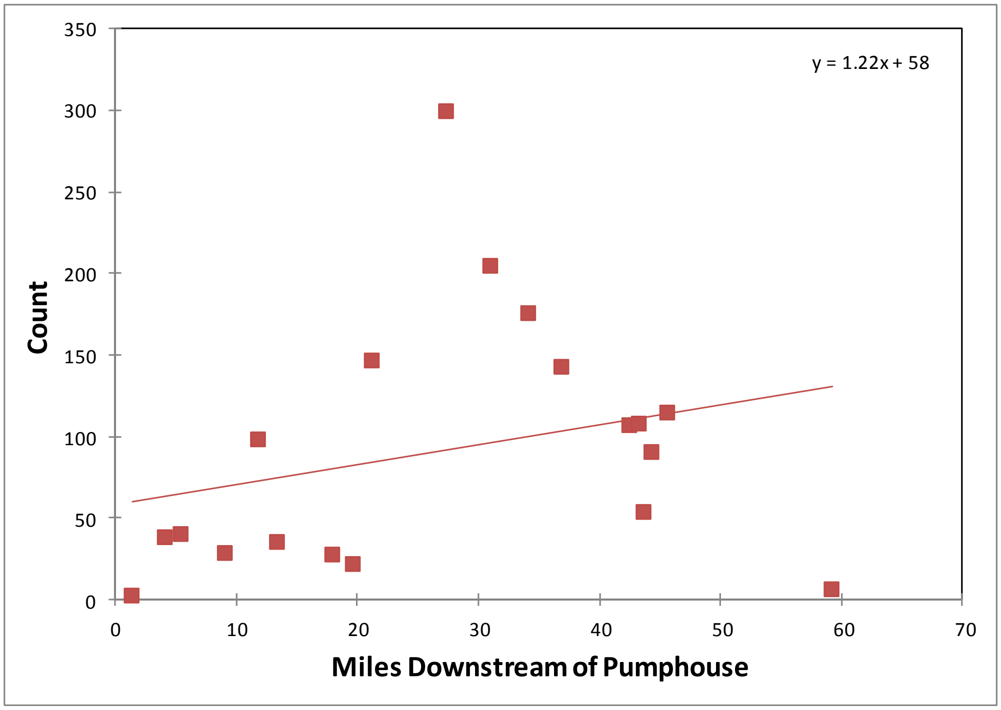


Figure E.2 – Sediment-tolerant *Ephemerella* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

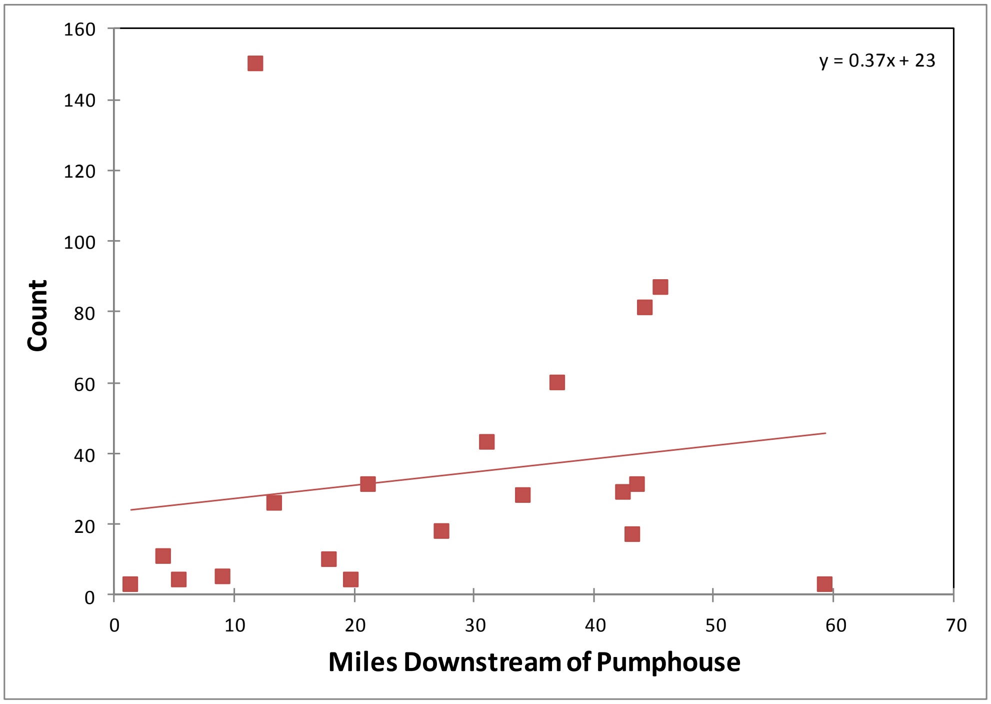


Figure E.3 – Sediment-tolerant *Tricorythodes explicatus* density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

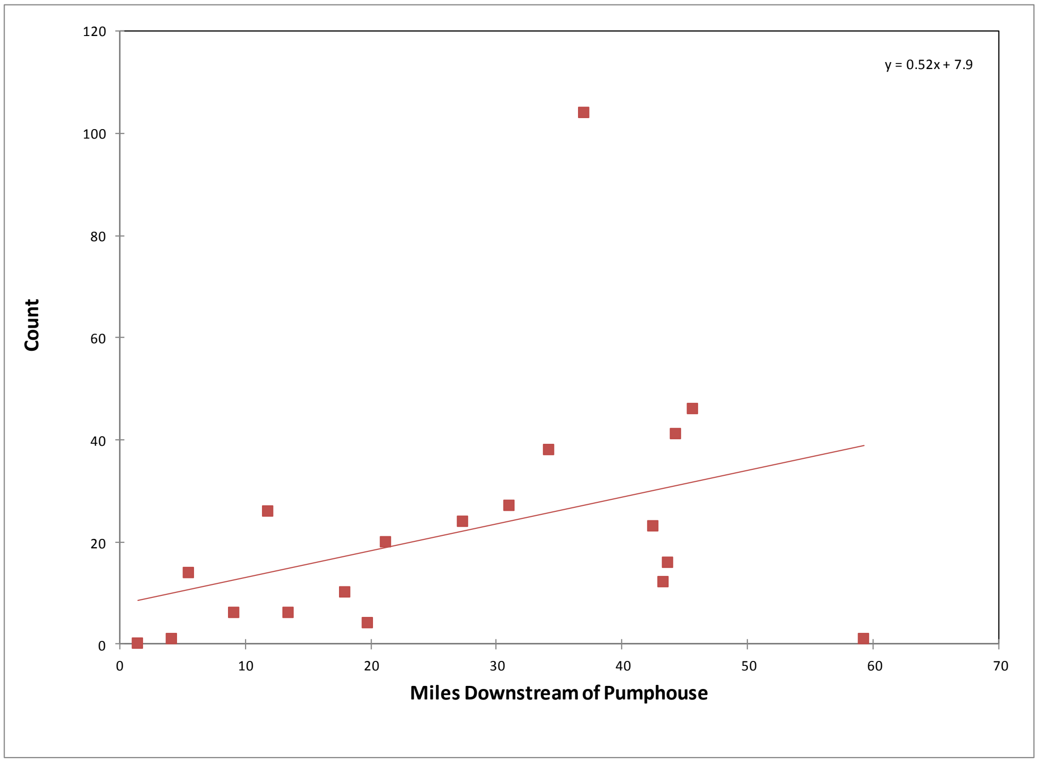


Figure E.4 – Sediment-tolerant *Paraleptophlebia* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

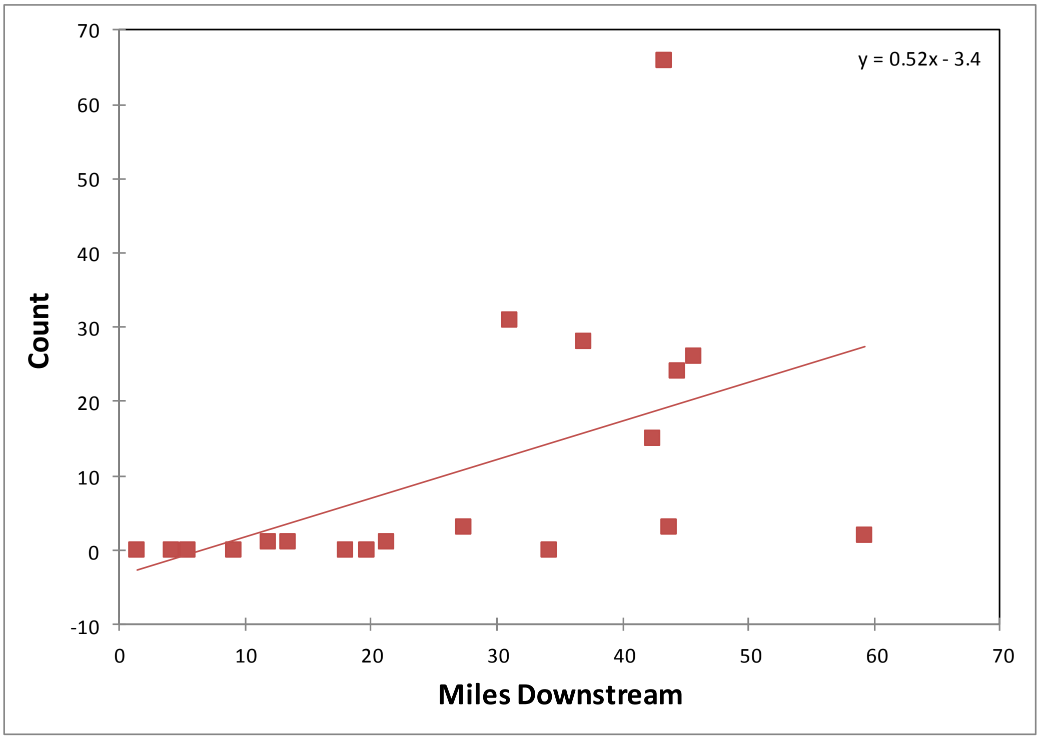


Figure E.5 – Sediment-tolerant *Hydroptila* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013. This trend was statically significant (p-value = 0.027).

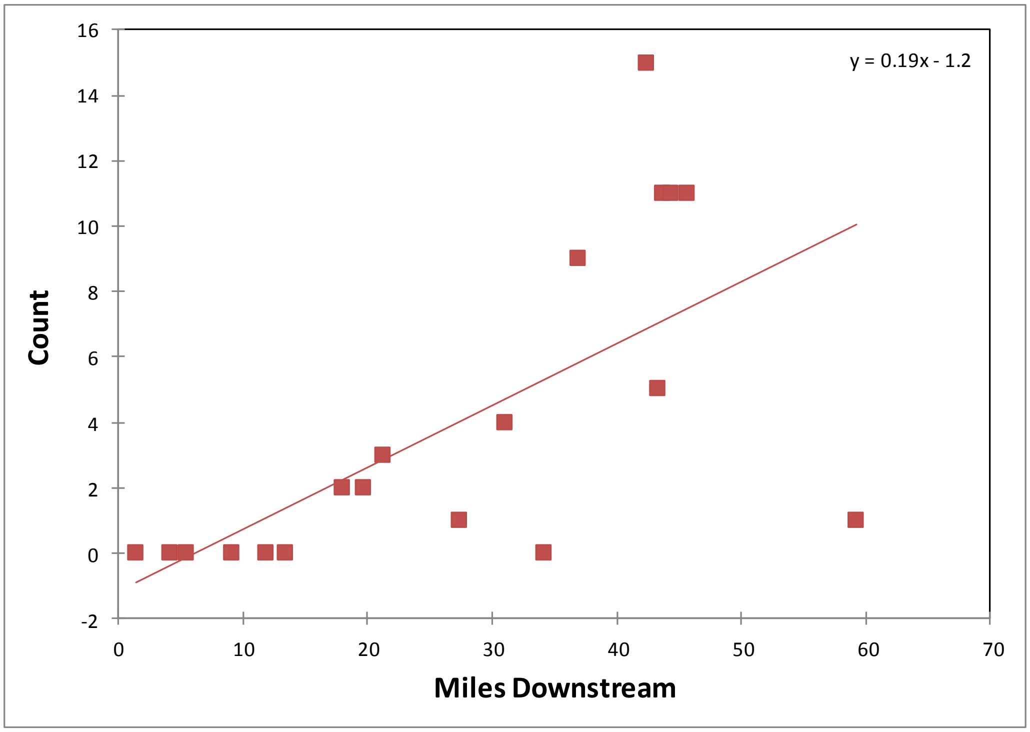


Figure E.6 – Sediment-tolerant *Heptagenia* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013. This trend was statically significant (p-value = 0.002).

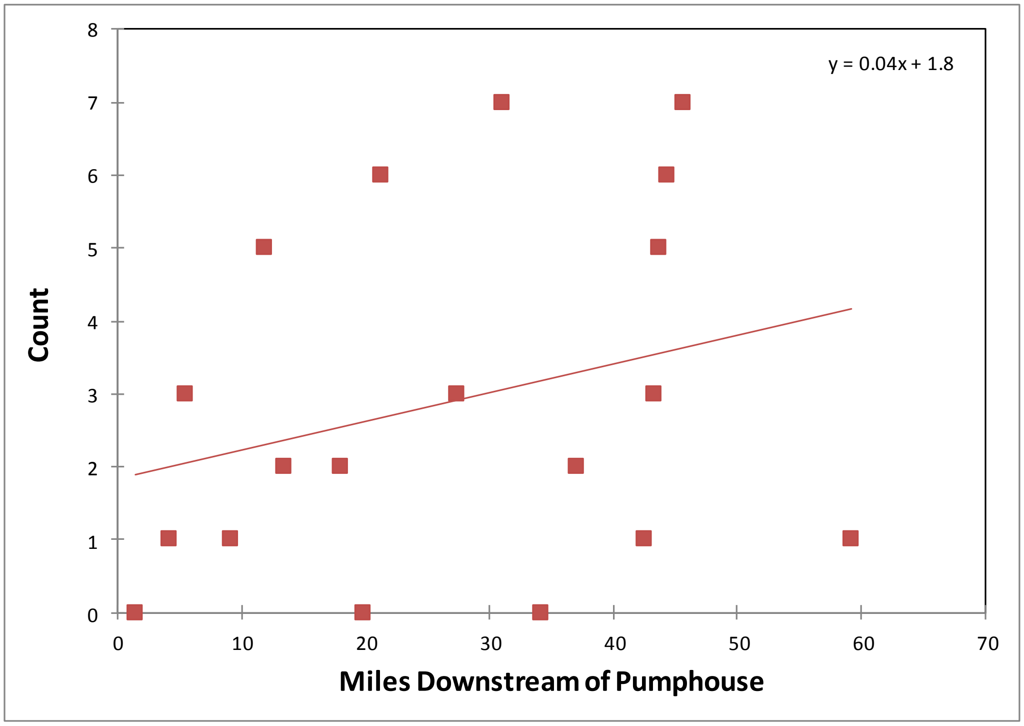


Figure E.7 – Sediment-tolerant *Isoperla* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

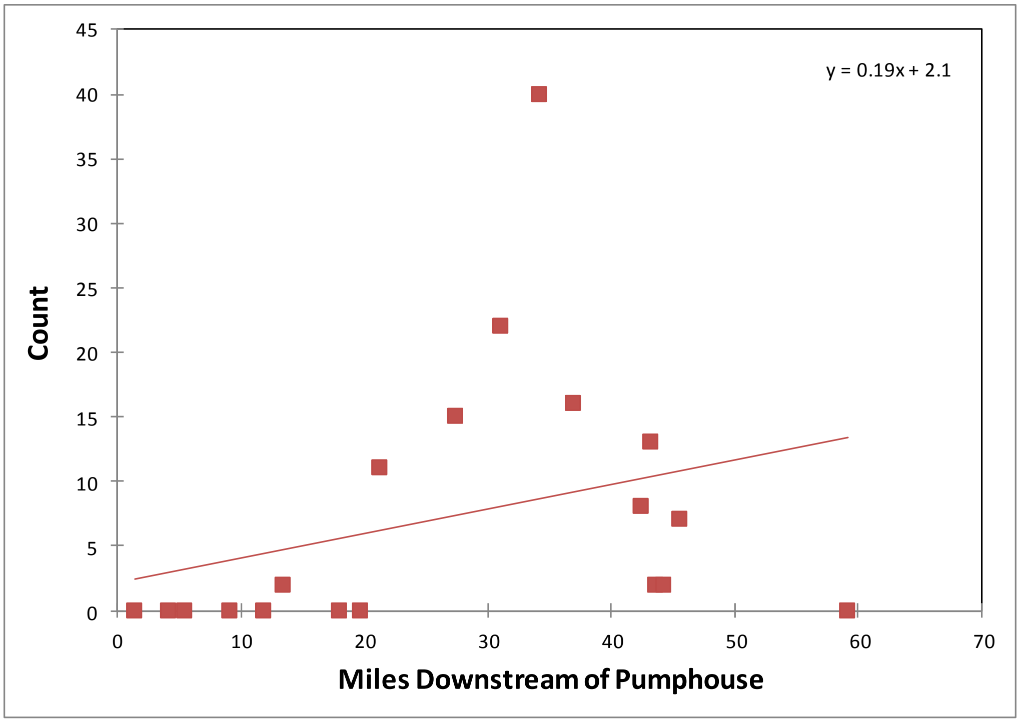


Figure E.8 – Sediment-tolerant *Cheumatopsyche* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

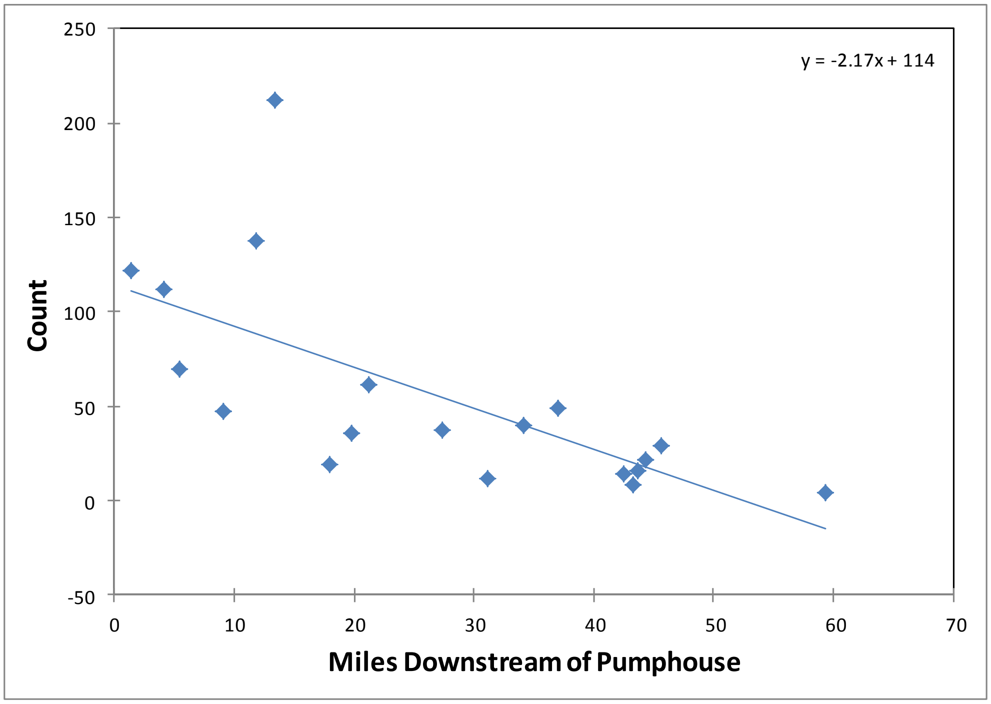


Figure E.9 – Sediment-intolerant *Orthocladiinae* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013. This trend was statically significant (p-value = 0.001).

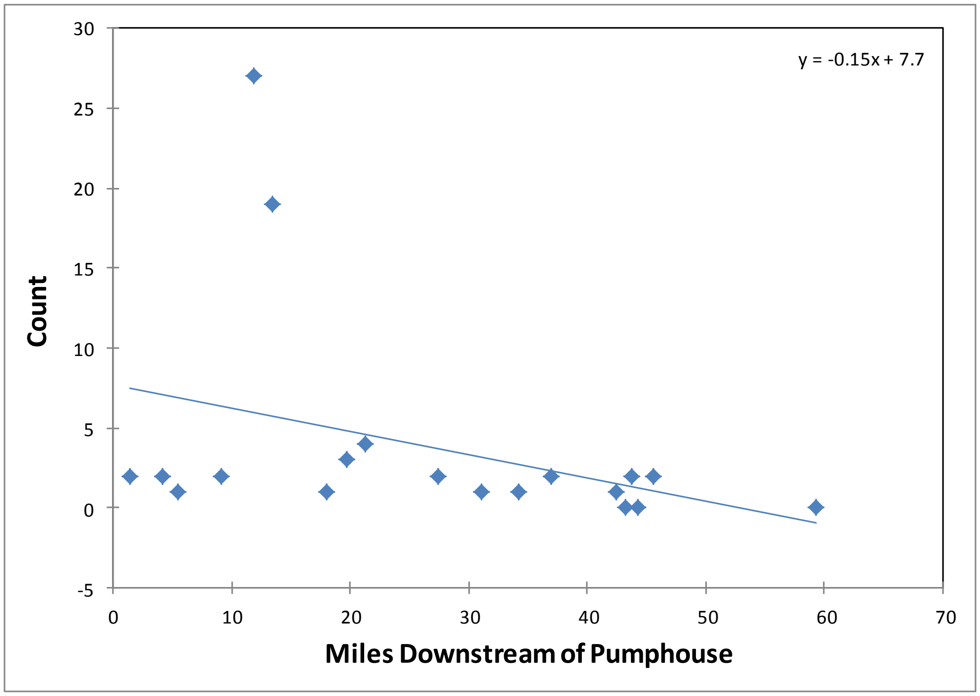


Figure E.10 – Sediment-intolerant *Chironomini* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

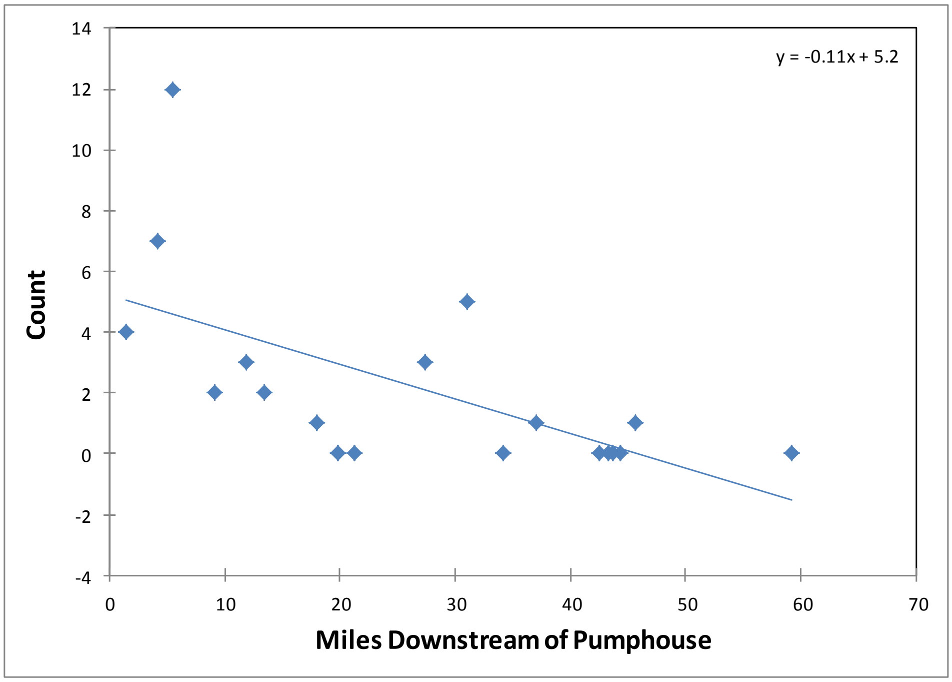


Figure E.11 – Sediment-intolerant *Epeorus* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013. This trend was statically significant (p-value = 0.005).

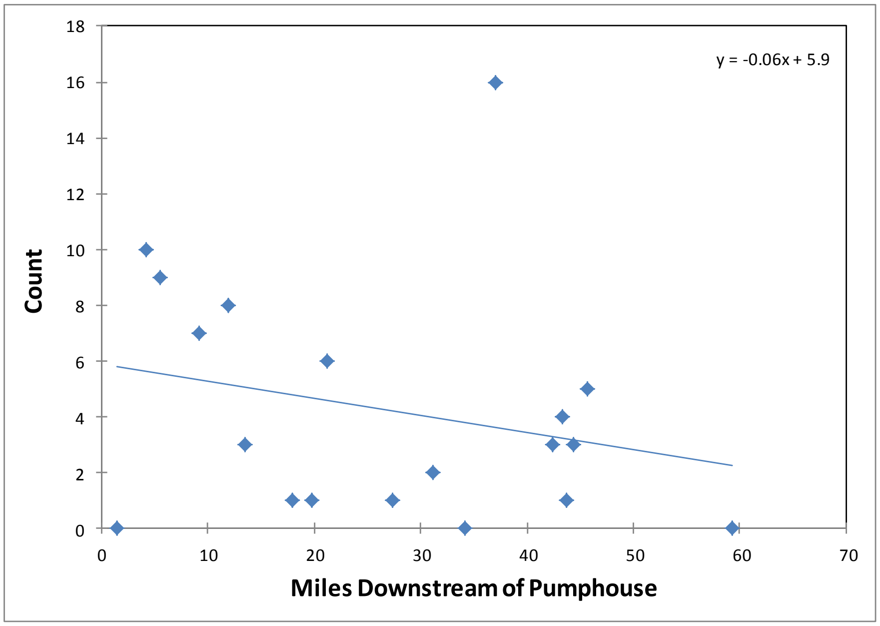


Figure E.12 – Sediment-intolerant *Cultus* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013.

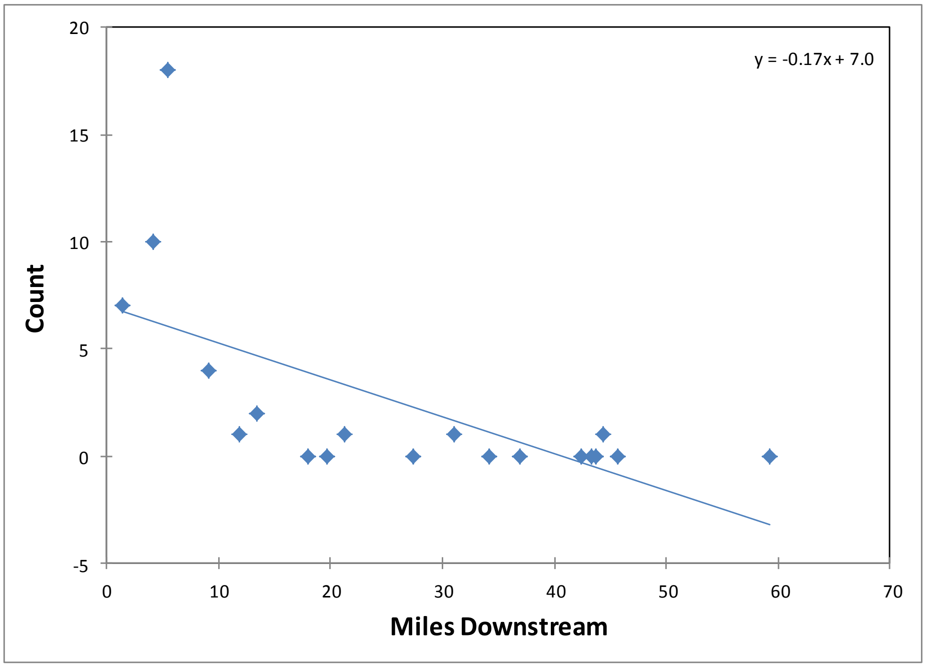


Figure E.13 – Sediment-intolerant *Lepidostoma* sp. density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013. This trend was statically significant (p-value = 0.004).

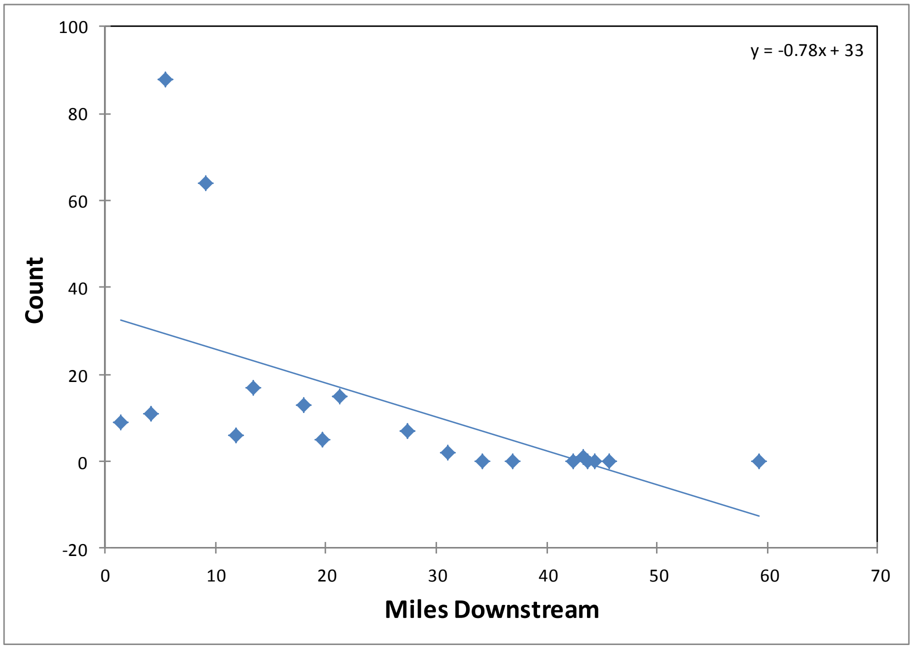


Figure E.14 – Sediment-intolerant *Pteronarcys californica* density (#/2700 cm^2) by river mile below Pumphouse in 2012 and 2013. This trend was statically significant (p-value = 0.011).

Appendix F – Flushing Flow Methods

F.1 Hydraulic Characterization

Variables necessary to conduct the sediment entrainment analysis include flow resistance, slope, hydraulic geometry, and critical dimensionless shear stress. Manning *n* (flow resistance) was calculated at each site using the Manning equation (Eq. (F.1)). This calculation incorporated field measurements of hydraulic radius and slope with USGS measurements of instantaneous discharge. Manning *n* values were then estimated at each site by comparing field photographs with calibrated photographs (Hicks and Mason, 1999; Jarrett, 1984). Based on these multiple lines of evidence and expert judgment, a standard deviation (SD) reflecting variability in the final estimated Manning *n* was identified for inclusion in the uncertainty analysis of critical discharge described below. Slope values were calculated from total station longitudinal surveys of bankfull elevations (based on field evidence of annual high water / flat depositional features), water-surface elevations and channel bottom elevations along each reach.

At-a-station hydraulic geometry relationships describe the change in a dependent hydraulic variable as it relates to changes in another independent hydraulic variable (usually discharge) at a given “station” or cross section of river channel. For this study, we developed a relationship equating effective flow width to changes in volumetric flow rates for a given cross-sectional geometry. Effective flow width is identified as the average depth-integrated width to account for potential errors in using cross-section averaged values. The Manning equation was chosen as the flow resistance equation and takes the form:

$$V = \frac{\phi}{n} R^{2/3} S_f^{1/2} \qquad \textbf{Eq. (F.1)}$$

where

V = cross-section average velocity;
ϕ = constant (1.49 English, 1 International System of Units (SI));
n = Manning roughness coefficient;
R = hydraulic radius; and
S_f = friction slope.

Volumetric flow rates and effective flow widths were calculated for each cross section at depth increments of 0.01 ft. Calculations were continued for each cross section until the flow depth exceeded the lower of the maximum elevations between the right and left banks (i.e., water must be contained within the cross-sectional survey extents). The previously calculated/estimated roughness value was assumed across the entire cross section. The logarithmic values (base 10) of volumetric flow rates and effective flow widths were then taken for each flow depth increment, and the logarithmic value of effective flow width was plotted against the logarithmic value of volumetric flow rate (both base 10). A linear regression analysis was then performed on the log-transformed data to obtain the following linear relationship between the dependent (*w*) and independent (*Q*) variables:

$$\log_{10} w = \beta_1 \log_{10} Q + \beta_0 \qquad \textbf{Eq. (F.2)}$$

where

w = effective channel width; and
Q = volumetric flow rate.

The results of the linear regression analysis provide values of the intercept (β_0) and the coefficient variable (β_1). The resulting values are then transformed out of logarithmic space as follows:

$$w = 10^{\beta_0} Q^{\beta_1} \qquad \textbf{Eq. (F.3)}$$

The finalized relationship follows the form:

$$w = a Q^{b} \qquad \textbf{Eq. (F.4)}$$

Dimensionless shear stress (τ_*) referenced to d_{50} (τ_{*50}) was used in the sediment entrainment analysis:

$$\tau_{*50} = \frac{\tau}{(\gamma_s - \gamma)d_{50}} = \frac{RS}{1.65 d_{50}} \qquad \textbf{Eq. (F.5)}$$

where

τ = shear stress;
γ_s = specific weight of sediment;
γ = specific weight of the water/sediment mixture;
d_{50} = median diameter of bed material;
R = hydraulic radius; and
S = slope.

The rationale for selection of τ_{*50} values used in the sediment entrainment analysis is described in the following subsection.

F.1.1 Sediment Entrainment Analysis

We used a weight-of-evidence approach to estimate critical discharges for flushing flows. Critical shear stress values were ascertained from scientific literature on similar systems, flume studies on the behavior of fine sediments in armored river beds, and expert judgment. An explicit analysis of uncertainty was performed using Monte Carlo methods to account for parameter uncertainty in grain size, slope, Manning *n*, and critical shear stress values. The resulting estimates of critical discharges for substrate maintenance are described as ranges and probability distributions to inform risk-based decision-making and adaptive management of environmental flows.

In addition to performing a literature review to support the selection of shear stress thresholds for the Upper Colorado River and its tributaries, we elicited expert opinion from three recognized experts in sediment mechanics of gravel-bed rivers to identify thresholds of dimensionless shear stress associated with varying degrees of substrate flushing and scour (pers. comm. with Dr. Kristin Bunte, CSU; Dr. Robert Milhous, Retired – USGS; and Dr. Peter Wilcock, Johns Hopkins University). Based on the best available information from the scientific literature on sediment movement in gravel-bed river systems similar to the Upper Colorado River and its tributaries, including expert judgment elicited from K. Bunte, R. Milhous, and P. Wilcock; critical dimensional shear stress values of 0.021 to 0.06 referenced to d_{50} were chosen for their efficacy in predicting substrate mobility on a spectrum from surface flushing to full mobilization of a coarse armor layer in lower gradient reaches (Buffington and Montgomery, 1997; Ferguson, 2012; Milhous, 2000, 2003; Parker, 2008). We selected a τ_{*50} value of 0.021 ± a SD of 0.0015 as a threshold for surface flushing at low-gradient sites per analyses performed by Milhous (2003, 2009) based on scour data from Colorado rivers. To estimate flows that initiate motion of coarse particles and interstitial flushing to the depth of the surface layer, we evaluated a range of fixed τ_{*50} values in increments of 0.005 up to the maximum plausible value for initiation of coarse substrate mobilization or to the point where the 25th percentile estimate exceeded the highest point in the survey cross section and maximum reliable discharge. τ_{*50} values ≥ 0.035, representing the lower threshold for movement of the coarse armor, were identified based on studies in comparable systems (Andrews, 1983; Andrews and Nankervis, 1995; Milhous, 2000, 2003, 2009; Parker, 2008; Wilcock, 1998) and were adjusted for the effects of channel slope and relative submergence based on Lamb *et al*. (2008), Ferguson (2012), Bunte *et al*. (2010), and K. Bunte (pers. comm.).

Roughness estimates used to calculate shear stresses were primarily based on roughness values observed and calculated during field visits as described above. However, primary emphasis was placed on accurate estimation of Manning *n* at much higher discharges within the range of flushing flows, requiring careful evaluation of high-flow indicators, field measurements, and expert judgment.

F.2 Critical Discharge

Critical discharge (Q_c) describes the volumetric flow rate at which an appreciable amount of sediment located on the river bed begins to move. The derivation for Q_c involves manipulation of the following four relationships:

1) The Manning equation, describing flow resistance:

$$V = \frac{\phi}{n} R^{2/3} S_f^{1/2} \qquad \textbf{Eq. (F.6)}$$

where

V = cross-section average velocity;
ϕ = constant (1.486 English, 1 SI);
n = Manning roughness coefficient;

R = hydraulic radius; and
S_f = friction slope.

2) Critical dimensionless shear stress, describing incipient motion of channel-bed material:

$$\tau_{*c} = \frac{\tau_c}{(\gamma_s - \gamma)\, d_{50}} = \frac{RS_f}{(G-1)\, d_{50}} \qquad \textbf{Eq. (F.7)}$$

where
τ_{*c} = critical dimensionless shear stress (Shields parameter);
τ_c = critical shear stress (shear stress at incipient motion);
γ_s = specific weight of sediment;
γ = specific weight of the water/sediment mixture;
d_{50} = median diameter of bed material;
R = hydraulic radius;
S_f = friction slope; and
G = specific gravity of sediment.

3) At-a-station hydraulic geometry relationship, relating effective channel width to discharge as previously described:

$$w = a\,Q^b \qquad \textbf{Eq. (F.8)}$$

where
w = effective channel width;
a, b = constants; and
Q = volumetric flow rate.

4) The flow continuity relationship, describing the conservation of fluid quantity in transport:

$$Q = VA \qquad \textbf{Eq. (F.9)}$$

where
Q = volumetric flow rate;
V = velocity; and
A = cross-section area.

Using the shear stress identity, $\tau = \gamma RS_f$, and assuming wide channel geometry such that R is approximately equal to flow depth, the following relationship is developed:

$$Q_c = \left[\frac{a\phi}{nS_f^{7/6}} \left[\tau_{*c}(G-1)d_i\right]^{5/3} \right]^{1/(1-b)} \qquad \textbf{Eq. (F.10)}$$

where

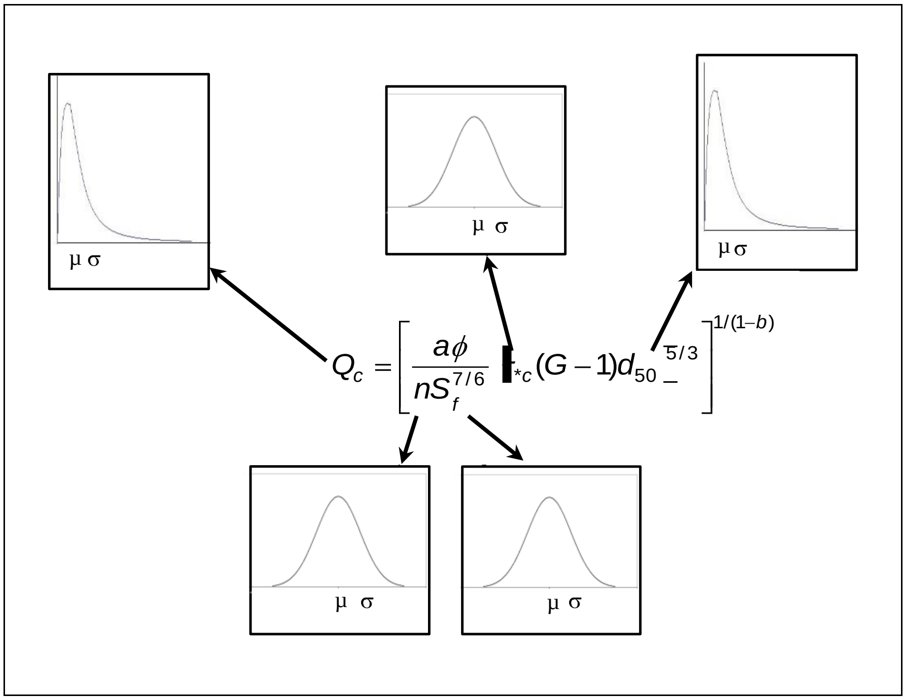
Q_c = critical discharge;
a, b = constants;
ϕ = constant (1.486 English, 1 SI);
n = Manning roughness coefficient;
S_f = friction slope;
τ_{*c} = critical dimensionless shear stress (Shields parameter);
G = specific gravity of sediment; and
d_i = diameter of the *i*th percentile grain size of the distribution.

This relationship describes critical discharge as a function of friction slope, Manning roughness coefficient, critical dimensionless shear stress, sediment size, and the constants from at-a-station hydraulic geometry.

Using the channel hydraulic geometry and slopes estimated from field surveys in conjunction with site-specific grain-size distributions, we used this relationship to estimate critical discharges that correspond to ecologically-relevant thresholds of dimensionless shear stress for each study site.

F.3 Monte Carlo Critical Discharge Simulation

Founded on the principles of repeated random sampling from a specified distribution, Monte Carlo simulations evaluate the sensitivity of potential outcome values for a given relationship to potential changes in the input parameters by statistically incorporating the probability distribution of potential input values. Each input parameter is assigned a unique probability distribution function by way of a statistical mean, SD, and probability distribution type (e.g., Gaussian). A random sample of each input parameter is then input into the given relationship, in this case the critical discharge relationship above, to develop a potential outcome value. As this process is repeated, a population of potential outcome values is compiled and characterized by a specific probability distribution function. Figure F.1 depicts this process conceptually. A probability distribution function is assigned for each input parameter: Manning roughness coefficient (n) assumed to fit a Gaussian distribution with mean centered on the estimated n previously described, friction slope (S_f) assumed to fit a Gaussian distribution centered on the estimate from the field survey, and d_{50} fit to a log-normal (base 2) distribution based on visual inspection of grain-size distributions with d_{50} values taken from the post-runoff grain-size distributions truncated at 2 mm for each site. For surface veneer flushing flows with τ_{*50} of 0.021, critical dimensionless shear stress values were also assumed to fit a Gaussian distribution. For coarse substrate mobilization flows, τ_{*50} values ≥ 0.03 were held constant in increasing increments of 0.005 with the slope, grain size, and Manning n varying according to the distributions previously described.



where

μ = mean of input distribution;
σ = SD of input distribution;
Q_c = critical discharge;
a, b = constants;
ϕ = constant (1.486 English, 1 SI);
n = Manning roughness coefficient;
S_f = friction slope;
τ_{*C} = critical dimensionless shear stress (Shields parameter);
G = specific gravity of sediment; and
d_{50} = median diameter of bed material.

Figure F.1 – Depiction of probabilistic estimation of Q_c using varying distributions of input variables slope, grain size, Manning *n*, and critical dimensionless shear stress.

A random sample of each parameter is obtained using Microsoft™ Excel®'s built-in 'NORMINV' function, utilizing a random probability generator (RAND() function), a mean, and SD. Since the median grain-size data were assumed to fit a log-normal distribution, each of these randomly-sampled values are transformed out of logarithmic space by raising each value exponentially to the base 2 as follows: ($2^{\wedge sampled\ value}$). Next, each sample value is input into the above critical discharge relationship. This process is repeated for 10,000 iterations to ensure the sample of critical discharge values (N = 10,000) accurately represent the entire population of potential critical discharge values ($N \rightarrow \infty$). Standard statistical analyses are then performed on the distribution of critical discharge values to describe the range of variability and uncertainty in estimates at all study sites.

In evaluating the central tendencies of the resulting estimates of Q_c, we primarily focused on median values given the asymmetrical distributions that result from inputting the naturally-skewed distributions of grain size (Figure F.1). Confidence intervals were calculated in addition to statistical mean, median, and SD for each sample (N = 10,000) of critical discharge values. The upper and lower bounds for each confidence interval were calculated using the built-in PERCENTILE function, using a two-tail confidence interval approach, such that the area between the upper and lower bounds for the 98% confidence interval equals 98% (i.e., total area greater than the 98% confidence interval upper bound equals 1%). Figure F.2 depicts a sample asymmetrical distribution of critical discharge values resulting from a Monte Carlo critical discharge simulation. The relative uncertainty associated with the resulting non-symmetrical distributions of Q_c was assessed using the interquartile range (25th percentile to 75th percentile) divided by the median. This metric is analogous to a coefficient of variation and was used to assess relative confidence in flushing flow estimates.

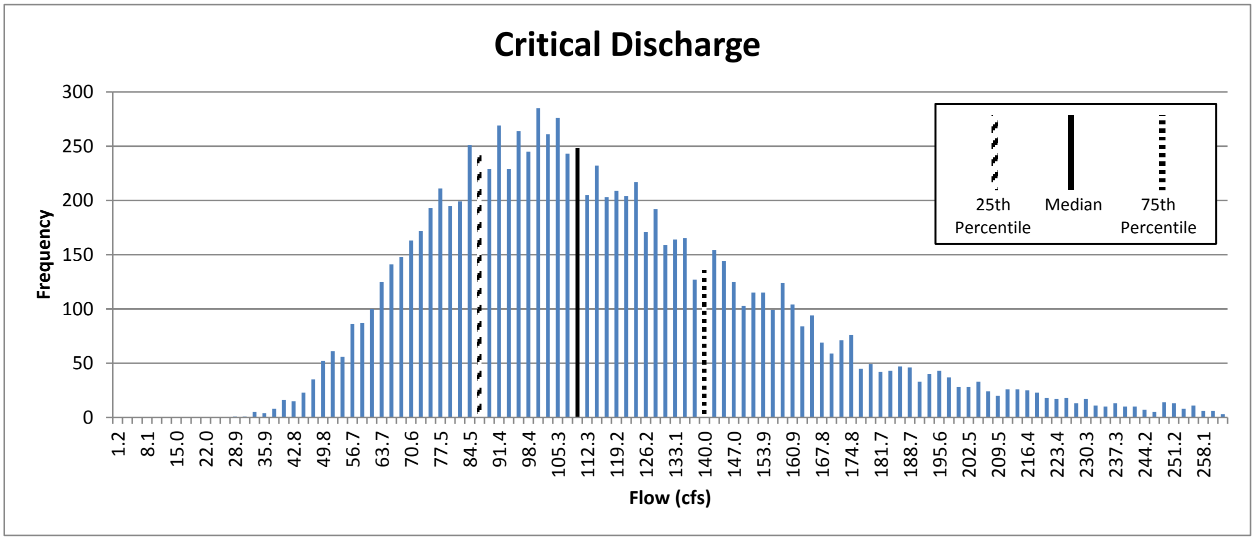


Figure F.2 – Sample critical discharge distribution resulting from a Monte Carlo critical discharge simulation.

Appendix G – Cross Sections

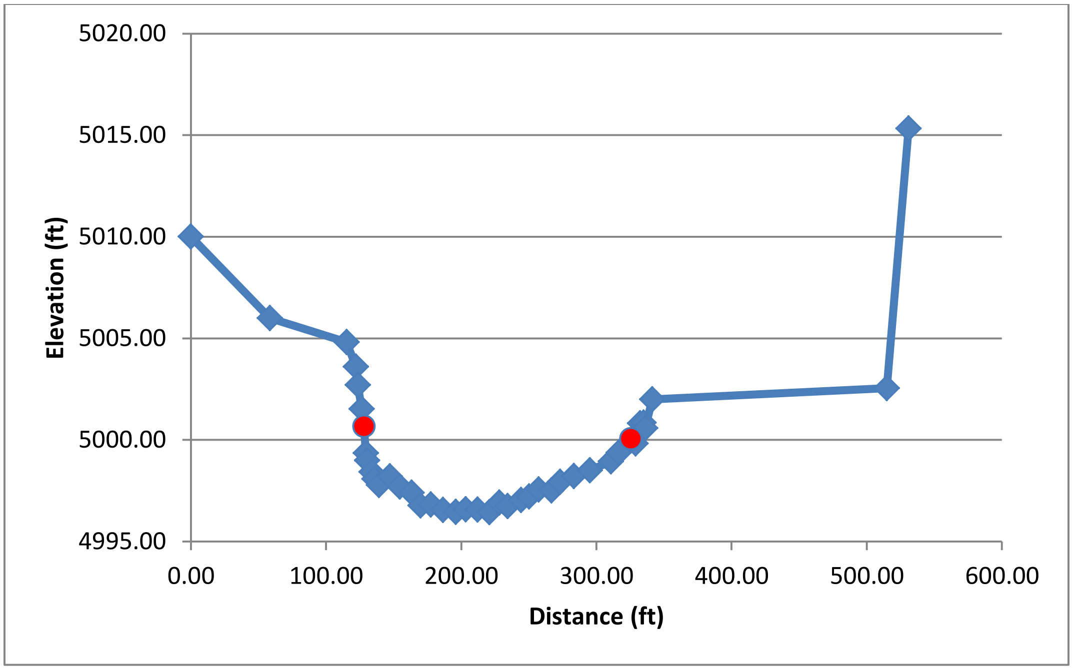


Figure G.1 – Pumphouse cross section looking upstream.

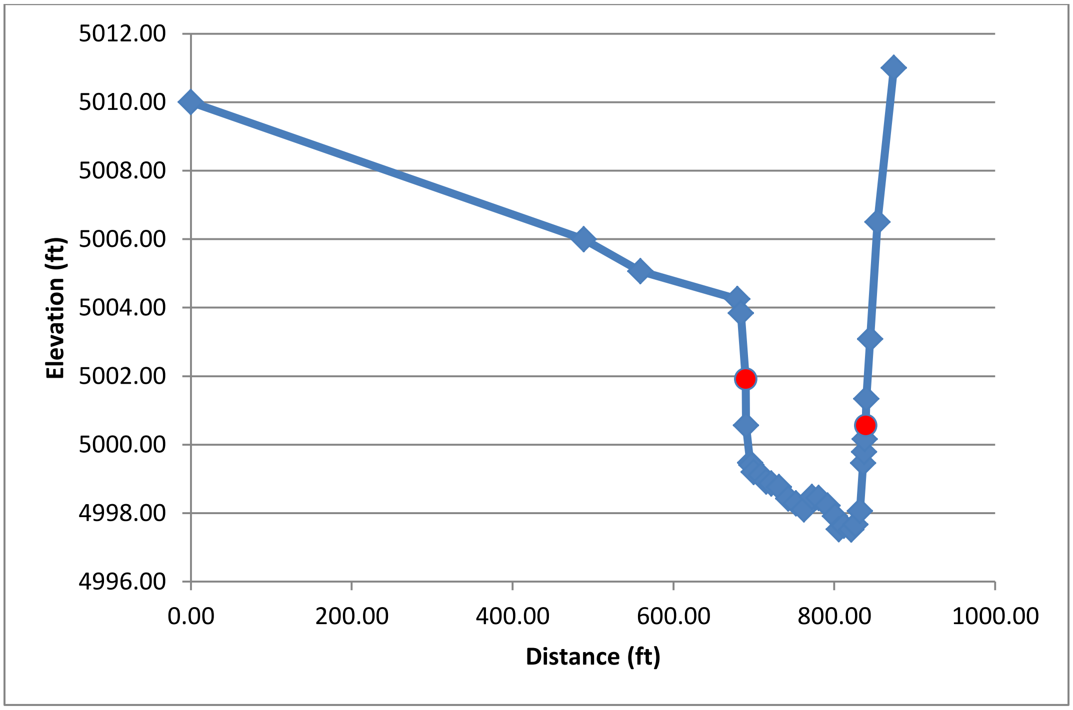


Figure G.2 – Radium cross section looking downstream.

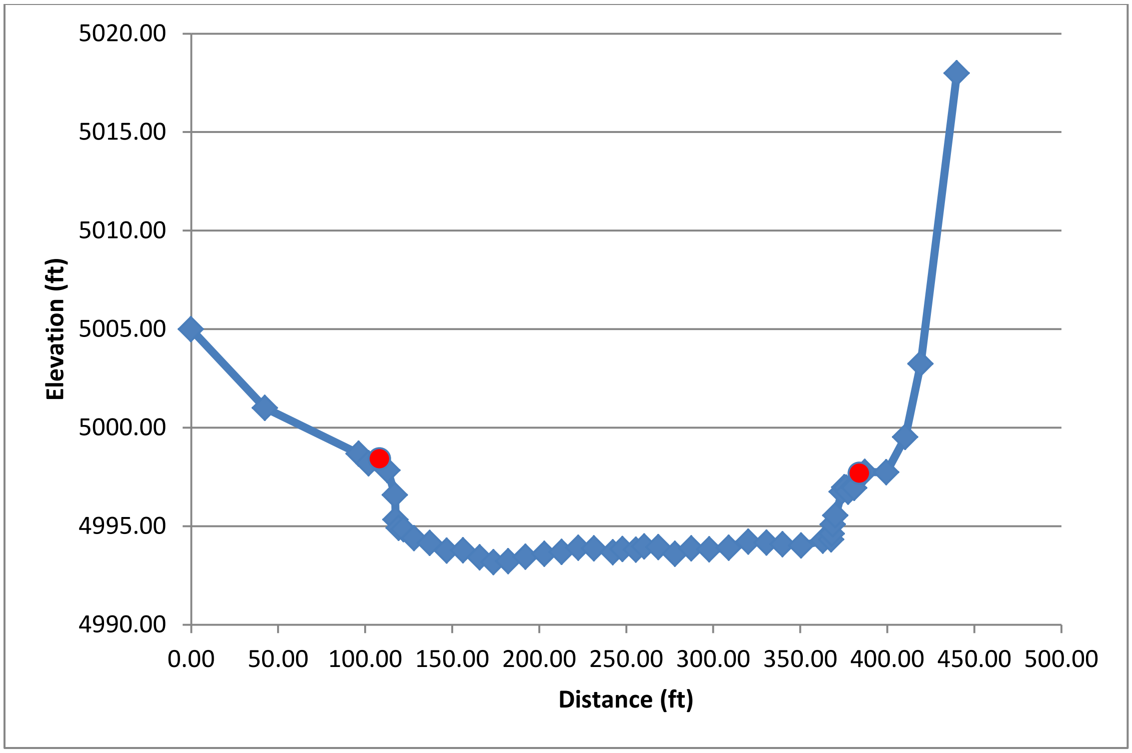


Figure G.3 – Above Catamount cross section looking downstream.

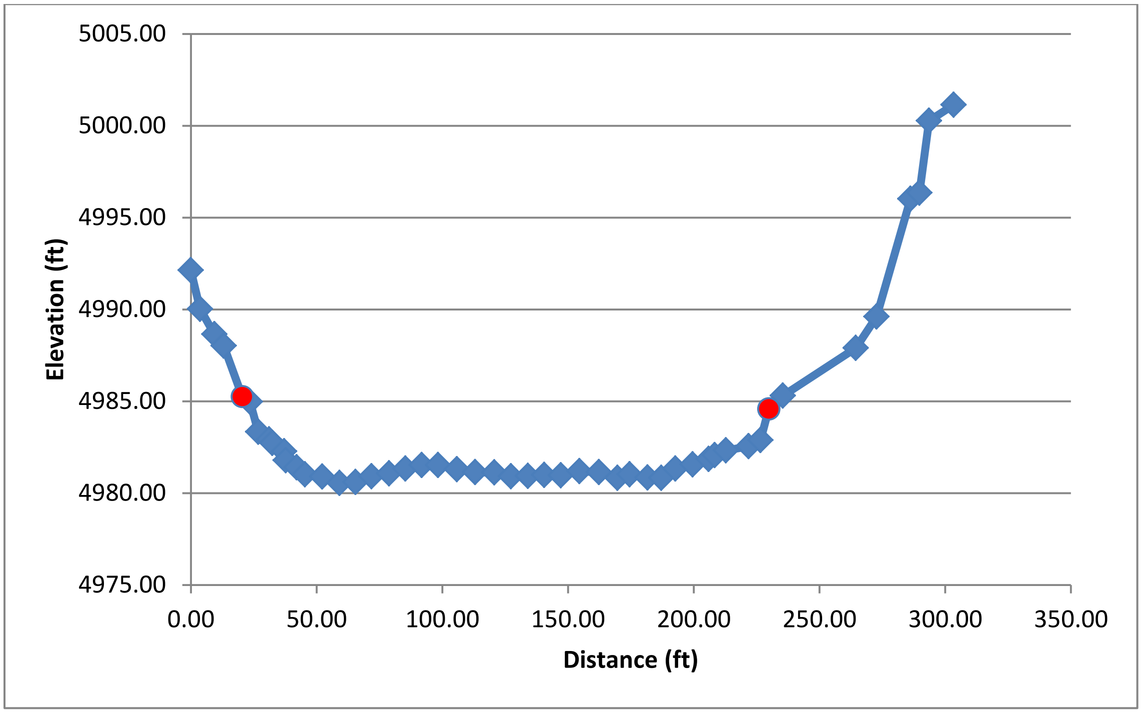


Figure G.4 – Below Sweetwater cross section looking downstream.

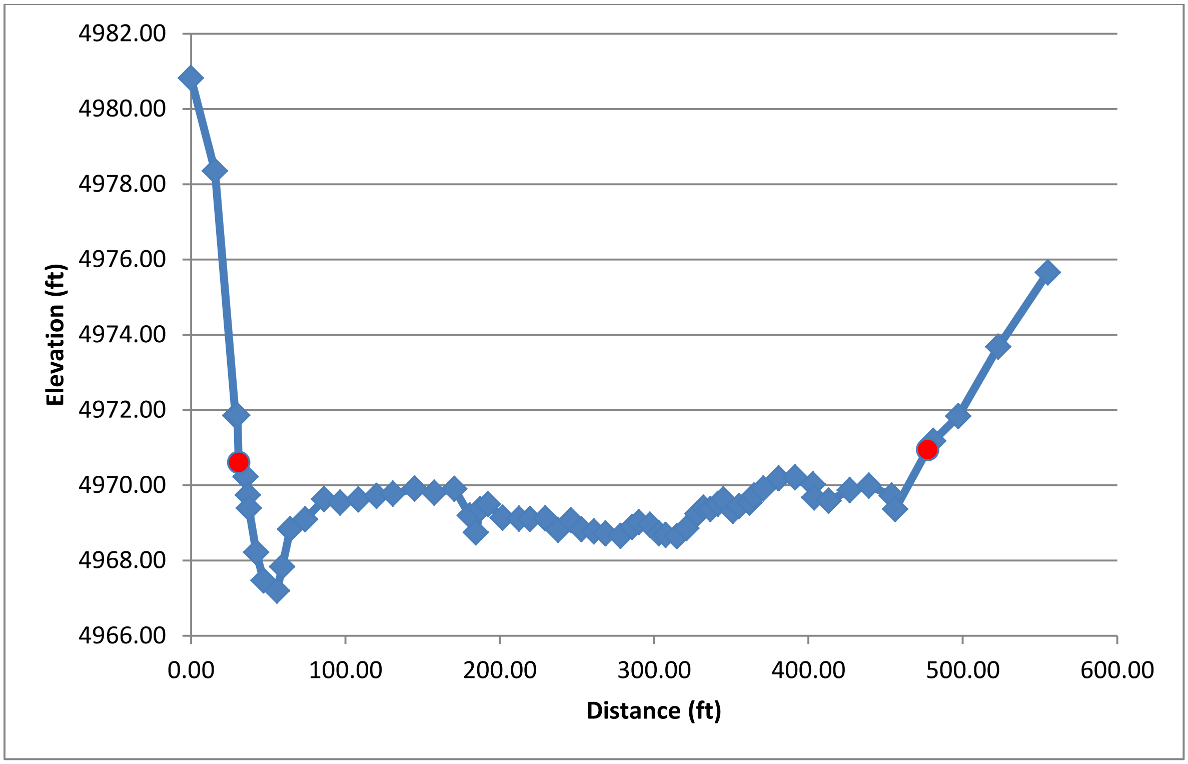


Figure G.5 – Above Dotsero cross section looking upstream.

Appendix H – Grain-size Distributions

Table H.1 – Grain-size distributions for the Above Dotsero cross section.

Winter 2012				Summer 2013			
Diameter (mm)	**Above Dotsero**			**Diameter (mm)**	**Above Dotsero**		
	Count	**Retained %**	**Passing %**		**Count**	**Retained %**	**Passing %**
360	0	0	100	360	0	0	100
256	2	1.2	98.8	256	2	1.2	98.8
180	4	2.5	96.3	180	13	7.7	91.1
128	7	4.3	92.0	128	16	9.5	81.7
90	33	20.2	71.8	90	23	13.6	68.0
64	34	20.9	50.9	64	13	7.7	60.4
45	28	17.2	33.7	45	8	4.7	55.6
32	8	4.9	28.8	32	11	6.5	49.1
22.5	6	3.7	25.2	22.5	8	4.7	44.4
16	3	1.8	23.3	16	8	4.7	39.6
11.3	0	0.0	23.3	11.3	4	2.4	37.3
8	0	0.0	23.3	8	2	1.2	36.1
5.6	0	0.0	23.3	5.6	2	1.2	34.9
4	0	0.0	23.3	4	2	1.2	33.7
2.8	0	0.0	23.3	2.8	0	0.0	33.7
2	0	0.0	23.3	2	7	4.1	29.6
<2	38	23.3	0.0	<2	50	29.6	0.0
Total:	**163**			**Total:**	**169**		

Above Dotsero		**d_{84} (mm)**	**d_{64} (mm)**	**d_{50} (mm)**	**d_{16} (mm)**
Not Truncated	Winter 2012	109	80	63	1.5
	Summer 2013	145	80	35	1.6
Truncated at 2 mm	Winter 2012	119	91	77	1.7
	Summer 2013	164	110	80	1.7

Table H.2 – Grain-size distributions for the Below Sweetwater cross section.

Winter 2012				Summer 2013			
Diameter (mm)	Below Sweetwater			Diameter (mm)	Below Sweetwater		
	Count	Retained %	Passing %		Count	Retained %	Passing %
360	0	0	100	360	0	0	100
256	0	0.0	100.0	256	6	5.7	94.3
180	3	2.4	97.6	180	7	6.7	87.6
128	36	28.6	69.0	128	19	18.1	69.5
90	35	27.8	41.3	90	18	17.1	52.4
64	22	17.5	23.8	64	18	17.1	35.2
45	15	11.9	11.9	45	9	8.6	26.7
32	1	0.8	11.1	32	6	5.7	21.0
22.5	1	0.8	10.3	22.5	5	4.8	16.2
16	1	0.8	9.5	16	2	1.9	14.3
11.3	3	2.4	7.1	11.3	3	2.9	11.4
8	0	0.0	7.1	8	2	1.9	9.5
5.6	0	0.0	7.1	5.6	0	0.0	9.5
4	0	0.0	7.1	4	0	0.0	9.5
2.8	0	0.0	7.1	2.8	0	0.0	9.5
2	0	0.0	7.1	2	0	0.0	9.5
<2	9	7.1	0.0	<2	10	9.5	0.0
Total:	**126**			**Total:**	**105**		

Below Sweetwater		d_{84} (mm)	d_{64} (mm)	d_{50} (mm)	d_{16} (mm)
Not Truncated	Winter 2012	160	122	100	55
	Summer 2013	170	120	86	22
Truncated at 2 mm	Winter 2012	148	125	107	53
	Summer 2013	170	122	95	22

Table H.3 – Grain-size distributions for the Above Catamount cross section.

Winter 2012				Summer 2013			
Diameter (mm)	Above Catamount			Diameter (mm)	Above Catamount		
	Count	Retained %	Passing %		Count	Retained %	Passing %
360	0	0	100	360	0	0	100
256	0	0.0	100.0	256	3	2.5	97.5
180	5	3.3	96.7	180	5	4.2	93.3
128	20	13.1	83.7	128	31	26.1	67.2
90	58	37.9	45.8	90	19	16.0	51.3
64	42	27.5	18.3	64	7	5.9	45.4
45	14	9.2	9.2	45	13	10.9	34.5
32	9	5.9	3.3	32	4	3.4	31.1
22.5	5	3.3	0.0	22.5	4	3.4	27.7
16	0	0.0	0.0	16	7	5.9	21.8
11.3	0	0.0	0.0	11.3	1	0.8	21.0
8	0	0.0	0.0	8	0	0.0	21.0
5.6	0	0.0	0.0	5.6	2	1.7	19.3
4	0	0.0	0.0	4	4	3.4	16.0
2.8	0	0.0	0.0	2.8	0	0.0	16.0
2	0	0.0	0.0	2	7	5.9	10.1
<2	0	0.0	0.0	<2	12	10.1	0.0
Total:	**153**			**Total:**	**119**		

Above Catamount		d_{84} (mm)	d_{64} (mm)	d_{50} (mm)	d_{16} (mm)
Not Truncated	Winter 2012	129	110	95	60
	Summer 2013	165	125	87	2.8
Truncated at 2 mm	Winter 2012	128	106	94	60
	Summer 2013	166	129	100	2.8

Table H.4 – Grain-size distributions for the Radium cross section.

Winter 2012				Summer 2013			
Diameter (mm)	Radium			Diameter (mm)	Radium		
	Count	Retained %	Passing %		Count	Retained %	Passing %
360	0	0	100	360	0	0	100
256	0	0.0	100.0	256	1	0.8	99.2
180	1	0.7	99.3	180	11	9.0	90.2
128	5	3.7	95.6	128	15	12.3	77.9
90	25	18.5	77.0	90	17	13.9	63.9
64	40	29.6	47.4	64	19	15.6	48.4
45	24	17.8	29.6	45	10	8.2	40.2
32	17	12.6	17.0	32	7	5.7	34.4
22.5	6	4.4	12.6	22.5	9	7.4	27.0
16	1	0.7	11.9	16	5	4.1	23.0
11.3	0	0.0	11.9	11.3	4	3.3	19.7
8	3	2.2	9.6	8	2	1.6	18.0
5.6	0	0.0	9.6	5.6	0	0.0	18.0
4	0	0.0	9.6	4	0	0.0	18.0
2.8	0	0.0	9.6	2.8	0	0.0	18.0
2	0	0.0	9.6	2	9	7.4	10.7
<2	13	9.6	0.0	<2	13	10.7	0.0
Total:	**135**			**Total:**	**122**		

Radium		d_{84} (mm)	d_{64} (mm)	d_{50} (mm)	d_{16} (mm)
Not Truncated	Winter 2012	100	78	67	31
	Summer 2013	155	93	67	2.4
Truncated at 2 mm	Winter 2012	106	81	70	30
	Summer 2013	157	99	75	2.3

Table H.5 – Grain-size distributions for the Pumphouse cross section.

Winter 2012				Summer 2013			
Diameter (mm)	Pumphouse			Diameter (mm)	Pumphouse		
	Count	Retained %	Passing %		Count	Retained %	Passing %
360	1	0.9	99.1	360	5	4.5	95.5
256	7	6.5	92.5	256	11	9.8	85.7
180	21	19.6	72.9	180	15	13.4	72.3
128	7	6.5	66.4	128	24	21.4	50.9
90	30	28.0	38.3	90	15	13.4	37.5
64	17	15.9	22.4	64	9	8.0	29.5
45	11	10.3	12.1	45	3	2.7	26.8
32	5	4.7	7.5	32	6	5.4	21.4
22.5	2	1.9	5.6	22.5	3	2.7	18.8
16	1	0.9	4.7	16	2	1.8	17.0
11.3	1	0.9	3.7	11.3	1	0.9	16.1
8	0	0.0	3.7	8	0	0.0	16.1
5.6	0	0.0	3.7	5.6	0	0.0	16.1
4	1	0.9	2.8	4	7	6.3	9.8
2.8	1	0.9	1.9	2.8	0	0.0	9.8
2	0	0.0	1.9	2	2	1.8	8.0
<2	2	1.9	0.0	<2	9	8.0	0.0
Total:	**107**			**Total:**	**112**		

Pumphouse		d_{84} (mm)	d_{64} (mm)	d_{50} (mm)	d_{16} (mm)
Not Truncated	Winter 2012	220	123	110	52
	Summer 2013	248	160	126	5.6
Truncated at 2 mm	Winter 2012	230	120	102	55
	Summer 2013	253	165	132	5.6