EAGLE RIVER INVENTORY AND ASSESSMENT

Report prepared for the:

Eagle River Watershed Council

ERIA

2003 - 2005

August 2005

Colorado State University
Engineering Research Center
Fort Collins, CO 80523

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Dear Stakeholder:

On behalf of the Eagle River Watershed Council, we are proud to present the results of the Eagle River Inventory and Assessment. It is our hope that you find this report informative, interesting and a useful tool for future management decisions in the Eagle River watershed. Conclusions drawn in previous studies have been incorporated with new information gathered in 2003-4 to provide a comprehensive, up-to-date look at the river system and the many uses it supports. Most people will find what they need in the Executive Summary, but readers looking for more specific information can benefit from the full report and appendices.

The project coalesced in 2002, when evidence dictated a clear need to develop a scientifically-based inventory detailing the condition of the Eagle River to assist with decisions regarding river restoration, conservation, and access. After reviewing the goals of the Eagle River Watershed Plan developed in 1996, and meeting with many people who live, work and play along the river, we decided the Inventory and Assessment should integrate scientific data with public desires to assist in making more responsible choices for the health and conservation of the watershed. This cooperative effort involved natural resource agencies, local governments, outfitters and guides, and citizens interested in land and water resources. A wide variety of input from across the Eagle Valley, the region and the state contributed to the success of the project.

The primary objectives sought to create an inclusive, baseline inventory and assessment of the 110 miles of the main stem and lower tributaries of the Eagle River, as well as develop a set of recommendations to efficiently guide future river conservation work. The report provides a prioritized list of restoration and conservation projects, including brief descriptions and cost estimates. The Inventory and Assessment measures public support for various, prospective projects and other recommended action throughout the river corridor. From the headwaters to the Colorado River, the report synthesizes ecological and social benefits to the river and local communities. **This is an essential tool for decision makers to ensure financial resources are spent in areas of noted ecological priority combined with strong community support.**

The success of the process and the report will ultimately be measured by the ability of the Eagle River Watershed Council to assist local decision-makers, community members, and regional and national funding partners in selecting projects to pursue for implementation. Also, we believe that the seven recommendations outlined in the report can function as “management principles” to ensure the health and conservation of the river well into the future.

If you have questions or comments about this report, please contact the Eagle River Watershed Council at (970) 827-5406 or email us at info@eagleriverwatershedcouncil.org.

Thanks for your participation, and we’ll see you on the river!

Caroline Bradford
Executive Director

Joe Macy
President, Board of Directors

Eagle River Watershed Council

Acknowledgements

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EXECUTIVE SUMMARY

The Eagle River watershed is an extraordinary resource that providing a host of ecosystem services and benefits. It is also a system characterized by complexity and change. With a rapidly growing population focusing land use conversions in and near the river corridor coupled with growing pressures for water from within and without, the fate of the Eagle River is increasingly determined by our decisions and stewardship.

This report describes the results of the *Eagle River Inventory and Assessment* (ERIA), a joint effort of Colorado State University (CSU) and the Eagle River Watershed Council (ERWC) to assess the current state of the Eagle River watershed from a basinwide ecological perspective and to prioritize potential restoration activities to improve the integrity of the river system. The objectives of the *Eagle River Inventory and Assessment* are:

1. Undertake a systematic, watershed-wide inventory of channel, riparian, and upland characteristics that currently control the ecological integrity of the Eagle River.
2. Collect and assess planning efforts of this type that have been performed by various agencies and organizations on selected sites within the watershed.
3. Perform an analysis of existing monitoring information to assess the status of various waterbodies and river reaches in the watershed and determine sources of pollution and degradation.
4. Identify and describe candidate conservation and restoration projects (structural and non-structural) and link them to current issues and likely outcomes through field reconnaissance, meetings with watershed stakeholders, Geographic Information System (GIS) inventory and analysis (e.g., riparian conditions, land cover, geomorphic processes, etc.), and scientific assessment.
5. Prioritize restoration strategies in a decision matrix based on potential benefits, likelihood of success, rough estimates of costs, and stakeholder input.
6. Produce a report describing the results of watershed inventory and prioritized recommendations for restoration projects and strategies.

With a drainage area of nearly 1,000 square miles, the Eagle River watershed encompasses a complex array of natural processes, human influences, and candidate restoration activities. Time, as well as financial constraints, inevitably limit the ecological, hydrologic, and geomorphic assessment of large river basins. The *Eagle River Inventory and Assessment* is no exception in that these constraints necessitated a restricted focus on the predominant stressors in the watershed, maintaining balance between collection of new information and adequate analysis of the large body of existing information relevant to the project. The approach adopted for this study primarily relied on the targeted utilization of numerous existing data sets, rapid synoptic surveys of riparian and instream conditions, interpretation of aerial photography, GIS analyses, historical information, local knowledge, and expert judgment.

Fortunately, a wide variety of water quality, hydrologic, and other types of data have been collected in the basin, albeit often for disparate purposes and using variable protocols. Many of the existing data sets collected have been examined in the context of individual projects or agency goals related to some specific aspect of water quality or management, as opposed to basin-scale assessment, management, and restoration of ecological integrity. Nonetheless, the large body of existing data coupled with field reconnaissance provided a sufficient basis to identify general patterns and trends in system characteristics, key stressors, and potential benefits of various management and restoration activities.

Although some questions were answered during this effort, numerous questions remain and many new questions arose. Ultimately, the results of the *Eagle River Inventory and Assessment* point to the necessity of an ongoing adaptive management effort in the region. Adaptive watershed management may be described simply as a process of:

1. setting goals,
2. taking actions based on the best available information,

3. conducting a monitoring program designed to answer specific questions linking the goals and actions, and
4. updating and improving management based on program results.

ES.1 PUBLIC INVOLVEMENT / STAKEHOLDERS

In laying the groundwork for the *Eagle River Inventory and Assessment*, the Eagle River Watershed Council conducted extensive stakeholder outreach to identify and better define the most pressing issues and potential restoration activities throughout the basin prior to CSU involvement. The CSU project team subsequently communicated with hundreds of individuals from watershed stakeholders to key scientific experts. This work, along with the previous efforts of the Eagle River Watershed Council, were instrumental in identifying critical questions about the watershed as well as identifying the set of candidate restoration projects. This approach was augmented through field reconnaissance, statistical analysis, and a multi-criterion decision analysis to rank the ecological effectiveness of potential projects.

ES.2 WATERSHED RESTORATION PRINCIPLES IN THE *EAGLE RIVER INVENTORY AND ASSESSMENT*

Previous watershed management and restoration activities throughout the U.S. have been plagued by an emphasis on localized tactics that are not part of an overarching strategy addressing the underlying causes of degradation at the system level. While restoring a reach of river may provide a tangible sense of accomplishment, such projects often have little system-level benefit, especially if the restored reach has inadequate streamflows or is contaminated with pollution. Alternatively, identifying and removing chronic stressors at the system level and strategically prioritizing the restoration of segments that reconnect existing high quality habitats, such projects can have synergistic benefits for large segments of the watershed. **Thus, to be successful in the long term, watershed restoration requires a focus on protecting and restoring the *watershed processes that create and sustain habitats* as opposed to engineering habitats using a piece-meal, 'band-aid' approach to achieve a static condition.**

Scientific literature and numerous case studies indicate the likelihood of successful watershed restoration is greatly improved by adhering to these ten principles:

1. Address the causes of problems and not just symptoms, i.e., focus on ecosystem processes rather than achieving a particular condition.
2. Recognize many scales and potentially limiting factors, such as nonpoint source pollution or chronic flow shortages. A long-term, large-scale, multidisciplinary perspective is critical.
3. Work with rather than against natural watershed processes and reconnect severed linkages (e.g., channels and floodplains).
4. Clearly define goals and make both sustainability and enhancing ecological integrity explicit goals.
5. Utilize the best available science in predictive assessments that are risk-based and decision-oriented. For inclusive decision-making, predictive assessments should link system manipulations to probable outcomes of primary interest to stakeholders: clean water, productive fisheries, other valued biota, reliable water supply, recreation, and aesthetics.
6. Honestly identify and openly debate key knowledge gaps and uncertainties. Adopt an action-oriented principle that ensures that the decision-making exercise will lead to results.
7. Make decisions in a transparent, organized framework that:
   - structures the problem clearly,
   - provides a ranking of the options even though the uncertainties may not be resolved in the foreseeable future,
   - involves stakeholders,
   - documents and justifies the decision process to stakeholders, and

- provides research priorities by showing whether resolving particular uncertainties would affect the preferred option(s).

8. Watershed restoration projects are as much a social undertaking as an ecological one: understand social systems that may support or constrain restoration while establishing long-term personal, institutional, and financial commitments.
9. Some strategies will work, some won't, and some will take many years to assess. Be patient and learn through careful long-term monitoring of key ecological processes and biotic elements. Reevaluate and update the restoration strategy.
10. The best strategy is to prevent degradation rather than attempting to control or repair damage after it begins.

The *Eagle River Inventory and Assessment* has been guided by these principles. Scientific literature on river restoration constructs a compelling case for making a system-level assessment of watershed processes the highest priority. Given the large body of existing information and data available for the watershed, an essential first step is translating fragmented disciplinary information into interdisciplinary understanding of processes. First and foremost, we have sought to adhere to this principle, identifying watershed-scale patterns in major stressors and alterations. Such effort necessitates investigations of hydrologic processes and instream flows, nutrient loading, metals loading, large-scale habitat loss and fragmentation, potential interactions between water quantity and quality, and future threats to ecological integrity.

This approach is substantially different from assessments that generate reach-by-reach snapshots of physical habitat structure to target site-specific tactics. The frequent failure of tactical projects to restore ecosystem amenities and ecological integrity warrants the initial investment in examining these larger questions. Although the recommendations presented in the *Eagle River Inventory and Assessment* inevitably fall short of providing comprehensive information on all processes and potential projects, the focus on detecting system-level stressors and integration of existing knowledge is requisite for building comprehensive and sustainable strategies to restore the integrity of the Eagle River watershed.

ES.3 WATERSHED OVERVIEW, HISTORY, AND POLICY

Over the course of the project, CSU reviewed and compiled hundreds of documents. Previous reports and existing data sources that played a critical role in developing the *Eagle River Inventory and Assessment* include the: *2002 Eagle River Water Quality Management Plan* (Northwest Colorado Council of Governments (NWCCOG), 2002), *Eagle River Watershed Plan* (1996), Eagle River Assembly (ERA), U.S. Geological Survey (USGS) reports and water-quality database, Eagle Mine monitoring and analysis reports, instream flow quantification field forms and related reports by the Colorado Water Conservation Board (CWCB) and Colorado Division of Wildlife (CDOW), and numerous historical documents and photographs from the Denver Public Library and other sources. In addition to a brief review of these documents, this report provides a synopsis of watershed characteristics, a brief history of the Eagle River watershed, and a survey of current policies relating to riparian zones and stormwater management.

ES.4 ANALYSIS OF WATERSHED CHARACTERISTICS (THE AFFECTED ENVIRONMENT)

ES.4.1 Land Use

GIS and aerial photograph analyses indicate that the most intense land use change is focused in or near the riparian corridors of the main stem Eagle River and Gore Creek, despite small percentages of developed land use in the overall watershed. For example, an analysis of land cover data suggests that total developed land use in the Gore Creek watershed is approximately 2%. Developed land cover within 100 m and 30 m of

Gore Creek between the Black Gore confluence and the Eagle River is estimated at 7% and 35%, respectively. Similar patterns exist in the Eagle main stem, particularly between Minturn and Edwards where basin topography, development practicality, and human desires to be near the water place disproportionate development pressures in alluvial valleys. Results of an analysis of the imperviousness of developed areas (an often-cited indicator of stream health) revealed comparable trends. Future development will continue increasing imperviousness as the population of Eagle County approaches anticipated growth of 75% (Colorado Division of Local Government, 2003) over the next 25 years. These patterns are perhaps not surprising but nonetheless underscore the added challenges surrounding management of impervious surfaces, stormwater, and riparian zones in mountainous watersheds with rapidly growing population centers focused in and near ecologically critical zones.

ES.4.2 Water Use

Consumptive use accounts for approximately 10 to 15% of the Eagle River's average annual yield of 410,000 acre feet at the Gypsum gage. The greatest consumptive use in the basin results from transmountain exports which account for 60% of consumptive use. Irrigation is the second largest consumptive use at approximately 32%. Domestic/municipal and reservoir evaporation uses are estimated at 3% and 4%, respectively. From 1985 to 1995, a shift from irrigation consumptive use to domestic consumptive use was apparent, as was a 54% decrease in irrigation consumptive use.

ES.4.3 Hydrology

Although the flow regime of the Eagle main stem is more intact than some other rivers of comparable size on the western slope of Colorado, reservoirs and diversions have influenced the flow regime of several segments in the basin. We performed a detailed analysis of current and historical flow regime characteristics at 35 locations in the Eagle River watershed. We have included numerous metrics describing the magnitude, frequency, duration, timing, and rate of change of streamflows at these gaging sites in the main report.

Changes in flow regime are most pronounced in Homestake Creek below Homestake Reservoir and in the upper Eagle River below the Wurtz and Columbine Ditches. The combined effects of these flow modifications are transmitted below the confluence of Homestake Creek and the Eagle River through the Eagle Mine site and Minturn. The relative hydrologic effects of these modifications diminish in a step-like fashion as the Eagle main stem accumulates tributary inflows. Reductions in peak flows have both geomorphic and ecological implications discussed in the *Eagle River Inventory and Assessment*. In general, the analysis and description of several ecologically relevant flow attributes performed in this study provide a framework for managing flows with a better understanding of historical variability.

Despite distinct shifts in peak flow magnitudes in the upper Eagle and Homestake Creek, differences in pre- and post-alteration *low flow* regimes are much more subtle. Although there are detectable changes in low flows in the upper Eagle and Homestake Creek, it appears that the most detectable changes in the low flow regime of the Eagle River are associated with a reduction in irrigation return flows and the timing of low flow minima. Thus, it appears that there has been a historical sequence in which baseflows were originally supported by greater overbank flooding during snowmelt, then altered by irrigation diversions, return flows, and peak flow reductions, and most recently reduced by a shift from irrigation to domestic/municipal uses. The net effect of these changes over the last half century is a reduction in low flows in the main stem Eagle in the late summer and fall months when greater irrigation returns formerly supported higher baseflows.

ES.4.4 Instream Flows

Instream flows rights have been established by Colorado law to "preserve the natural environment to a reasonable degree." In the Eagle River watershed, instream flow rights have priority dates ranging from 1975 to 1986. We analyzed data from USGS flow gages in stream and river segments with decreed instream flow rights to (1) examine the frequency of flows below the instream flow rights, and (2) compare the instream flow rights to the average and deviation of actual flows at different times of year. **Of 67 segments in the Eagle River watershed with instream flow rights, 47 are ungaged, and the remaining segments have instream flows that are not met at widely varying frequencies.** Nine of the 19 segments that have been gaged for at least 10 years have instream flow rights that have not been met at least one time per year in each year of the record since appropriation.

A comparison of instream flow rights with average monthly flows along the Eagle River main stem indicated that (in most locations) the instream flow rights were set more than one standard deviation below the average flow computed from post-transbasin diversion gage records for September to October and February to March. At the Gypsum and Minturn gages, it appears that instream flows are set at levels that are more than two standard deviations below recorded average flows. Thus, these rights are met the vast majority of the time, especially in the case of winter flows.

Given the current administrative structure, instream flow rights generate a “call” on the Eagle River main stem when (1) flow is more than a standard deviation below average post-diversion conditions, (2) departures from instream flow levels are being monitored and reported to CWCB, (3) CWCB makes a “call” on the river, and (4) the call halts diversions that are junior to the priority date of the instream flow right. A call by the CWCB to protect an instream flow water right in the Eagle River rarely occurs. Instream flow rights are protected in changes of water rights and plans for augmentation. An organized local effort to monitor instream flows in the Eagle River watershed does not currently exist. The state instream flow monitoring program is small (one person for the entire state) and suffers from lack of resources.

Most instream flow recommendations in Colorado are based on the R2CROSS methodology. Current CWCB implementation of the R2CROSS methodology seeks to satisfy three established hydraulic criteria in the summer, and two of the same three criteria in the winter based on field discharge measurement at 40-250% of the recommended instream flow. We reviewed the original field forms describing the R2CROSS analysis used to determine minimum flow recommendations. The results of this analysis for the Eagle River main stem are summarized in Table ES.1.

Table ES.1: Summary of results of reviewing instream flow field forms for the Eagle River main stem.

Segment of Eagle River Main Stem	Segment Length	No. of Transects Used to Set ISF	Discharge Meeting Three Habitat Criteria	Discharge Meeting Two Habitat Criteria	CDOW Rec. ISF for May-Sept. / Oct.-April	Final ISF Right for May-Sept. / Oct.-April	Notes
Homestake Creek to Cross Creek	6 miles	1	82-85 cfs	20 cfs	25/11 cfs	25/11 cfs	ISF outside range of 0.4-2.5Q measured, Meets one of three criteria in winter and two of three criteria in summer
Cross Creek to Gore Creek	4 miles	1	290 cfs	87-107 cfs	50/20 cfs	50/20 cfs	ISF outside range of 0.4-2.5Q measured, Meets one of three criteria in winter and one of three criteria in summer
Gore Creek to Lake Creek	10.1 miles	no survey available	?	?	85/45 cfs	85/35 cfs	No survey located, winter flow reduced from recommended 45 cfs to 35 cfs
Lake Creek to Brush Creek	20 miles	1	226 cfs	130 cfs	130/50 cfs	110/45 cfs	Recommended summer / winter flow of 130/50 reduced to 110/45 cfs, Decreed right meets one of three criteria in winter and one of three criteria in summer, Assumed Manning n value
Brush Creek to Colorado River	12.8 miles	1	135 cfs	92-108 cfs	130/50 cfs	130/50 cfs	Top width = 100 ft yet average top width of 7 bankfull sections measured at Gypsum SWA = 252 ft, Meets one of three criteria in winter and two of three criteria in summer

CDOW – Colorado Division of Wildlife; ISF – instream flow; cfs – cubic feet per second; Q – discharge; SWA – State Wildlife Area; ft -- feet

Although the Eagle River exhibits substantial variability in morphology and hydraulic geometry, the length of river represented by a single transect (cross section) ranges from 4 to 20 miles. Excluding the Gore to Lake Creek segment (for which field records were not obtained), instream flow recommendations for the remaining 43 miles of the Eagle River main stem between Homestake Creek to Dotsero were based on measurements at 4 locations using the single-transect R2CROSS method. Two of eight instream flow quantities decreed for reviewed segments of the Eagle main stem meet recommended habitat criteria.

According to a study that is widely regarded as providing the scientific basis for R2CROSS, the single-transect R2CROSS method used on the Eagle River main stem was to provide rapid and repeatable estimates of minimum flow requirements in "streams of little to perhaps moderate value as far as the fisheries resource is concerned" and "where encroachment by diversion, pollution, and development is not anticipated as a serious problem" (Nehring, 1979). The method used to quantify instream flows on the Eagle River main stem is not designed to serve as the primary decision making tool for managing flows in river systems such as the Eagle. It does not address several key factors linked to low flows such as recreation, water quality, land use changes, wastewater dilution, and temperatures.

Given that current instream flow quantities do not meet recommended criteria, and that the quantification procedure used for the main stem Eagle River is questionable, it is not recommended that existing instream flow rights be used as a standard by which the potential ecological consequences of flow changes be evaluated.

ES.4.5 Water Quality

Water quality is inextricably linked with water quantity and flow regime. For example, the low-flow regime of the Eagle River influences numerous aspects of water quality including:

- growth and persistence of algae on the river bed,
- flushing and dilution of fine sediment from tributaries and land disturbance,
- concentrations of nutrients and oxygen below wastewater discharges,
- late summer temperatures for coldwater fishes, and
- dilution of pollutants from mine sites and urban runoff.

A future challenge for stakeholders in this watershed will be to maintain and in some cases improve water quality despite greater demands on the valley's water resources due to larger volumes of treated wastewater and urban stormwater runoff entering the river. With this as a general context, we can state that water quality is good in most parts of the watershed, due to maintenance of key physical and ecological processes in the headwaters comprising the vast majority of stream length in the watershed. Room for improvement remains and changes will be necessary to avoid further degradation of water quality.

ES.4.6 Nutrients

Sources of nutrient additions above background levels in the Eagle River watershed include:

- wastewater and septic systems,
- fertilizers and animal waste,
- soil erosion,
- automobile exhaust, and
- dishwashing detergents.

By far, the largest source of nutrient additions above background levels in the Eagle River watershed is wastewater effluent. Municipal wastewater treatment facilities account for approximately 70% of the nitrogen load at Wolcott, 90% of the nitrogen load at Gypsum, and over 90% of the phosphorus load at both locations (NWCCOG, 2002). **Nutrient concentrations in the Eagle River and Gore Creek are now substantially higher (in some cases more than 2x - 7x higher) than levels observed in less disturbed streams and rivers of the Colorado Rockies. They also exceed values recommended to prevent impacts to aquatic insect communities and nuisance accumulations of algae (Table ES.2).**

Table ES.2: Median annual nutrient values for selected sites in the Eagle River watershed and regional reference values.

Site Name	Nitrate NO_3 (mg/L)	Total Phosphorus TP (mg/L)
Gore Creek Background[1]	0.11	<0.01
Gore Creek just upstream of Vail WWTP[2]	0.40	0.06
Gore Creek at Mouth[3]	0.48	0.08
Eagle River at Red Cliff[3]	0.03	<0.01
Eagle River just upstream of Avon WWTP[2]	0.60	0.11
Eagle River just upstream of Edwards WWTP[2]	0.70	0.21
Eagle River near Wolcott[3]	0.60	0.09
Eagle River at Gypsum[3]	0.43	0.08
Upper Colorado River Basin Background[4]	0.09	0.03
Upper Colorado River Basin Developed[4]	0.30	0.04
Colorado Rockies (Ecoregion 21)[5]	<0.10	0.02

[1]Wynn *et al.* (2001)

[2]Eagle River Water and Sanitation District Data (1998 - 2002); WWTP – wastewater treatment plant

[3]USGS, Eagle River water quality database (1998 - 2002): http://co.water.usgs.gov/cf/eaglecf/default.cfm

[4]Spahr and Wynn (1997)

[5]U.S. Environmental Protection Agency (USEPA, 2000); nitrate value is total NO_3 - NO_2 as nitrogen

In Gore Creek and the Eagle River main stem, aquatic insect monitoring indicates a shift from a 'clean water' fauna to greater relative abundance of pollution-tolerant taxa. Limited data suggest an incease in periphyton. Under current management strategies, nutrient loads will continue to rise for the foreseeable future due to both point and diffuse sources. In the shorter term, phosphorus and nitrogen loading from the five largest wastewater discharges in the Eagle River watershed can be expected to increase by more than 50% and 40%, respectively, by the time facilities reach 80% of design capacity based on current effluent concentrations and treatment technology. Nonpoint source pollution from future land use change and stormwater inputs will further increase nutrient loading. If left unchecked, nutrient concentrations will further exceed levels associated with aesthetic degradation due to periphyton growth and result in additional changes in biological communities in the Eagle River main stem and Gore Creek.

ES.4.7 Metals

Significant reductions in metal loading and biological recovery have occurred within and downstream of the Eagle Mine segment. The Eagle Mine however continues to constrain water quality both within the Superfund site and further downstream. Biological impacts associated with current zinc concentrations include:

1. reduced weights in brown trout; and
2. suppression or elimination of sensitive organisms such as the mottled sculpin and certain mayfly taxa.

As a result of reductions in other sources, the majority of current zinc loading to the Eagle River occurs in the Belden segment from ‘unaccounted’ sources. The Rock Creek drainage is the second largest contributor. A re-examination of monitoring data points to the Belden Tramway area as a major bracketed source of zinc loading. Implementation of capture/treatment or passive remediation technologies at this location could potentially result in substantial reductions in zinc concentrations and improvements in biological water quality both within and below the Eagle Mine site. However, further monitoring and evaluation are requisite to quantify the likely cost-effectiveness of additional cleanup activities in this area.

Field reconnaissance upstream of the Superfund site boundary revealed additional sources of current and potential metals loading. Several historical wooden structures or ‘cribbings’ that were used to stabilize waste rock piles are decaying and collapsing in the Belden segment. A series of cribbings readily observable from U.S. Highway 24 is of particular concern given hillslope angles, proximity to the river, and the relatively large amounts of fine waste rock material that would probably be delivered directly into the Eagle River in the event of a catastrophic failure. Analyses of waste rock for paste pH and leachable zinc indicate that ongoing degradation and potential failure of these structures represent a significant risk to the biological improvements that have been achieved in the Eagle Mine site.

ES.4.8 Sedimentation Impacts

Suspended sediment and turbidity from Milk, Alkalai, and Ute Creeks severely limit the coldwater fishery of the Eagle River below Wolcott. Highly erodible soils, southerly aspects, and historic overgrazing have combined to initiate widespread geomorphic instability including incision, mass wasting of channel banks, and headward migration of channel networks. Sediment concentrations as high as 12,000 mg/L have been recorded by the Bureau of Land Management (BLM) during spring runoff and impacts to the fisheries in the Eagle River have been documented by the CDOW in 1971, 1982, and 1989. These inputs of fine sediment diminish fish production by an order of magnitude and often reduce the fishing season by approximately 50%. The pervasive nature of these problems necessitates a comprehensive geomorphic assessment to identify incised channel types, gauge the relative importance of these processes and upland sources in sediment production, and establish geomorphic design criteria. Adequate reductions would likely necessitate a long-term effort (one or more decades) involving grade control, detention basins, drop pipes to check headward migration of channels, ‘brush-beating,’ and improved grazing management.

In the headwaters, traction sand from Interstate 70 on Vail Pass continues to affect the Black Gore Creek watershed. The protection and recovery of water quality and aquatic habitat conditions in Black Gore Creek is a high priority for the local community. In 1997, a coalition of more than ten agencies in cooperation with local stakeholders was formed to address the problem. Since 2000, significant progress has been made and over $4 million has been invested in sediment control and cleanup in and adjacent to the I-70 corridor. Sediment basins have been constructed in nearly all highway shoulder locations vulnerable to traction sand runoff. In 2002, the Colorado Water Quality Control Commission added Black Gore Creek to the State’s 303(d) list of impaired waters, requiring a Total Maximum Daily Load (TMDL) for sediment from I-70 sand and other sources. Stream monitoring efforts have been initiated to support TMDL development and track water quality conditions.

ES.4.9 Geomorphic / Physical Habitat Assessment

From a geomorphic standpoint, the Eagle River main stem and tributaries are generally stable and resilient in most segments due to lateral confinement and coarse armored bed material. There are many documented areas of local instability. These areas tend to occur in relatively low gradient segments of the main stem river, in smaller streams where tributary valleys enter the Eagle valley, and in highly erodible materials of the lower basin. Various influences including channelization, riparian vegetation removal and grazing as well as natural processes such as meander migration affect geomorphic stability and physical habitat in the watershed. A common trend among almost all of the tributaries to the Eagle River, with a few exceptions (including Homestake, Milk, and Alkali Creeks) is the tendency towards higher quality habitat with increasing valley confinement and distance from the Eagle River.

Field reconnaissance was focused in areas where past and current human influences are most prevalent and where these influences have degraded habitat at valley segment scales. Rapid surveys of physical habitat examined attributes including:

- substrate characteristics,
- channel hydraulic complexity,
- fish cover,
- riparian condition,
- bank stability,
- woody debris, and
- overall stability.

These surveys revealed localized instances and a few large-scale occurrences of geomorphic instability, riparian disturbance, and physical habitat degradation. In general, the most egregious and large-scale examples of disturbance and/or geomorphic instability occur at Camp Hale, in the Milk, Alkali, and Ute Creek subbasins near Wolcott, and Black Gore Creek. A few segments of Gore Creek have also been channelized and straightened. Brush Creek near the Town of Eagle, has also been disturbed over relatively long segments. Encouragingly, a rehabilitation project addressing these issues is currently underway on a small segment of this stream. Aside from Camp Hale, the Eagle River has been channelized in Red Cliff, through portions of the Eagle Canyon, and below Minturn through the I-70 interchange. Although the Eagle is laterally armored and entrenched through much of the urban corridor between Minturn and Edwards, it is hydraulically diverse and frequently shaded by at least a narrow forest riparian buffer in much of this segment.

Localized reaches with excessive width to depth ratios were identified along the Eagle main stem, primarily in the vicinity of Avon.

In general, the broader, lower elevation valleys of several tributary segments affected by grazing or other riparian disturbance present opportunities to improve channel stability and physical habitat. These include Lake Creek, Squaw Creek, Eby Creek, Brush Creek, and Gypsum Creek. Given the large number of private landowners along these stream corridors, planning and implementation of stream improvement activities in these areas will require both extensive landowner involvement and more focused analyses at the sub-basin scale.

The geologic controls that shape the Eagle and its tributaries change dramatically in the vicinity of Wolcott. The broader valleys and more erodible material of the lower basin result in higher sediment loads, greater floodplain widths and connectivity, and a more dynamic river planform. Planform analyses were conducted to examine the risk of braiding in the lower river and meander geometry as it affects lateral migration. The analysis suggests that the Eagle River in this part of the watershed is near the threshold for braiding. This tendency towards braiding is evident along the lower Eagle River at localized areas of channel widening, chute formation, and mid-channel bar development. Therefore, restoration activities designed to establish a narrower, single-thread geometry must carefully account for this tendency and the accompanying prospects of chute cutoff formation and aggradational trends. The widths and radii of curvature of several meander bends of the Eagle River below Eagle are in the range associated with the most rapid lateral migration rates.

Overall, there are three relatively long segments of the river corridor with substantially degraded habitat that provide outstanding opportunities to reconnect existing high quality habitats and/or reestablish wetland and riparian functions on a disproportionately large scale: (1) Eagle River at Camp Hale, (2) Eagle River at Edwards / Lake Creek Segment, and (3) Eagle River at Gypsum State Wildlife Area (SWA).

(1) At Camp Hale, five miles of meanders and hundreds of acres of wetlands were filled, and replaced with a straight canal. The current channel containing homogeneous and degraded habitat is hydrologically disconnected from the adjacent valley floor.

(2) The Edwards / Lake Creek segment is severely overwidened. It has degraded habitat, unstable banks, and poor substrate. The 1.7-mile segment is located between two extant segments of very good aquatic habitat in the Eagle River.

(3) The Gypsum Ponds SWA segment of the Eagle River is a key riparian corridor in the lower Eagle valley. Portions of this two-mile segment are geomorphically unstable and have a tendency toward braiding. Multiple meanders have been truncated by I-70. The high quality riparian corridor on the south bank is vulnerable to future development.

The section of the Eagle River from the Minturn railroad yard to I-70 contains several reaches of highly disturbed habitat. Although this corridor holds the potential for significant improvements in physical habitat, riparian re-vegetation, and recreational access, ongoing metals loading would limit the ecological benefits of restoration project in this segment.

ES.4.10 Riparian and Wetland Habitat

Riparian areas in the Eagle River watershed have experienced both direct and indirect human alteration. Heavy historical grazing and land use changes associated with the rise of tourism led to rapid modification of riparian areas and native vegetation. Other actions initiated a slow process of barely discernible change. The conditions of the riparian zones in the Eagle River watershed have been most altered by riparian encroachment of urbanization, filling of wetlands, grazing and clearing activities, and flow modification.

The largest loss of wetlands in the watershed has occurred at Camp Hale, where hundreds of acres of wetlands were filled. The channelization and subsequent incision of the river channel, combined with the placement of fill material, resulted in floodplain disconnection and a complete shift in the vegetation community. Historic flooding maintained montane wetland species but conditions extant since the creation of Camp Hale are more suitable to upland and invasive species.

Tamarisk, an exotic vegetation species that has invaded many areas of the southwestern United States, has also been found in the lower river. More tolerant to drought conditions and saline soils than native species such as willows and cottonwoods, it is out-competing native species in many areas of the lower Colorado River. Selective grazing by livestock and wildlife also favors tamarisk.

The potential exists for tamarisk to spread in the lower Eagle River valley. Initial evidence suggests that it is unlikely that it will invade elevations higher than 7,000 ft to a significant extent. This is primarily due to climatic influences, especially the rapid decreases in temperature associated with high elevation zones. Sudden, hard frosts in early fall or late spring are highly unfavorable for tamarisk. However, there is growing evidence that hybridization is occurring and tolerance of cold temperatures is increasing.

ES.4.11 Biological Resources

The Eagle River watershed contains a rich and diverse array of wildlife. The greenways along rivers and streams act as conduits for the migration of many species, either to access seasonal habitat, or for juveniles to disperse into other sections of the range of the species. Many of the housing developments in the watershed are located in and around riparian areas due to aesthetics, tranquility, and convenient location adjacent to utility and transportation corridors. This has resulted in destruction and fragmentation of riparian habitat.

The Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) is the only indigenous trout of the upper Colorado River watershed. Although once ubiquitous in mountain streams west of the Continental Divide, in Colorado, southern Wyoming, eastern Utah, extreme northwestern New Mexico and northeastern Arizona, the Colorado River cutthroat trout (CRCT) now occupies less than five percent of its historic range. This cutthroat is now found primarily in isolated, small headwater streams, with only one to two miles of suitable, continuous habitat. This severe range reduction can be attributed to the destruction, modification, or curtailment of its habitat. Stocking of streams and lakes with non-native species and overutilization for recreation and commercial purposes are also causes of cutthroat decline.

Existing Colorado River cutthroat populations have been identified and assigned a purity index based on DNA analyses. So called "core" populations, 99% pure CRCT, have been found in Abrams, Hat, and West Cross Creeks. "Conservation" populations, at least 90% pure CRCT, have been identified in Black Gore, Indian, Cross, Polk, Pitkin, Booth, Berry, and East Lake Creeks. The continued existence of genetically pure Colorado River cutthroat populations is partially due to the presence of natural and artificial barriers to fish passage that have allowed the native fish to remain isolated from introduced species.

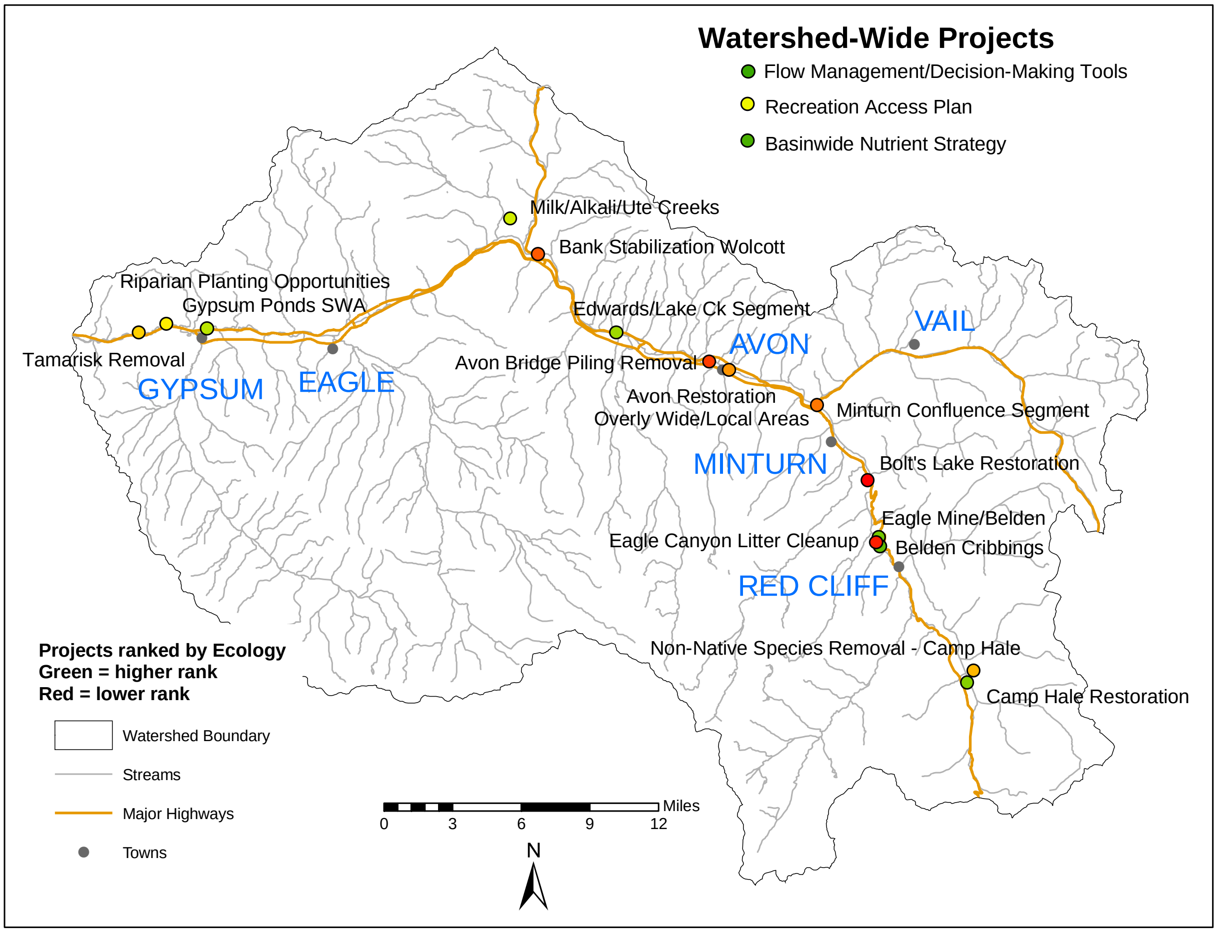
ES.5 POTENTIAL PROJECTS: IDENTIFICATION AND PRIORITIZATION

Engineers, managers, and planners are frequently faced with deciding between multiple project alternatives. In the case of watershed restoration, environmental, social, technical, economic, and political considerations can become intertwined to the point of intractability. Accordingly, these criteria need to be systematically examined through an organizing framework for rational analysis and comparison of alternatives. A Multi-Criterion Decision Analysis (MCDA) approach provides a flexible, rational, and transparent means to establish decision-making criteria and prioritizing alternatives. The MCDA approach selected for the *Eagle River Inventory and Assessment* is more structured, transparent, and defensible than 'best professional judgment' yet more interpretable and less data intensive than complex computer optimization schemes. Ecological, technical, practical, socioeconomic and strategic considerations were included in the criteria used to assess and rank candidate projects in the MCDA.

Potential projects were identified through both extensive stakeholder input and scientific assessment. Ongoing projects such as the I-70 sediment control work in Black Gore Creek watershed were not considered. The MCDA framework was used to analyze 18 candidate projects. The projects were ranked using the resulting Total Score for each of the four decision-making components. A detailed breakdown of the criteria ratings is provided in Appendix L of the main report. For spatial orientation and comparison, the results were superimposed on maps of the watershed. Figure ES.1 illustrates the Ecology rankings for all of the projects; the rankings are displayed with green indicating higher priority projects and red indicating lower priority projects.

The project rankings and weights are estimates based on currently available information. They provide a general overview of what projects are likely to provide the most significant benefits in the watershed. We are confident in the overall structure of the project rankings, particularly with regard to ecological benefits. It must be reiterated, however, that the MCDA technique clusters projects of similar benefits and character in a relative sense and that attaching significance to slight differences in scoring among closely ranked projects is not warranted given the precision of the scores. Socioeconomics, Practicality, and Watershed Strategy rankings will undoubtedly require additional refinement as more detailed information becomes available and stakeholders provide additional input. Specific benefits for the top-ranked projects are provided below.

For the three components besides *Practicality*, Camp Hale Restoration, Eagle Mine/Belden Cleanup, Gypsum Ponds SWA Restoration, Edwards/Lake Creek Restoration, Basinwide Nutrient Strategy, and Flow Management Tools are consistently among the top-ranked projects. The Belden Cribbings and the Recreation Access Plan are among the top-ranked in two of these three components. Taking *Practicality* into account and averaging the ranks for all of the projects, the aforementioned projects are at the top of the list, with the Recreation Access Plan ranked highest among all projects. The common thread among these projects is their



Color shades ranging from red to yellow to green correspond to lower, moderately, and higher ranked projects, respectively. Watershed-wide projects are not given a location on the map but are listed at the upper right.

Figure ES.1: Watershed projects ranked by Ecology criteria.

potential to connect high quality habitats in the watershed and/or their watershed-wide benefits. Several of these projects were also identified as high priorities during preliminary watershed stakeholder meetings.

Among the smaller projects, Minturn Confluence Segment (restoration at the U.S. Forest Service (USFS) access site), and Riparian Planting/Tamarisk Removal are ranked highly. These projects generally do not offer the wide-ranging benefits of the larger projects, but are practical to implement should resources become available and have a high potential for volunteer support.

ES.5.1 Seven Recommended Elements of a Restoration Strategy for the Eagle River Watershed

ES.5.1.1 Recommendation 1 – Define and manage for key ecological aspects of flow regime

Flow regime is a master variable profoundly influencing numerous ecological processes in stream and river systems. Although the flow regime of the Eagle main stem is less altered than in some other rivers of comparable size on the western slope of Colorado, reservoirs and diversions have influenced the flow regime in several segments in the basin. Demands for water associated with anticipated local growth, Front Range water rights, and snowmaking are expected to increase.

Making informed decisions about potential changes in flow regime necessitates the development of decision-support tools to assess potential ecological consequences of flow alteration schemes. The method used to quantify instream flows on the Eagle River main stem does not address several key factors linked to low flows such as recreation, water quality, land use changes, wastewater dilution, and temperature. **Given that current instream flow quantities do not meet recommended Colorado Division of Wildlife hydraulic criteria in several segments, and that the past application of a single-transect quantification approach to the main stem Eagle River is questionable under current conditions, it is not recommended that existing instream flow rights be used as a standard by which the potential ecological ramifications of flow modifications be evaluated.**

Tools supporting decision-making for flow management are most effective if underpinned by sound science and designed to account for interactions between water quantity and water quality factors (current and future) in a spatially explicit manner, i.e., the likely effects of flow extraction and augmentation within the specific river and stream segments can be evaluated on a site-specific basis.

Given ongoing metals loading and expected increases in nutrient loading in the Eagle River main stem and Gore Creek, risk-based tools allowing incorporation of future water demand, pollutant loading and climate/streamflow scenarios could provide critical information to assess probable future conditions. **We recommend the development of decision-oriented tools based on, or comparable to, the Instream Flow Incremental Methodology (IFIM) to more rigorously assess the potential effects of flow alterations on instream fish habitat and water quality in the Eagle River.**

Linking flow regime with key ecological processes and decision support tools provides critical information on 'how much water the river needs' to support various services and amenities valued by stakeholders. However, satisfying these needs is more complex. The seniority of other water rights over instream flow rights constrains options for emulating natural flow processes. Nonetheless, implementing this recommendation will help stakeholders and policy-makers balance competing interests with a clearer vision of future ecosystem states with regard to fisheries, water quality, recreation, aesthetics, and other values.

Monitoring is an essential component of flow management. Because the Colorado Water Conservation Board is the only entity eligible to hold instream flow rights and lacks the resources to consistently monitor instream flow levels in the Eagle River watershed, we strongly recommend an organized monitoring program for instream flows. Currently, no such strategy exists to ensure that instream flows are met prior to junior rights. Monitoring activities would rely on USGS real-time gages along with volunteers to develop stage-discharge relationships and maintain 'educational' staff gages at critical locations in the watershed.

Water conservation is another critical element of exploring options for flow regime management in the watershed. We concur with numerous water conservation and planning activities recommended in the Eagle River Watershed Plan and 208 Report. Planning for future growth, education, xeriscaping, recycling and gray water systems, and metering can reduce consumptive uses. Collaboration with the Colorado Water Trust and the Colorado Water Conservation Board is also recommended to further this recommendation.

Several uncertainties that may constrain future flow management of the Eagle River exist. Additional transbasin diversions are likely to occur on a small scale in the headwaters. Vast, existing conditional water rights in the lower watershed may eventually translate into a 100,000+ acre-feet off-channel reservoir near Wolcott. Increasingly intricate substitution and exchange patterns will also complicate coordinated flow management.

ES.5.1.2 Recommendation 2 – Implement restoration projects that have the potential to provide synergistic benefits across relatively large segments of the system

There are three relatively long segments of the river corridor with substantially degraded habitat, which provide outstanding, feasible opportunities to reconnect existing high quality habitats and/or reestablish wetland and riparian functions on a disproportionately large scale. These segments occur at: (1) Eagle River at

Camp Hale, (2) Eagle River at Edwards / Lake Creek Segment, and (3) Eagle River at Gypsum Ponds State Wildlife Area.

ES.5.1.2.1 Camp Hale Restoration

(Above: schematic of potential Camp Hale restoration alternative.)

The benefits of restoring portions of Camp Hale include:

- extensive high-elevation wetlands,
- improved fish habitat,
- greater food web support,
- historical enhancement, and
- education and recreation opportunities.

Possible restoration approaches are:

- restore meandering form and floodplain connectivity (~5 miles),
- leave straight channel as historical floodplain remnant,
- relocate willow / alder bank vegetation from channelized reach,
- several preliminary alternatives / site concepts have been developed, and
- enhance historical aspects.

Currently, the cost for this project is estimated between $5 and $8 million for the full site.

The most popular project among stakeholders in the Eagle River watershed is the restoration of Camp Hale, in the glacial valley known as Eagle Park. In 1942, the U.S. Army began constructing the former military base of the 10th Mountain Division. To create a stable building platform, the Eagle River was channelized and centered in the valley. Wetlands in the valley bottom were drained and covered with at least 200,000 cubic yards of fill material. Today, the river is incised throughout much of the segment, leaving the channel hydrologically disconnected from the valley floor and lacking a functional riparian corridor. Native riparian vegetation has not re-colonized the fill terraces and the valley is covered in upland and invasive plant species. The instream habitat is generally poor and homogeneous. Historical and aerial photos taken prior to construction were used with site surveys, geomorphic analysis, and a variety of other information to examine the feasibility of restoring the river channel to some semblance of its pre-channelized state.

Restoration alternatives under consideration include re-creating a sinuous planform, instream habitat enhancements, streambank bioengineering and riparian plantings, as well as educational and historical improvements. Because Camp Hale is on the National Register of Historic Places, any changes must be sensitive to the historical values of the site. At the time of this writing, the most plausible project seems to involve restoring a meandering form and riparian connectivity to approximately four to five miles of channel by removing part of the fill material along a floodplain swath, leaving the straight channel as a historical floodplain remnant, relocating willow/alder bank vegetation from channelized reaches and establishing additional riparian vegetation. Several preliminary alternatives/site concepts that simultaneously enhance historical aspects of the site have been developed. There was significant momentum for this project several years ago, prior to the designation of Camp Hale as a National Historic Register site. The site is located on the White River National Forest (WRNF).

Although it is not as urgent as other projects in the basin, restoration of the Eagle River and riparian wetlands at Camp Hale could bring a wealth of ecological benefits to this large, unique system. Channel restoration would reinstate complex habitat features for fish and other biota, and reconnect the channel to large areas of floodplain wetlands. The restored wetlands would increase water storage in the valley and sustain base flows, provide habitat for riparian fauna, increase food/energy input into the channel, and provide diverse habitat, shade and cover. Key advantages of this project site include its size and lack of development, providing unusual latitude in creating a functional restoration plan for the valley. Furthermore, an ecologically beneficial design could be readily integrated with features that enhance the historical significance and great educational value of the site. **The restored site could simultaneously increase awareness of the 10th Mountain Division legacy and the ecological significance of the valley, wetlands, and meandering river.** A separate summary of potential restoration work at Camp Hale is included in the Appendices to the main report.

ES.5.1.2.2 Edwards / Lake Creek Area

The benefits of river restoration near Edwards include:

- connectivity of high quality fish habitats,
- temperature reduction,
- increase dissolved oxygen,
- flushing fine sediments and coarser substrates,
- floodplain and wetlands creation, and
- improved recreation access.

Possible restoration approaches are:

- restore lower width/depth ratio and improve floodplain connectivity – fill material from wetland / pond complexes,
- enhanced access points, and
- integrated stormwater management.

Current estimated cost for the project is $1.7 to 3.7 million, not including land conservation measures.

(Above: Lake Creek, 1890; Below: Edwards, 2004)

Downstream of Edwards near the confluence of Lake Creek and the Eagle River, the river valley abruptly widens and flattens. Through this reach, the Eagle has an extremely high width to depth ratio and an insufficient capacity to transport sediment. The river has a substrate embedded with fine sediments that support tubifex worms (*Tubifex tubifex*), an organism associated with the occurrence of whirling disease (*Myxobolus cerebralis*) in trout. Relatively high temperatures occur in this segment during low flow periods. This site marked the upstream extent of the most recent severe fish kill in the Eagle River. The current, overly-wide channel has little habitat value. The segment disconnects high quality habitats upstream and downstream. The abrupt valley changes, bedrock control in the lower part of the segment, and uncertain land use near the upstream end of the segment constrain potential design alternatives for the site.

This project entails:

- reducing width and increasing depth to improve sediment continuity and substrate conditions,
- restoring mild sinuosity,
- bank bioengineering,
- restoring native riparian plant communities that are matched to site conditions,
- restoring wetlands and oxbow lakes on the floodplain,
- improving recreational access points, and
- educational/interpretive enhancements.

This project site also represents an opportunity to link future development could be coupled with channel/floodplain restoration. We recommend including ponds in the design for recreational, floodplain water storage, and stormwater management purposes.

ES.5.1.2.3 Gypsum Wildlife Area

(Above: Aerial view of Eagle River at Gypsum, 1998. Note encroachment of I-70 on meanders near top-center and right corner of photo.)

The benefits of restoration and conservation of the river channel near Gypsum include:

- conserve the best remaining riparian corridor in lower Eagle,
- improved instream habitat,
- enhanced floodplain connectivity, and
- stabilized riparian functions.

Possible approaches to achieve benefits are:

- voluntary conservation of south bank parcels,
- restore lower width/depth ratio and improve floodplain connectivity,
- fill material from floodplain wetland / pond complexes, and
- develop educational/recreational opportunities with Division of Wildlife and Town of Gypsum.

Current estimated cost for the project is $0.7 to $1.1 million for channel work, not including land conservation.

The Gypsum Ponds State Wildlife Area near the town of Gypsum offers excellent public recreation access along the lower Eagle River. The river channel through this reach is wide and braided, but affords opportunities for physical habitat improvements. Channel restoration would involve realigning and narrowing of the channel. The narrower channel leads to more overbank flows, establishing a better connection to the floodplain. The project would also include protection of the outstanding remnant riparian forest community and noxious weed control. Full implementation of the project would rely on voluntary land conservation efforts involving landowners along the south bank of the reach. These parcels are privately owned and have been rumored for development in the past, although no plans have materialized.

The project would conserve the relatively undamaged riparian parcels on the south bank. Protection and restoration efforts at the Gypsum Ponds State Wildlife Area would also maintain and enhance an excellent public access point to the lower Eagle. Other ecological benefits are improved instream fish habitat, reestablishment of floodplain connectivity, and enhanced riparian functions.

ES.5.1.3 Recommendation 3 – Further reduce metals loading from historical mining impacts and stormwater and defuse toxic 'time bombs'

ES.5.1.3.1 Reduce Metals Loading from the Belden Area

(Above: Waste rock pile 14 and the Tramway tributary area in Belden: a key source of zinc loading to the Eagle River.)

The benefits of additional reductions of zinc may include:

- enhanced brown trout fishery (abundance, relative weight, fish health),
- greater diversity of aquatic insects, and
- decreased cumulative impact of urban stormwater loading downstream.

Possible approaches to achieve additional reductions are:

- capture and treatment at Belden,
- implementation of passive treatment – permeable reactive barrier,
- combination of strategies to yield best result, and
- some room left in consolidated tailings pile.

The estimated cost to further reduce zinc loading in the Eagle River from the Belden area is unknown.

Reductions in metals loading have resulted in significant ecological improvements within and downstream of the Eagle Mine site. The Eagle Mine, however, continues to constrain water quality both within the Superfund site and further downstream. Biological impacts associated with current zinc concentrations include reduced weights in brown trout and suppression or elimination of sensitive organisms such as the native mottled sculpin and certain aquatic insects. As a result of reductions in other sources, the majority of current zinc loading to the Eagle River occurs in the Belden segment from 'unaccounted' sources. The Rock Creek drainage at Gilman is the next largest contributor. Monitoring data point to the Belden Tramway area as a primary source of the remaining zinc load. Implementation of capture/treatment or passive remediation technologies could potentially result in substantial reductions in zinc concentrations and further improvements in biological water quality both within and below the Eagle Mine site. This recommendation involves: (1) further evaluation and bracketing of loading sources in the Belden reach, (2) conducting cost-benefit analyses to link specific remediation activities, expected loading reductions, and likely environmental benefits for river segments in the mine site and downstream, and (3) implementation of cost-effective remediation projects.

Further reductions in metals loading from historical mining impacts could (1) increase brown trout relative weights and abundance in the Belden to Gore Creek segment of the Eagle River, (2) increase the extent of native sculpin recolonization in downstream segments as documented at Arrowhead, (3) increase the occurrence and abundance of metal-sensitive aquatic insects, and (4) decrease the risk of chronic and synergistic effects associated with stormwater / nonpoint source loading in urbanized segments downstream.

Key uncertainties include:

- groundwater dynamics in the Belden segment;
- the efficacy and design life of passive treatment technologies at temperatures and iron levels occurring at Belden;
- connectivity of waste rock piles 13 and 14 to surface and subsurface delivery pathways;
- the relationship between mine pool elevation and groundwater loading patterns; and
- costs relative to incremental ecological benefits.

ES.5.1.3.2 Belden Cribbings Stabilization

The cribbings upstream from Belden are an ecological "Time Bomb." The potential for catastrophic failure exists.

Possible methods for stabilizing the cribbings area include:

- buttressing the 'toe' of slope,
- backfilling with limestone material, and
- address multiple cribbings.

Projected cost for this project is between $500,000 and $2 million. The most likely estimate is approximately $1.2 million.

(Left: Aging cribbings holding waste rock / tailings precariously over the Eagle River.)

Several historical wooden structures known as 'cribbings' used to stabilize mining waste rock piles are located immediately upstream of the Eagle Mine Superfund site. Many of these structures are decaying and collapsing. A series of cribbings readily observable from U.S. Highway 24 is of particular concern given hillslope angles, proximity to the river, and relatively large amounts of fine, low pH waste rock material that could be directly delivered into the Eagle River in the event of a structural failure. The potential exists for these cribbings to fail catastrophically.

The ongoing degradation and potential failure of these structures represent a substantial risk to the biological improvements that have been achieved in the Eagle Mine site. Chronic and acute impact estimates based on failure/direct loading scenarios and measured leachable zinc concentrations suggest stream pulses with elevated zinc concentrations ranging from 13,000 μg/L to 350,000 μg/L over current conditions. For comparison, the generic water quality Table Value Standard suggested by the USEPA for zinc is 106 μg/L for background conditions in the Eagle River.

Uncertainty exists regarding the ownership of these various sites. This project involves surveying the cribbings and associated waste rock piles, a determination of ownership and property boundaries, and stabilization of piles posing the greatest threat to the Eagle River. Buttresses placed at the slope toe to stabilize waste rock piles could be backfilled with acid neutralizing materials. We strongly recommend addressing the leaking adit located just upstream of the site as part of a cribbings stabilization project.

Implementing this project decreases the risk of waste rock loading directly into the Eagle River. This project could reduce current metals loading from runoff, as well.

Key uncertainties include:

1. The probability of occurrence of different failure and delivery modes. i.e. – what are the chances it will fail? How completely will it fail? How much waste rock will end up in the river?
2. The extent of downstream impacts from estimated pulse inputs.
3. Landowner uncertainties. Extensive title and survey work must be completed to determine ownership.

Finally, it must be noted that increases in metals loading from diffuse stormwater sources are expected to increase with sub/urban development over time. Improved stormwater management for new development and retrofitting existing stormwater 'hotspots' have the potential to reduce the cumulative impacts of metals loading in the Eagle River and its tributaries. Specific stormwater recommendations are described under Recommendation 5.

ES.5.1.4 Recommendation 4 – Develop and implement a watershed strategy for addressing nutrient enrichment

Nutrient concentrations in the Eagle River and Gore Creek are now substantially higher than levels observed in less disturbed streams and rivers of the Colorado Rockies. They exceed values recommended to prevent impacts to aquatic insect communities and nuisance accumulations of algae. Ecological impacts from nutrient enrichment can occur abruptly with little indication prior to threshold responses in biological processes. **No general nutrient criteria that set targets for total nitrogen (TN) and total phosphorus (TP) loading are currently in place for streams and rivers in the Eagle River watershed. Point source discharge permits are currently evaluated and issued on an individual basis. Nutrient loading is expected to increase under current point source discharge permits and from polluted runoff.**

We recommend the creation of a watershed-wide strategy to manage nutrient enrichment, based on the best available scientific information. Steps in implementing such a strategy would include: (1) linking current and expected future total nitrogen and phosphorus loading, and streamflows, with probable ecological responses of algae (periphyton), aquatic insects, and trout, (2) setting nutrient loading targets that are likely to result in desired ecological states, (3) simultaneously assessing National Pollutant Discharge Elimination System (NPDES) discharge permits in a watershed-wide, collective analysis to achieve loading targets in the most cost-effective manner and to facilitate collaboration among all dischargers and nonpoint sources, and (4) implementing a monitoring program specifically designed to assess whether target nutrient loads are achieving the desired ecological endpoints identified by stakeholders.

Benefits of this initiative include preventing eutrophication and aesthetic degradation due to algal proliferation, maintenance of sensitive species, reduced risk of impacts to the Gore Creek and Eagle River trout fisheries, reduced disinfection byproducts in drinking water supplies, and a better understanding of links between future growth, flow regime, and water quality. As part of this process, all NPDES permits in the watershed could be evaluated and issued simultaneously based on the results of a coordinated monitoring program providing up-to-date information. This approach facilitates:

1. comprehensive analysis of the cumulative effects of NPDES discharges from an ecological standpoint,
2. integrated management of point and nonpoint source pollution, and

3. collaboration among dischargers and nonpoint sources in achieving water quality goals in a market based, cost-effective manner.

Basinwide permitting approaches have improved the ecological and economic effectiveness of managing point sources of nutrients in many river basins. Basinwide permitting basically involves the simultaneous evaluation of all permits, typically on a 5-year schedule. As a result, monitoring guides permit decisions by examining the cumulative ecological influence of all discharges. Economic benefits are derived from targeting any necessary reductions at facilities where they are most readily achieved and cost-effective. In very large urbanized basins like the South Platte, such an approach could prove difficult to manage. However, in the Eagle River watershed where consolidation of water resources infrastructure has already occurred to a substantial extent, such a strategy has the benefit of allowing financial resources to be targeted in a manner that maximizes ecological benefits. For example, if improvements in advanced treatment processes are more cost-effective at one or a few wastewater facilities as opposed to all facilities, a desired load reduction could be achieved by targeting resources at the appropriate facilities and avoiding a costly "one-size-fits-all' approach. Further information on basin-wide management of point source discharges is provided in Appendix K of the main report.

Together, nutrient budgets (point and nonpoint sources) and scientific assessments link desired ecological states and nutrient concentrations, providing the foundation of a unified strategy to manage point and nonpoint nutrient sources. Ecological goals are achieved by meeting target nutrient loads and concentrations. For example, stakeholders set a goal of keeping periphyton biomass below 100 mg Chl *a* /m^2 in the Clark Fork River, Montana, by maintaining mean concentrations of total nitrogen and phosphorus below 0.3 mg/L and 0.02 mg/L, respectively.

In identifying nutrient loading goals, it is recommended that *decision-oriented* scientific assessments be developed. Exclusive reliance on mechanistic modeling is strongly discouraged given the complexity of processes, parameter uncertainty, and the additional need for decision endpoints valued by stakeholders. Instead, these assessments should be risk-based and include a mix of small models, decision trees or probability networks, and expert judgment (e.g., National Research Council (NRC, 2001); Reckhow, 1999; Reckhow and Chapra, 1999). Such an approach facilitates the definition of future ecosystem states that matter most to stakeholders and links those states with specific nutrient goals.

Key uncertainties include:

1. The nutrient loading and flow conditions at which current diatom communities are likely to shift to filamentous algae at nuisance levels are uncertain.
2. Best available technology can achieve very low TN and TP concentrations but the feasibility and costs of implementing additional advanced treatment technologies at various facilities in the Eagle River watershed are unknown.
3. Eutrophication impacts on fisheries are difficult to predict given complex interactions with other factors such as flow and temperature.
4. The spatial and temporal density of biological monitoring (including periphyton) necessary to assess whether biological goals are being met and the cost of such monitoring.

ES.5.1.5 Recommendation 5 – Develop and implement an integrated strategy to manage stormwater and riparian corridors as growth occurs

Research conducted as part of the *Eagle River Inventory and Assessment* indicates that local stormwater and riparian zone policies are highly variable and fragmented among local governments in the Eagle River watershed in terms of protectiveness, compliance monitoring, and enforcement mechanisms. We concur with previous studies including the *Eagle River Watershed Plan* (1996) and 208 Plan (NWCCOG, 2002) in recommending the development and implementation of improved strategies to manage stormwater and riparian zones in the Eagle River watershed. Extensive resources including technical assistance and model ordinances are currently available to stakeholders (e.g., http://www.stormwatercenter.net/). A summary of existing policies in the Eagle River watershed is provided in Sections 3.5 and 3.6 of the main report and additional information on ordinances for stormwater and riparian zones is provided in Appendices I and J of the main report, respectively.

In particular, the Eagle River Watershed Plan provided several specific recommendations regarding stormwater management and riparian buffers. We fully endorse these recommendations and suggest that local governments in the watershed:

- Strive to integrate both stormwater and riparian zone ordinances and management programs among jurisdictions.
- Proactively develop and implement stormwater programs consistent with the six minimum control measures required under NPDES Phase II stormwater:

  1. Public education and outreach on stormwater impacts.
  2. Public involvement/participation.
  3. Illicit discharge detection and elimination.
  4. Construction site stormwater runoff control.
  5. Post-construction stormwater management in new development and redevelopment.
  6. Pollution prevention/good housekeeping for municipal operations.

- Ensure that ordinances require implementation of water quality best management practices (BMPs) that capture and treat small runoff events in addition to 'peak shaving' of 2-year and larger events in new development and redevelopment.
- Establish long-term maintenance of water quality BMPs as part of permit requirements.
- Improve compliance monitoring, couple compliance monitoring with technical assistance, and require performance bonds for sediment and erosion control.
- Promote better site design concepts including 'low impact development,' especially the minimization of directly connected impervious areas.
- Address septic tanks through inspection and maintenance, e.g., require functionality when property ownership is transferred.
- Inventory stormwater retrofit opportunities, especially those involving potential 'hotspots' like gas stations and industrial facilities.
- Ensure best management practices are implemented for snow storage and disposal to prevent direct delivery of polluted melt water.
- Develop riparian ordinances that address soil disturbance, vegetation disturbance, fertilizers and pesticides, and native riparian vegetation in streamside buffer zones.

Note that functionality of the approximately 2,200 septic systems in the Eagle River watershed has never been surveyed. The political feasibility of coordinated stormwater and riparian buffer management programs and collaborative compliance monitoring among jurisdictions is uncertain, as well.

Protection and restoration of riparian zones is a cornerstone of watershed management. Similar to the tools available for protection of riparian zones in urban areas, specific guidance is also available for agricultural lands. For example, the Natural Resources Conservation Service (NRCS) conservation practice standard for Riparian Forest Buffers (Code 391) on agricultural lands is discussed in Appendix J of the main report.

Riparian corridors of the lower Eagle River and tributaries entering the main stem valley are characterized by sparse or no woody vegetation in many locations. Where vegetation is sparse along the riparian corridor due to grazing, mechanical removal, or other factors, erosion is often accelerated. Based on field reconnaissance and aerial photo analysis, several sites have been identified to re-establish native vegetation along the riparian corridor. Many of these sites are grazed and would require alternative management to allow re-vegetation. In addition to increasing geomorphic stability, re-establishing woody vegetation provides a buffer against nonpoint source pollution, shade to decrease temperatures, cover and organic inputs to improve instream habitat. Tree planting along tributaries entering the Eagle valley below Edwards could result in the greatest shading and temperature reduction benefits. Restoration of riparian zones along lower river tributaries would provide important coldwater refugia during periods of low flows and elevated temperatures. Riparian planting requires careful planning and evaluation but provides excellent opportunities for volunteer involvement.

We recommend the following initial steps to restore riparian corridors in the lower Eagle River watershed:

- Protect existing riparian forest buffers and restore native riparian communities in areas where vegetation and accompanying benefits for habitat, thermal regime, and food web support have been lost. Particular emphasis should be placed on tributaries below Edwards.
- Develop sub-basin specific plans for key tributaries to the Eagle River below Edwards including Lake Creek, Brush Creek, Eby Creek, and the Milk Creek, Alkali, and Ute Creek area. The complex management and ownership patterns of these sub-basins necessitates extensive landowner communication and a more focused inventory of opportunities for protection of existing riparian forest buffers, restoration, and mitigating negative effects of grazing. Such plans involve working closely with landowners with the assistance of agencies including Natural Resources Conservation Service, Bureau of Land Management, and Cooperative Extension as appropriate, and potentially implementing demonstration projects in the process of developing comprehensive strategies for the sub-basins. Although preliminary strategies have been previously developed for reducing sediment yield from the Milk Creek area, these plans have lacked (1) specific goals linked to desired biological outcomes, (2) adequate quantification of expected reductions in sediment yield, and (3) the necessary detail on system-level geomorphic processes needed to target grade control, drop pipes, sedimentation basins and other measures based on specific reduction goals. The efficacy, cost, and time frame of achieving adequate reductions of sediment loading from the Milk Creek area are unknown.

  For maximum effectiveness, a geomorphic strategy should link with estimated reductions from upland restoration activities including brush beating and improved grazing management. Specifically, we suggest mapping incised channel evolution types, headcuts, bank heights, materials, morphology, longitudinal profiles, and other characteristics needed to identify specific geomorphic design criteria. Reductions in sediment transport capacity associated with various treatment scenarios (channel and upland) can be subsequently quantified and linked to estimates of suspended sediment loading and impacts on fishes (Newcombe and Jensen, 1996; Section 4.6.6.1 of the main report) in the Eagle River.
- Utilize the GIS resources and riparian inventory developed during these processes to guide landowner contacts and better define specific restoration opportunities. Ascertaining landowner willingness to re-establish riparian forest buffers through improved grazing practices will be critical.

A critical hurdle for any coordinated stormwater/riparian management plan is the capability of policy-makers to balance environmental protection/public trust and individual property rights. Any riparian restoration program will be highly dependent on private landowners.

ES.5.1.6 Recommendation 6 – Enjoy the river, but also recognize that there are limits to its capacity and resilience – Develop and implement a long-term access plan for low-impact recreation

Rapid future growth in Eagle County will increase pressure on the few existing public access points for boating and fishing. There are few developed recreation/access areas along the Eagle River between Edwards and Red Canyon. **Currently there is no plan or program that ensures access along the river, manages**

the parking along Highway 6 for existing access sites, or provides for additional access to accommodate rising recreational demand. In order to create a "stewardship ethic," it is critical that the entire community be connected to the river. One way to achieve this is to augment existing access points with small, accessible parks along the river near population centers.

As the watershed's population continues to grow, the river system will depend more heavily on the intent of residents to maintain water quality, self-sustaining fisheries, and trash-free environments. Implementing this recommendation would:

- inventory the ecological condition and legal status of existing access points;
- identify future access sites along with methods to enhance poorly designed access points;
- redesign existing access points to ensure ecological values are safeguarded; and
- yield a comprehensive strategy to improve and enhance all access points throughout the watershed in sustainable ways.

Initially, it would also create an organized process for stakeholders to provide input and develop long-term recreation goals. We recommend that this process be facilitated by experts and managers with specialized knowledge of forecasting of future pressures and carrying capacity studies.

This effort plays a key role in ensuring, not only a sustainable economic base associated with recreation and tourism, but provides aesthetic and ecological improvements to riparian areas degraded by existing access practices. Although this initiative was not ranked highest in any individual category of the MCDA, it had the highest average score across categories of any project considered.

ES.5.1.7 Recommendation 7 – Prevent further degradation – protect the headwaters, existing high quality habitats, and native species

It is critical to establish an ongoing process to protect and secure remaining healthy biotic refuges by minimizing the possibility that past and future activities will degrade them. Protection of a well-dispersed network of habitat refuges and hot spots is necessary to sustain current populations and ensure sources of colonists are available to seed recovered habitats. **The final and perhaps most important recommendation is the comprehensive protection of the remaining relatively healthy headwaters, biotic refuges, less-disturbed watersheds, riparian areas, floodplains, and network of biological "hotspots"** (Doppelt *et al.*, 1993; Frissell, 1997). This recommendation is directly linked to recommendations for improving riparian zone management described above. Protection can be achieved through a number of mechanisms, including conservation easements, land purchases, water rights, local ordinances, USFS planning and the National Environmental Policy Act (NEPA) process. We offer the following recommendations to prevent further degradation:

- **Protect native species and their habitats.** Actively work toward the goals and implementation strategies described in the Colorado Natural Heritage Program (CNHP) (Armstrong, 2000) and the Conservation Agreement and Strategy for Colorado River Cutthroat Trout (*Oncorhynchus clarki pleuriticus*) (CRCT Task Force, 2001).
- **Enhance communication and collaboration** between the Colorado Natural Heritage Program, Colorado Division of Wildlife, U.S. Forest Service, and the Eagle Valley Land Trust (EVLT). For example, CDOW, CNHP, and USFS are simultaneously engaged in activities supporting native cutthroat trout. USFS is conducting a culvert and fish passage study that includes monitoring of fish assemblages in the White River National Forest. This study may provide information that is highly relevant to CDOW and CNHP initiatives including utilization of existing barriers to facilitate native cutthroat trout restoration, restoring connectivity among fragmented habitats (except where it would have negative impacts on native cutthroat trout), passage of native sculpin, and minimizing risk of culvert failures, sedimentation, and mass wasting.

- **Support protection of biodiversity through the Eagle Valley Land Trust and local governments.** EVLT has identified several properties containing high quality aquatic and riparian habitats. Protecting threatened elements of these properties through voluntary land conservation or purchase is a critical component of sustained ecological integrity in the Eagle River watershed. Community support for the Eagle County open space tax can contribute to this goal.
- **Utilize GIS tools, a system-level perspective, the best available science, and multidisciplinary teams of experts to prioritize conservation areas.** Give priority to locations at greatest risk for degradation of riparian functions, water quality benefits, wildlife corridors, and connectivity among key habitats. For example, CDOW scientists can provide stakeholders with the latest scientific information and expert judgment to identify conservation properties that, if protected, could prevent further loss of connectivity in large-scale corridors for movement and dispersal of wildlife. Prioritization frameworks such as the MCDA approach presented in Chapter 5 can be readily adapted to land conservation activities by envisioning likely future impacts, weighing urgency, and systemically identifying the functions and values to be maintained.
- **Protect riparian areas** by developing incentives and educational programs for private landowners to initiate their own efforts.
- Protect native riparian plant communities and riparian functions through management of high flows.
- **In support of native riparian communities, we suggest completing an existing inventory of tamarisk sites** (with permission from private landowners), contacting those landowners along the river to offer tamarisk removal, **and eradicating tamarisk in the lower Eagle River**.

Note that locations of instream biological hotspots (e.g., tributary confluences that support a high diversity of fishes, key refugia) have yet to be fully surveyed. Critical biological resources on many large private landholdings have not been inventoried, and models need to be developed to quantify flow regime attributes that protect riparian functions in the Eagle River.

ES.6 CONCLUSION

The seven primary recommendations described above build on numerous previous recommendations in addressing major ecosystem processes either currently altered or at greatest risk of becoming altered through anticipated land and water use changes. **In summary, the greatest threats to the integrity of the Eagle River watershed are:**

- **flow regime changes,**
- **nutrient loading,**
- **metals loading,**
- **land use change (impervious surfaces, stormwater, and riparian disturbance), and**
- **cumulative impacts from future recreation intensity.**

While uncertainty is a fact of life in watershed management and restoration, given the rapid changes occurring in the Eagle River watershed, forestalling action in the hopes of having perfect information, understanding, and consensus remains the greatest threat. The precautionary principle states "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically." Thus, there is a critical need for a collaborative framework supporting continual action, learning, and reevaluation. It is clear from surveys conducted by Eagle County (Eagle County Community Development (ECCD), 2003) that water quality and quantity are at the forefront of citizens' concerns about their future quality of life. They understand that clean and ample water, healthy fisheries, biodiversity, quality recreational experiences, and economic sustainability all depend on careful stewardship of the Eagle River watershed.

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Symbols

%WP	percent wetted perimeter (%)
d	grain size
m	rank
n	number, sample size
r_c	radius of curvature
R^2	coefficient of determination
S	slope
Q	discharge
$Q_{1.1}$	1.1-year discharge
$Q_{1.3}$	1.3-year discharge
$Q_{1.4}$	1.4-year discharge
$Q_{1.5}$	1.5-year discharge
$Q_{1.7}$	1.7-year discharge
Q_2	2-year discharge
Q_s	sediment discharge
$\overline{x}_d$	average depth (ft)
$\overline{x}_v$	average velocity (ft/sec)
X	looking downstream – river left is at X = 0
w	channel width

Units

%	percent
cfs	cubic feet per second
cm	centimeter(s)
cu ft	cubic feet
ft	feet
ft/s	feet per second
ft^2	square feet
g	gram(s)
km	kilometer(s)
L	liter(s)
lbs/hr	pound(s) per hour
m	meter
m^2	square meter(s)
mm	millimeter(s)
mg/L	milligram(s) per liter
mya	million years ago
µg/L	microgram(s) per liter
ppm	parts per million
sq mi	square mile(s)

Abbreviations

°	degrees
#	number
+/-	plus or minus
>	greater than
<	less than
1E3	acute low streamflows – 1 day, 3 year
30E3	chronic low streamflows – 30 day, 3 year
B-IBI	benthic Index of Biotic Integrity
BLM	Bureau of Land Management
BMPs	Best Management Practices
BOD	biochemical oxygen demand
ca.	circa
CDLG	Colorado Division of Local Governments
CDOW	Colorado Division of Wildlife
CDPHE	Colorado Department of Public Health and Environment
CDPS	Colorado Discharge Permit System
CDSS	Colorado Decision Support System
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
Chl *a*	Chlorophyll *a*
CIA	Central Intelligence Agency
CNHP	Colorado Natural Heritage Program
CO	Colorado
COD	chemical oxygen demand
CRCT	Colorado River cutthroat trout
CRWCD	Colorado River Water Conservation District
CSU	Colorado State University
CTP	Consolidated Tailings Pile
CWCB	Colorado Water Conservation Board
CWP	Center for Watershed Protection
D&RGW	Denver and Rio Grande Western
°C	Degree Celsius
°F	Degrees Fahrenheit
DEMs	digital elevation models
DO	Dissolved O_2
DOW	Division of Wildlife
E	east
ECCD	Eagle County Community Development
ECM	event mean concentration
ECPC	Eagle County Planning Commission
ECPD	Eagle County Planning Division
ERA	Eagle River Assembly
ERWC	Eagle River Watershed Council
ERWSD	Eagle River Water and Sanitation District

etc.	etcetera
EVLT	Eagle Valley Land Trust
GIS	Geographic Information System
GPS	Global Positioning System
HEC-RAS	Hydrologic Engineering Center-River Analysis System
I-25, I-70	Colorado Interstates
IFIM	Instream Flow Incremental Methodology
IFG	Instream Flow Group
IHA	Indicators of Hydrologic Alternation
ISF	instream flow
LC50	lethal concentration killing 50% of the population (μg/L)
MCDA	multi-criterion decision analysis
MFE	Ministry for the Environment
MGD	million gallons per day
MOU	Memorandum of Understanding
N	north
N	nitrogen
N:P	nitrogen phosphorus ratio
NAATA	National Asian American Telecommunications Agency
NAWQA	National Water-Quality Assessment
NCDC	National Climatic Data Center
NEPA	National Environmental Policy Act
NLCD	National Land Cover Data
No.	number
NPDES	National Pollutant Discharge Elimination System
NR	no record
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NWCCOG	Northwest Colorado Council of Governments
NWI	National Wetland Inventory
OU-1	Operable Units 1
OU-2	Operable Units 2
P	phosphorus
PCA	potential conservation area
pers. comm.	personal communication
PRISM	Parameter-elevation Regressions on Independent Slopes Model
PUDs	planned urban developments
ROD	Record of Decision
rm	river mile
RTAGs	Regional Technical Assistance Groups
SEV	severity
SNOTEL	snowpack telemetry
SWA	State Wildlife Area
SWE	snow water equivalent
SWMP	Stormwater Management Plan

TKN	total Kjeldahl nitrogen
TMDL	Total Maximum Daily Load
TN	total nitrogen
TP	total phosphorus
TN:TP	total nitrogen total phosphorus ratio
Total Cu	total copper
Total Pb	total lead
Total Zn	total zinc
TSS	total suspended solids
TVS	Table Value Standard
U.S.	United States
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WQCC	Water Quality Control Commission
WQCD	Water Quality Control Division
WRNF	White River National Forest
WSP	Wetted Surface Profile
WWTP	wastewater treatment plant
XS-1, XS-2, XS-3, XS-4	cross sections

Introduction

"We end, I think, at what might be called the standard paradox of the twentieth century: our tools are better than we are, and grow better faster than we do. They suffice to crack the atom, to command the tides. But they do not suffice for the oldest task in human history: to live on a piece of land without spoiling it." – Aldo Leopold

From the torrential streams of the high country to the meanders and cottonwood forests of its lowland valleys, the Eagle River watershed is an extraordinary resource that provides a host of ecosystem services and aesthetic benefits. It is also a system characterized by complexity and rapid change. In many ways, the Eagle River watershed is a microcosm of the many challenging issues facing western slope rivers in Colorado and other river systems throughout the western U.S. With a rapidly growing population focusing land-use conversions in and near the river corridor coupled with growing pressures for water from within and without, the fate of the Eagle River is increasingly determined by our decisions and stewardship.

Sound stewardship is predicated upon applying knowledge of the current state of the river system, how it arrived at its current state, how the system 'works,' and how it is likely to respond in the future. Given the complexity of the Eagle River watershed, there are inevitably many critical but unanswered questions regarding both natural processes and the growing human influences affecting river system integrity. In turn, these questions lead to uncertainty regarding the best strategies for preventing and reversing system degradation. A few examples of such questions are:

- What future water quality scenarios are most likely, given current strategies for build out, water development, stormwater management, and riparian zone protection?
- How have chemical pollutants from historic mining impacts and stormwater interacted with other stressors to affect fish health?
- How has nutrient enrichment influenced other water-quality characteristics such as algal growth, temperature, and dissolved oxygen levels in late summer?
- What restoration activities would result in the greatest ecological benefit per cost?
- Can we restore the natural processes that create high quality habitats as opposed to simply restoring habitat in a localized piecemeal or "band-aid" approach?
- What is the appropriate balance of structural restoration approaches such as fish habitat creation versus non-structural approaches involving policy, education, and monitoring?

- Which system processes can be rehabilitated within constraints imposed by existing development, floodplain encroachment, water rights, financial limitations, and institutional structures?

Obviously, these are very difficult and multifaceted questions that involve a host of technical, social, and political issues. There is, nonetheless, a pressing need to work towards answers. Progress towards answers will undoubtedly be a long-term adaptive process that involves both an evolving body of scientific knowledge and an evolving set of values and preferences among stakeholders in the Eagle River watershed and the people of Colorado.

This report describes the results of the *Eagle River Inventory and Assessment* (ERIA), a joint effort of Colorado State University (CSU) and the Eagle River Watershed Council (ERWC), to assess the current state of the Eagle River watershed from a basinwide ecological perspective and to prioritize potential restoration activities for improving the integrity of the river system. The objectives of the ERIA are the following:

1. Undertake an inventory of channel, riparian, and upland characteristics that currently control the ecological integrity of the Eagle River.
2. Collect and assess planning efforts of this type that have been performed by various agencies and organizations on selected sites within the watershed.
3. Perform an analysis of existing monitoring information to assess the status of various waterbodies / river reaches in the watershed and determine sources of pollution and degradation.
4. Identify and describe candidate restoration projects (structural and non-structural) and link to current issues and likely outcomes through 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.
5. Prioritize restoration strategies in a decision matrix based on likelihood of success, potential benefits, rough estimates of costs, and stakeholder input.
6. Produce a report describing the results of watershed inventory and prioritized recommendations for restoration projects and strategies.

Within a drainage area of nearly 1,000 square miles, the Eagle River watershed encompasses a complex array of natural processes, human influences, and candidate restoration activities. Time and financial constraints inevitably limit the ecological, hydrologic, and geomorphic assessment of large river basins. The ERIA is no exception in that it necessitated a balance between collection of new information and thorough analysis of the large body of existing information relevant to the project. In light of time and fiscal constraints, the approach adopted for this study primarily relied on the utilization of numerous existing data sets, rapid synoptic surveys of riparian and instream conditions, interpretation of aerial photography, GIS analyses, historical information, local knowledge, and expert judgment. Fortunately, a wide variety of water quality, hydrologic, and other types of data have been collected in the basin, albeit often for disparate purposes and using variable protocols. Many of the existing data sets collected in the Eagle River watershed have been largely examined in the context of individual projects or agency goals that relate to a specific location or aspect of the system as opposed to basin-scale assessment, management, and restoration of ecological integrity. Nonetheless, the large body of existing data coupled with field reconnaissance provided an adequate basis for evaluating patterns and trends in system characteristics and potential responses of the Eagle River to various management and restoration activities.

Although some questions were answered during this effort, numerous questions remain and many new questions arose. Ultimately, the goals and results of the ERIA point to the necessity of an ongoing adaptive management effort in the Eagle River watershed. Adaptive watershed management may be simply described as a process of setting clear goals, taking action towards the goals based on the best available information, conducting monitoring specifically designed to address key uncertainties related to the goals and actions, learning from the monitoring, and updating and improving management based on what is learned. It is the authors' hope that this report will assist in the protection, restoration, and adaptive basinwide management of the Eagle River and its tributaries.

1.1 PUBLIC INVOLVEMENT / KEY PLAYERS

In laying the groundwork for the ERIA, the ERWC conducted extensive stakeholder outreach to identify and better define the most pressing issues and potential restoration activities throughout the basin prior to CSU involvement. The CSU project team has subsequently communicated with numerous individuals ranging from long-time residents to government officials to key scientific experts. This work and the previous efforts of the ERWC was instrumental in identifying critical questions about the watershed as well as identifying the set of candidate restoration projects which has been investigated and augmented by CSU through field reconnaissance, statistical analysis, and a multi-criterion decision analysis (MCDA) approach for ranking the ecological effectiveness of potential projects.

Individuals who contributed to this report are listed in the Acknowledgements.

CHAPTER 2

Watershed Restoration Principles

"To keep every cog and wheel is the first precaution of intelligent tinkering." – Aldo Leopold

"We should be restoring the health of watersheds, not engineering habitat in stream reaches. We should be thinking across decades, not years. Strategies, not tactics should dominate environmental planning and management." – James Karr

Restoration has become an essential companion to conservation in the management of most river basins. However, despite legal mandates, massive expenditures, and the burgeoning industry of aquatic and riparian restoration, streams and rivers continue to deteriorate as a result of human influences (Karr and Chu, 1999). Further, many restoration activities have failed (Williams *et al*., 1997). This chapter describes general principles of watershed restoration derived from numerous case studies and the scientific literature in order to provide a context for the approach underpinning the ERIA. It also provides a brief overview of watershed processes and a conceptual framework to link watershed restoration with ecosystem amenities and ecological integrity.

In the parlance of stream and river management, 'restoration' describes activities ranging from quick fixes involving bank stabilization, fencing, or engineering fish habitat at the reach scale to river basin scale manipulations of ecosystem processes and biota over decades. The various perceptions and implied meanings of 'restoration' reflect the wide disparities in stakeholder interests, scientific knowledge, scale, and system constraints. We define watershed restoration as *assisting the recovery of ecological integrity in a degraded watershed system by reestablishing hydrologic, geomorphic, and ecological processes, and replacing lost or damaged biological elements*. Because both technical and social constraints often preclude 'full' restoration of ecosystem structure and function, rehabilitation is sometimes distinguished from restoration. Our definition encompasses rehabilitation to the extent that it focuses on causes of system degradation through attainable reestablishment of processes and replacement of elements, rather than treating symptoms to achieve a particular condition (Wohl *et al*., In Press).

Unfortunately, previous watershed management and restoration activities throughout the United States have been plagued by an emphasis on localized tactics that are not part of an overarching strategy. Common causes of failure in restoration (Williams *et al.*, 1997; Frissell, 1997) include:

- Failure to understand the ecological history of an area;
- Failure to look at the proper scale;
- Failure to treat root causes of degradation instead of symptoms;
- Failure to integrate ecological principles;
- Failure to develop a system-level strategy and proper goals;
- Failure to work with local communities and solicit their support for project goals;
- Failure to institutionalize commitments within local communities and agencies; and
- Failure to monitor and adapt management accordingly.

Successful restoration requires recognition and reestablishment of key processes and linkages (Angermeier, 1997; Frissell, 1997; Wohl *et al*., in press); however, the majority of restoration projects focus on a single, isolated reach of stream or river. The definition of restoration provided above suggests that the watershed is the most appropriate spatial unit to use for river restoration. This reflects the view that successful restoration requires that key processes and linkages beyond the channel reach – upstream-downstream connections, hillslope, floodplain, and channel connections, hydrologic-geomorphic connections – also be considered (Poff *et al.,* 1997; Stanford and Ward, 1992; Wohl *et al*., in press). Water, sediment, heat, organic matter, nutrients and chemicals all move through watersheds while being exchanged between uplands, tributaries, floodplains, and channels at varying rates and concentrations. Fish move upstream and downstream during different portions of their lifecycles. These obvious examples of extra-channel connections are too often ignored in river restoration. Restoration has largely been done on a piece-meal basis, with little to no monitoring, and little integration with other projects. This undoubtedly reflects both the lack of process-based approaches in current practice and the fact that comprehensive restoration strategies to reestablish watershed-scale connections and processes are difficult to implement in terms of sociopolitical and financial constraints.

In summary, spending money on localized tactics in the absence of a watershed-scale strategy does not address the underlying causes of degradation at the system level. While restoring a reach of river may provide a tangible sense of accomplishment, such projects often have little system-level benefit, especially if the restored reach has inadequate streamflows or is contaminated with pollution. Alternatively, if we identify and remove chronic stressors at the system level and strategically prioritize the restoration of segments that reconnect existing high quality habitats, such projects can have synergistic benefits for relatively large segments of the watershed. Thus, to be successful in the long term, watershed restoration requires a focus on protecting and restoring the *watershed processes that create and sustain habitats* as opposed to engineering habitats using a piece-meal, 'band-aid' approach to achieve a static condition.

2.1 WATERSHED PROCESSES, ECOLOGICAL INTEGRITY, AND VALUED AMENITIES

Many of us are familiar with the mosaic of instream, riparian, and upland habitats found along the Eagle River corridor and the diverse communities of plants and animals that occupy these habitats at different times of year. Perhaps less familiar is how these diverse environmental conditions and habitats are naturally created, maintained, and sometimes destroyed by watershed processes. The term 'watershed processes' encompasses hydroclimatic, geologic, geomorphic, and vegetational factors and the associated fluxes of energy and materials that sustain ecosystem services and the environmental context for biological communities (Figure 2.1). Both subtle and overarching human influences from ongoing activities and historical 'legacy' effects are superimposed on the natural variability arising from watershed processes. Fishes, aquatic insects, plants, and other organisms in the watershed interact in the context of habitats resulting from the watershed processes depicted in Figure 2.1 as modified to varying degrees by humans.

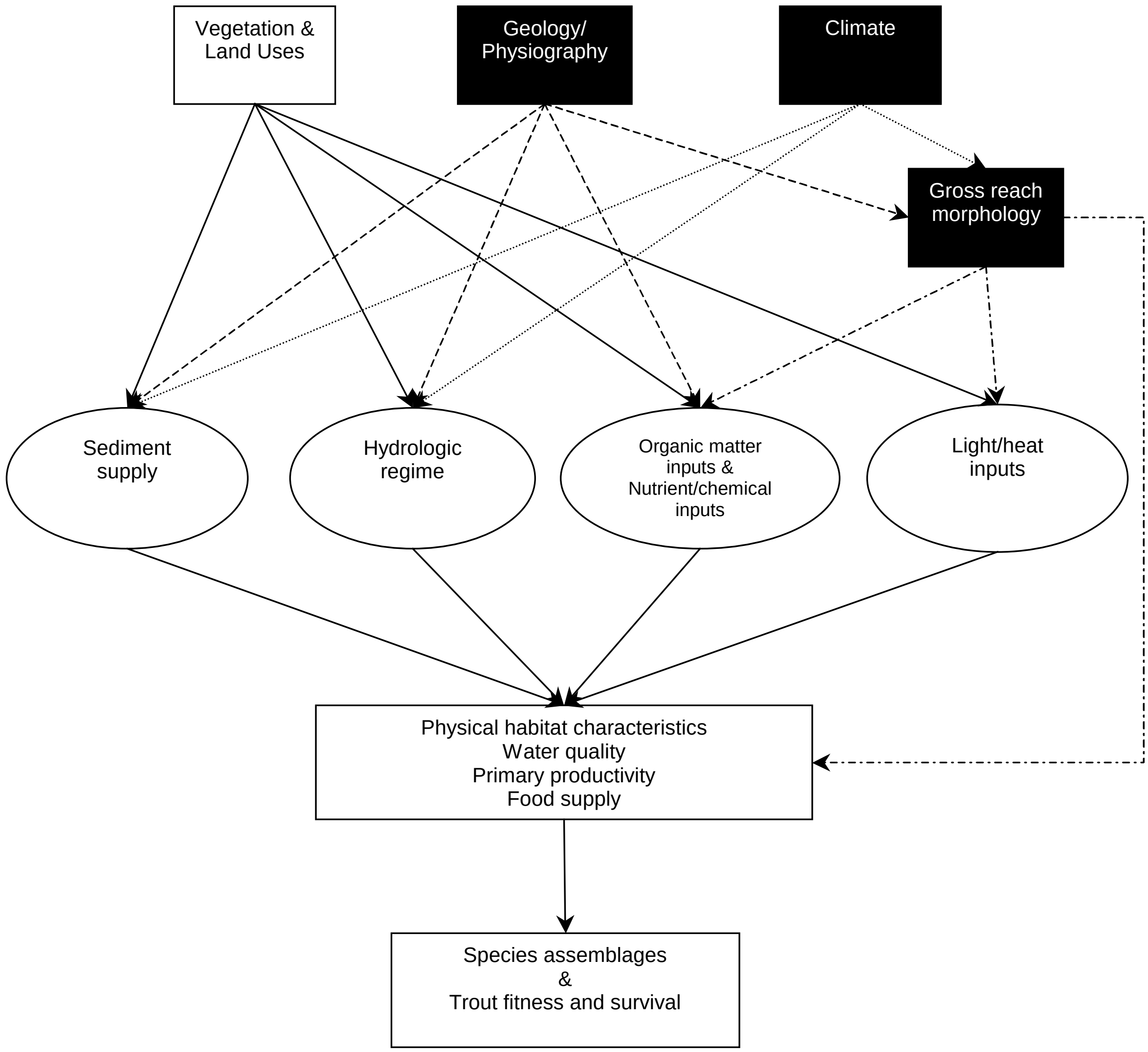


Figure 2.1: Schematic diagram of relationships between landscape and land-use controls on habitat characteristics (via habitat-forming processes), and between habitat characteristics and trout fitness and survival. Black boxes indicate controls not generally affected by land use (adapted from Pess *et al.* (2003)).

A basic principle of watershed restoration is to first identify relations between humans and key processes. In general, watershed systems have four major fluxes of energy and materials that are influenced by people: (1) water, (2) sediment, (3) organic matter, nutrients and chemicals, and (4) heat (Figure 2.1). For example, the construction of a reservoir typically modifies streamflow regime, traps sediments and organic materials, and alters water chemistry and temperature below its outlet. Similarly, impervious areas generally increase runoff magnitude and duration, decrease baseflow, reduce sediment delivery, provide direct pathways for delivery of nutrients, metals, and other urban pollutants, and increase the temperature of runoff. In both examples, all four general fluxes are altered along with the habitats of receiving waters, and the biological communities occupying those habitats. The rates and concentrations of these four major flows of materials and energy organize the ecological integrity of the Eagle River system. Thus, a key first step in identifying restoration strategies is to examine how these fluxes have been altered and may be modified in the future. This means that large-scale patterns in key processes such as flow regime alteration, nutrient loading, and chemical inputs must be assessed before prioritizing site-specific projects.

An understanding of these watershed processes is essential to restore ecological integrity. Integrity means that key processes and linkages are in place so that: (1) when stressors are imposed the system will be resistant to disturbance, and (2) when stressors are removed, the system has the capacity for self-repair (Karr, 1991; Angermeier, 1997). Similarly, Doppelt *et al.* (1993) argue that the most critical measures of *sustainability* are whether a riverine ecosystem (1) is free of "distress symptoms," (2) can self-repair after disturbances, and (3) supports native riverine-riparian biodiversity. Adopting ecological integrity as an explicit goal for restoration does not imply that the system must be returned to some previous pristine state. Instead, integrity refers more to a system's capacity and resilience than to its particular state.

Watershed processes and ecological integrity are also inextricably linked to ecosystem amenities directly valued by society. The primary amenities are typically clean water, productive fisheries, and edible (nontoxic) biota. Less commonly, restoration is also driven by desires for reliable water supply, persistence of valued (but non-food) biota, and aesthetics. The capacities of watersheds to provide these services depend on maintaining or restoring high levels of ecological integrity (Baron *et al.*, 2002; Postel and Richter, 2003). As the public increasingly recognizes the link between ecological integrity and these services, shifts in values may induce people to rethink assumptions about what is worthwhile in restoration scenarios. Thus, perceptions of what constitutes a restoration constraint versus an opportunity are continually evolving (Wohl *et al.*, in press).

2.2 SCIENCE AND SOCIAL ASPECTS OF WATERSHED RESTORATION

For watershed restoration projects to succeed, both good science and public support are critical. River restoration projects are as much, and perhaps more, a social undertaking as an ecological one (Anderson *et al.*, 2003). Societal perceptions and expectations of ecosystem performance ultimately determine whether restoration is a viable management option. The involvement of stakeholders in restoration decisions is growing and they have diverse preferences, institutional mandates, and expertise. Decisions to restore rivers (or not) often involve debates about which ecosystem amenities should take precedence and how benefits should be distributed; for example, whether consumptive uses of rivers take precedence over recreational uses or esthetic interests (Baron *et al.*, 2002; Wohl *et al.*, in press). The type of ecosystem amenity motivating restoration also dictates the types and complexity of scientific expertise germane to a given restoration effort (Table 2.1).

Restoration projects not based on sound science are unlikely to be successful in the long term (Williams *et al.*, 1997; Wissmar and Bisson, 2003; Wohl *et al.*, in press). Because restoration goals are derived from prevailing societal values, scientists and managers are rarely charged with choosing overarching management goals. Instead, their roles typically include (1) describing past, present, or future ecosystem states, (2) developing prescriptions to guide ecosystems toward preferred states, or (3) articulating the costs and benefits of maintaining ecosystems in selected states (Angermeier, 1997). Decisions for watershed restoration will continue to be made in the face of substantial scientific uncertainty, and there will continue to be a role for "qualitative" scientific judgments in informing restoration actions. Being able to confidently specify the direction of ecosystem response to a restoration action, if not the exact magnitude, is often adequate to inform a management decision. There is a pressing need to employ risk-based analytical tools that allow sound scientific advice to be offered in spite of residual uncertainty. These tools should be decision-oriented and accessibly link modeled components with the amenities (decision endpoints) valued by stakeholders (Table 2.1).

Table 2.1: River restoration scenarios based on five ecosystem amenities that commonly motivate restoration projects. Each amenity is typically limited by a few key conditions. Science-based restoration requires development of various conceptual models that explicate current knowledge of the determinants of key conditions and inform decisions about how to invest restoration resources. Herein, the amenities are ordered by the approximate scientific complexity of their restoration. More complex restoration problems require more types of models and a broader array of scientific expertise. Scientific complexity is probably unrelated to socio-political feasibility. Examples of management actions that might facilitate restoration of the respective amenities are also listed (adapted from Wohl *et al.* (In Press)).

Amenity of Interest	Key Conditions	Components to Model and Assess	Potential Restorative Actions
Clean water	• Water/sediment chemistry • Pathogen density	• Contaminant/pathogen loading • Water/sediment transport	• Clean up point-sources of pollution • Alter land use in watershed
Uncontaminated food	• Body-loads of contaminants	• Contaminant loading • Water/sediment transport • Food-organism/ contaminant contact • Food-organism metabolism of contaminant	• Clean up contaminant sources • Constrain contaminant contact with food-organism
Aesthetic appeal	• Water clarity • Bank stability • Channel shape • Riparian/aquatic vegetation	• Nutrient loading • Water/sediment transport • Suspended solids dynamics • Flow (disturbance) dynamics • Flow/vegetation interactions • Native/ exotic vegetation interactions	• Alter land/water use in watershed • Reinstate natural channel form • Manipulate flow regime • Manipulate sediment composition • Manipulate vegetation composition
Rare or valued biota	• Water/sediment chemistry • Habitat structure • Flow regime • Production dynamics • Other nonhuman biota	• Contaminant loading • Water/sediment transport • Organism/ contaminant contact • Habitat requirements/limitations • Organism/flow interactions • Trophic requirements/limitations • Interactions with competitors, predators, parasites	• Clean up contaminant sources • Alter land/water use in watershed • Reinstate key aspects of natural flow regime • Reinstate natural productivity • Reinstate natural habitat structure • Stock target biota • Reduce biota with adverse effects
Productive fishery	• Water/sediment chemistry • Habitat structure • Flow regime • Production dynamics • Other nonhuman biota • Harvest regime	• Contaminant loading • Water/sediment transport • Organism/contaminant contact • Habitat requirements/limitations • Organism/flow interactions • Trophic requirements/ limitations • Interactions with competitors, predators, parasites • Impacts of harvest	• Clean up contaminant sources • Alter land/water use in watershed • Manipulate flow regime • Manipulate system productivity • Manipulate habitat structure • Stock target biota • Reduce biota with adverse effects • Reduce harvest

2.3 APPROACH/PHILOSOPHY FOR THE ERIA

The scientific literature and numerous case studies indicate that the likelihood of successful watershed restoration is greatly improved by following these ten principles:

1. Address the causes of problems and not just symptoms, i.e., focus on ecosystem processes rather than achieving a particular condition.
2. Recognize many scales and potentially limiting factors. A long-term, large-scale, multidisciplinary perspective is critical.
3. Work with rather than against natural watershed processes and reconnect severed linkages (e.g., channels and floodplains).
4. Clearly define goals and make both sustainability and enhancing ecological integrity explicit goals.
5. Utilize the best available science in predictive assessments that are risk-based and decision-oriented. For inclusive decision-making, predictive assessments should link system manipulations to probable outcomes that are of primary interest to all stakeholders: clean water, productive fisheries, other valued biota, reliable water supply, recreation, and aesthetics.
6. Honestly identify and openly debate key knowledge gaps and uncertainties but adopt an action-oriented principle that ensures that the decision-making exercise will lead to results.
7. Make decisions in a transparent, organized framework that:
   - structures the problem clearly;
   - provides a ranking of the options even though the uncertainties may not be resolved in the foreseeable future;
   - involves affected stakeholders;
   - documents and justifies the decision process to all stakeholders; and
   - provides research priorities by showing whether resolving particular uncertainties would affect the preferred option(s).
8. Watershed restoration projects are as much a social undertaking as an ecological one: understand social systems and values that support and constrain restoration while establishing long-term personal, institutional, and financial commitments.
9. Some strategies will work, some won't, and some will take many years to assess. Be patient and learn through careful long-term monitoring of key ecological processes and biotic elements. Reevaluate and update the restoration strategy.
10. The best strategy is to avoid degradation in the first place. Emphasis should be placed on preventing further degradation rather than on controlling or repairing damage after it begins.

We have adhered to these principles throughout the development of the ERIA. Given the large body of existing information and data available for the Eagle River watershed, an essential first step is to translate fragmented disciplinary information into interdisciplinary understanding of processes. First and foremost, we have sought to identify watershed-scale patterns in major stressors and alterations. Such an effort necessitates investigations of hydrologic processes and instream flows, nutrient loading, metals loading, large-scale habitat loss and fragmentation, potential interactions between water quantity and quality, and future threats to ecological integrity. This approach is substantially different from assessments that generate reach-by-reach snapshots of physical habitat structure to target site-specific tactics. We believe the frequent failure of tactical projects to restore ecosystem amenities and ecological integrity warrants the initial investment in examining these larger questions. Although the recommendations resulting from this effort inevitably fall short of providing comprehensive information on all processes and potential projects, the focus on system-level stressors and integration of existing knowledge is requisite for building comprehensive and sustainable strategies for restoring the integrity of the Eagle River system.

CHAPTER 3

Watershed Overview, History, and Policy

"Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land" – Luna Leopold

3.1 WATERSHED OVERVIEW

The Eagle River watershed drains 944 sq mi of predominantly mountainous forest and rangeland just west of the Continental Divide in northwestern Colorado (Figure 3.1). It is contained almost entirely within the boundaries of Eagle County, with a small portion in the northeastern extremity of Pitkin County. The elevation of the drainage basin ranges from 6,150 ft near the confluence with the Colorado River, to over 14,000 ft at the summit of Mount of the Holy Cross (Figure 3.2).

The elevation difference from the highest regions to the outlet results in significant climate variation across the basin. The upper regions (Gore Creek drainage, Eagle River above Dowd Junction) receive an average of 28 inches of precipitation annually, whereas the lowlands receive 11 to 18 inches. Higher temperatures in the lower watershed areas contribute to higher evapotranspiration losses than in the upper regions. The watershed as a whole receives the majority of its runoff producing precipitation in the form of snowfall, which accumulates to form snowpack in the upper elevations. Detailed descriptions of analyses regarding the climate of the Eagle River watershed are presented in the Meteorological Characterization section of Chapter 4.

Streamflow due to snowmelt typically begins in March and April at lower elevations, peaks in June, and recedes throughout the summer months, resulting in about three-quarters of the 410,000 acre-foot average annual yield from the basin. The remainder of the runoff from the basin typically occurs due to a combination of localized, high-intensity convective thunderstorms from May to September and tributary groundwater that sustains baseflow from August to April.

Several inter-basin water resource infrastructure projects have occurred in the Eagle River watershed, the largest of which, Homestake Reservoir, is owned jointly by the Cities of Aurora and Colorado Springs. Transmountain diversions total nearly 10% of the annual yield from the basin. Analyses of the flow conditions of the Eagle River and its major tributaries, and interpretations of the influences of the major flow diversions in the watershed, are discussed in detail in the Hydrology section of Chapter 4.

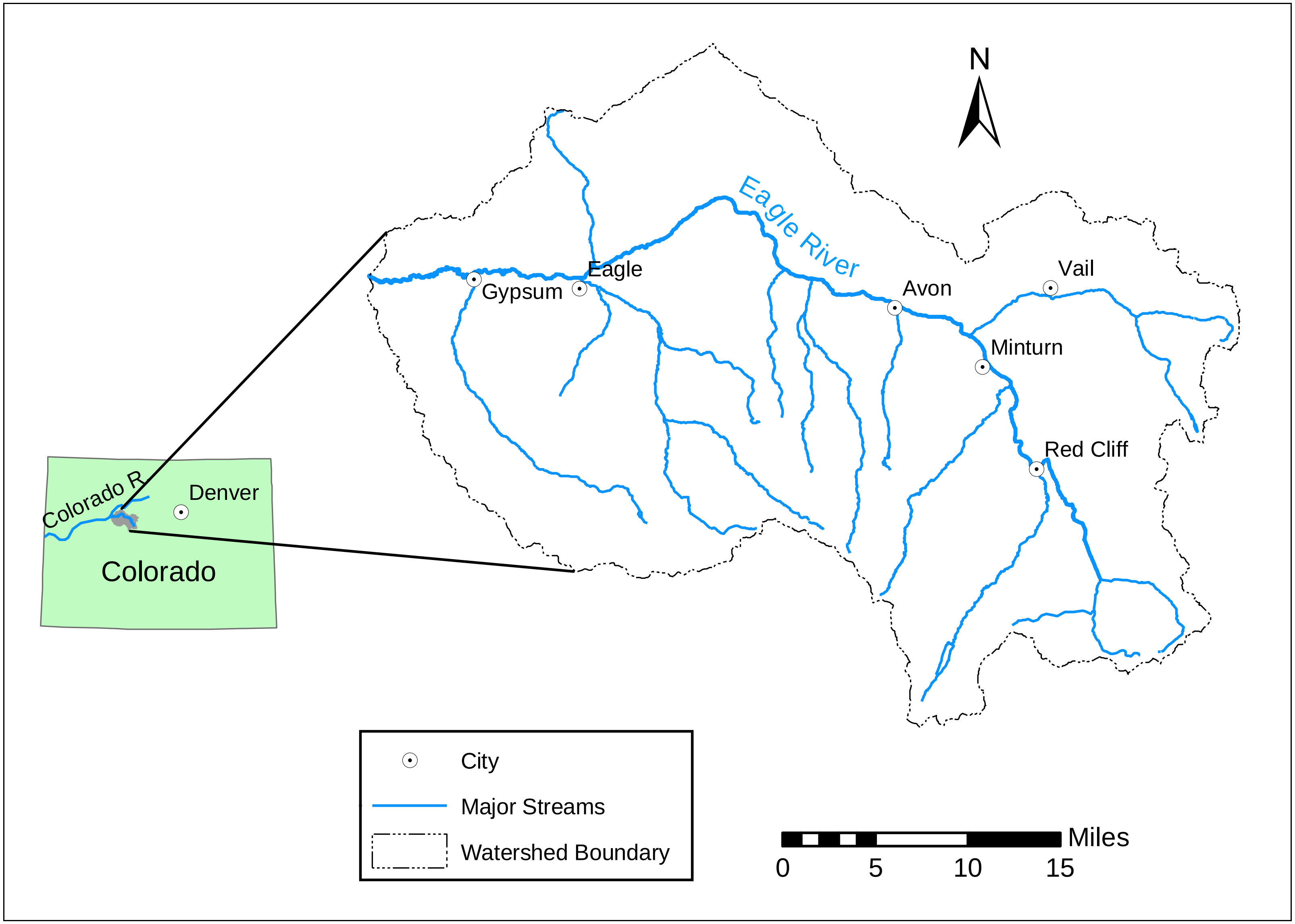


Figure 3.1: Eagle River watershed vicinity map.

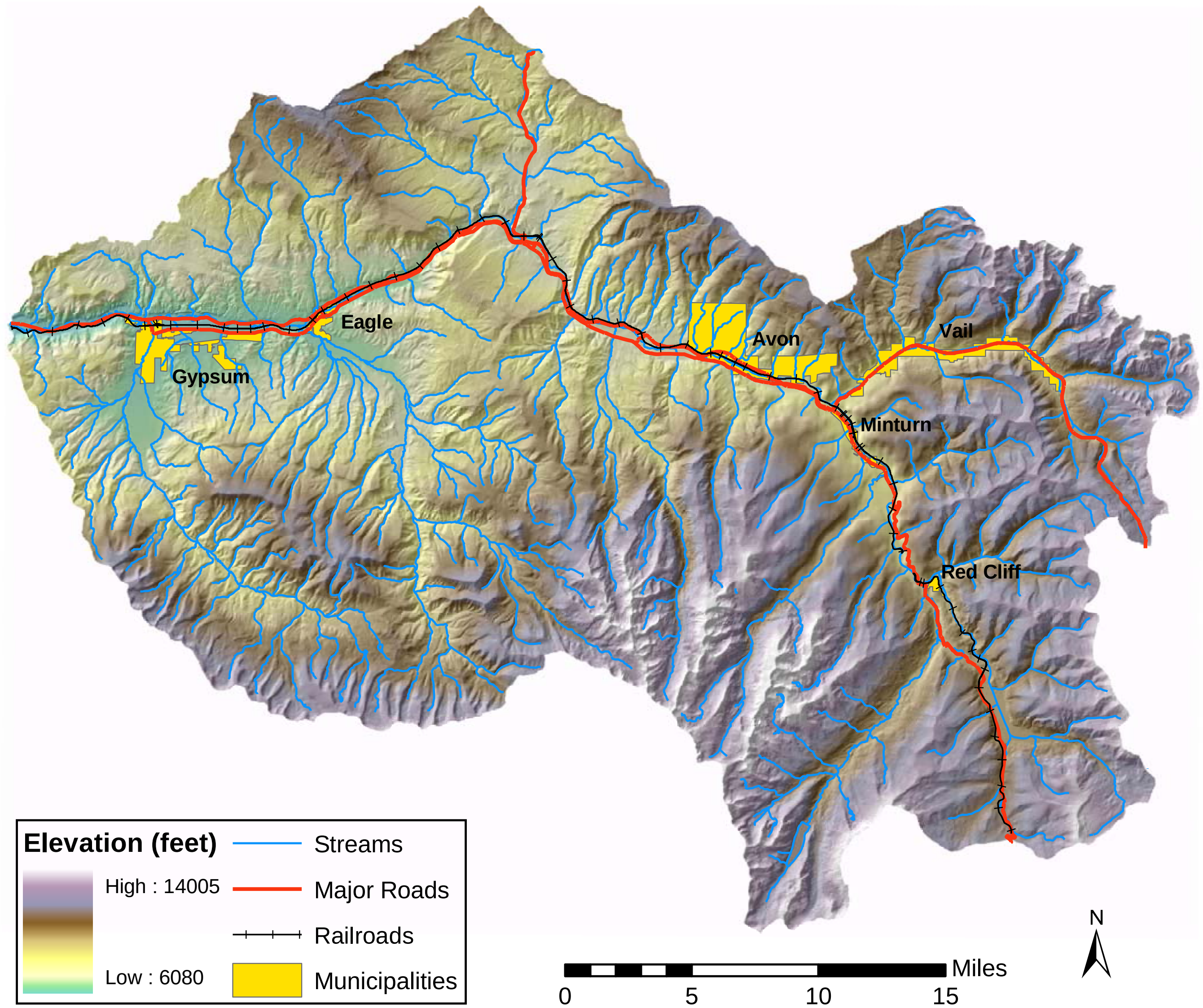


Figure 3.2: Eagle River watershed topography, streams, municipalities, and major transportation corridors.

The ERIA also describes current and historic land uses throughout the watershed. More than 75% of the land within the Eagle River watershed is federally owned and managed, primarily by the U.S. Forest Service. The U.S. Bureau of Land Management oversees the use of nearly 100,000 acres of the watershed, or about one-sixth of the total land area. The primary land use activities within the watershed are recreation, agriculture (including some timber harvesting), mining (largely historic), livestock ranching, and suburban development. The population of the watershed increased at a rate of 5.4% per year from 1990 to 1999 (Colorado Division of Local Government (CDLG), 2003), with the majority of new housing development occurring along the river corridor in the towns of Vail, Avon, Edwards, Eagle and Gypsum. The 2000 U.S. Census indicated that there were 41,569 year-round residents in the watershed, with an additional 9,813 people living there on a part-time basis.

3.2 GEOLOGY

The geologic context of the Eagle River watershed has fundamentally shaped the development of the region and continues to influence both natural processes and human activities. This section provides the reader with a brief overview of the geologic history of the watershed, discusses some aspects of historical significance, and interprets some of the ways that the formations of the Earth's surface continue to be of importance today.

The Eagle River basin is located near the northwestern terminus of the Colorado mineral belt. The Colorado mineral belt is a diagonal swath that contains most of the state's ore deposits, and is defined by centers of mineralization and igneous intrusives that formed during the Late Cretaceous and Tertiary age, about 65 million years ago (Lovering *et al.*, 1978; Bookstrom *et al.*, 1987).

Three major formations dominate the geologic structure of the region: (1) the Homestake shear zone, (2) the Arkansas Valley-San Luis-Rio Grande rift system, and (3) the Sawatch uplift. The Homestake shear zone comprises an approximately 10 km-wide northeast-trending network of folded and faulted rock that cuts across the Precambrian crystalline core of the northern Sawatch range, south of Red Cliff. The shear zone is best exposed on the east side of the range in the deep glacial valley of Homestake Creek that follows the shear zone for some 8 km below Homestake Reservoir (Warren and Pedersen, 2003).

The Arkansas Valley-San Luis-Rio Grande rift system represents a vast portion of southern and central Colorado where tectonic activity pulled the landscape in opposite directions, which allowed for widespread magma intrusions and volcanic activity (Aber, 2004). It is associated with the occurrence of a variety of metal deposits, including the molybdenum extracted at the Climax mine. The rift system developed after the mineralization of the Gilman district ores, and thus played no part in their occurrence. Those ores, which were mined primarily for their silver, copper, lead, gold and zinc content, were mineralized by the flow of metal-laden hydrothermal fluids through the Sawatch uplift (Tschauder *et al.*, 1990).

The Sawatch formation was most recently uplifted during the Laramide orogeny, 65 to 70 million years ago (mya). The eastern edge of the uplift, as it stands today, is contained within the Holy Cross Wilderness. The formation had been previously uplifted during the Early Pennsylvanian orogeny that gave rise to the ancestral Rocky Mountains.

A portion of the sediment from the uplift of the ancestral Rocky Mountains was transported by an ancient form of the Eagle River and deposited into a great sea approximately 300 mya. The sediment eventually formed the oldest sedimentary rocks that are present in the basin, a thick sequence of evaporitic rocks called the Eagle Valley Evaporite (Lidke *et al.*, 2002).

The Eagle Valley Evaporite and the Eagle Valley Formation are common in the lower part of the Eagle River watershed below Wolcott, and to some extent at Edwards (Tweto *et al.*, 1978). The evaporite deposits are comprised of halite, gypsum, and anhydrite, which are relatively soluble in water. As a result, the lower part of the watershed, especially near Wolcott, naturally has greater background levels of sodium and chloride than sites upstream (Tweto *et al.*, 1978). Groundwater flows that percolated through these deposits dissolved an estimated 400 cubic miles (2 trillion yards) of the evaporite, which is about enough material to fill a cube the size of 130 football fields on each side. The removal of the material resulted in deformation and collapse over an area of about 1,000 square miles in the Eagle and Colorado River basins between Vail, Dotsero, and McCoy, Colorado. Much of the evaporite deposit was overlain by basalt flows resulting from volcanic activity about 65 mya during the Miocene epoch, which have since collapsed more than 0.8 vertical miles near the present day Eagle River (Lidke *et al.*, 2002).

Many of the sedimentary rocks that are now present in the Eagle River basin are derived from sediment from the Laramide orogeny, the later mountain-building period that produced the present-day Rocky Mountains. Some visible formations include Leadville limestone, Dakota sandstone (USGS, 1922), and remnants of cretaceous age Pierre Shale of the Niobrara formation, which is often confused with Mancos Shale (Olson *et al.*, 2003). Much of the gold mined in this area was found in the fissures of the Leadville limestone, which is honeycombed with the tunnels of prospectors.

The presence of the Pierre shale stratum is of particular significance in this watershed for two reasons. The first is that it is highly erodible, and unless capped by more resistant strata, it is easily washed away by weathering and streamflow. As the Eagle River cuts down through the Dakota sandstone into the Pierre shale near the Town of Edwards, the valley opens dramatically, historically providing soil for ranching (USGS, 1922) and, more recently, widespread suburban development. The second notable characteristic is that soil parent material comprised of Pierre shale yields rather poor erosive soil, sometimes supporting only sparse vegetation. In particular, three sub-basins of the Eagle River watershed, Milk Creek, Alkali Creek, and Ute Creek, drain landscapes comprised primarily of soils derived from Pierre shale. These creeks contribute large amounts of fine sediment to the main stem of the Eagle River, thereby impacting fish populations downstream from Wolcott.

Dramatic landscapes have formed in the Eagle River watershed due to the periods of uplift, erosion, deposition, and glaciation. The uplift created the high relief of the mountain areas. The erosion of the mountains by flowing water resulted in scenic narrow canyons, rimmed by ancient rocky precipices that formed from deposited sediment. The broad valleys of Homestake Creek, the Eagle River through Camp Hale, and Cross Creek are all spectacular examples of glacial activity on the landscape. Glaciation is also responsible in part for many of the striking peaks and ridgelines of the Gore Range and Holy Cross Mountains.

The geologic foundation of a watershed dictates the ways the landscape will evolve over time. The resistance of the landscape to erosion by flowing water is variable across the Eagle River watershed, depending on the nature of the rock types that are present. Massive igneous rocks such as granite are more resistant to erosion than sedimentary formations. As a result, stream channels that incise through resistant rock masses form steep-walled valleys, which are present in some areas of the Eagle River watershed that have not been eroded by glaciers, which cause wide, U-shaped valleys. Channel incision through weaker sedimentary deposits results in more gradually sloping valley sides. A more detailed investigation of the geomorphology resulting from these processes in the Eagle River watershed is included in Section 4.7 of the ERIA.

3.3 LITERATURE REVIEW

There are numerous reports pertaining to water-quality assessment, water quantity, ecological restoration, and other issues in the Eagle River watershed. Following is a brief review of previous reports given particular attention during the course of this study.

3.3.1 *Eagle River Watershed Plan* (1996)

This report provided a detailed overview of water quantity, water quality, wildlife, recreation, and land use. A collaborative, local philosophy for protection and improvement of water quantity and quality, wildlife habitat, and recreational opportunities was outlined. Further, it promoted compatible land-use practice, while offering possible actions for protection or restoration of open space and sensitive areas. The report cited additional studies specific to the Eagle River watershed and defined actions that can be taken to ensure that the attributes of the watershed are protected and enhanced. These recommended actions were:

Implementation

- Establish an Eagle River Watershed committee
- Generate and provide information/education
- Develop a prioritized action plan and annual work programs

Water Quantity

- Determine optimal instream flows
- Determine water supply thresholds
- Utilize the Colorado River decision support system
- Obtain water plan review assistance
- Review/develop master plan policies specific to water issues of supply, demand, and capacity
- Adopt a local position on augmentation plans
- Encourage consolidation of special districts
- Work with Front Range communities
- Implement water conservation measures
- Investigate growth management tools
- Investigate storage and engineering solutions

Water Quality

- Inventory and coordinate water quality monitoring efforts
- Apply for water quality program funding
- Determine local water quality plan needs and draft a model plan
- Develop public information program about local water quality
- Develop wellhead protection programs to protect drinking water
- Implement appropriate best management practices

Wildlife

- Implement measures to protect and improve water quantity and quality
- Implement habitat improvement projects
- Support efforts to prevent spread of infectious disease to local fish populations
- Review/revise fishing bag limits and regulations
- Review/revise drainage and transportation regulations
- Inventory riparian zones and habitat boundaries
- Acquire riparian lands
- Implement stream buffer standards
- Preserve wildlife corridors to riparian areas
- Develop or improve appropriate access
- Request mitigation trust funds
- Manage noxious weeds in riparian areas
- Manage livestock in riparian areas
- Restrict access into and monitor and provide buffer zones for critical wildlife areas
- Designate watchable wildlife sites

Recreation

- Cooperatively initiate recreation carrying capacity study
- Cooperatively study fishery conditions
- Develop recreational maps for public

- Review/revise fishing and boating regulations
- Improve existing public access points
- Create appropriate, new public access points
- Implement river access improvement guidelines
- Preserve or create access through land development where appropriate

Land Use
- Create comprehensive watershed maps
- Develop master plans for each of the tributary valleys
- Implement a cooperative enforcement program of existing regulations
- Revise river/creek setbacks for consistency and sensitive lands protection
- Locate compatible land uses adjacent to rivers and streams
- Develop river/creekfront design standards
- Analyze ability to supply adequate water
- Analyze golf course and ski area proposals
- Develop a model sensitive lands overlay zone
- Review related regulations (floodplain, wetland, drainage) for effectiveness and possible revision
- Improve local authority on 35 acre exemptions
- Protect riparian lands as highest open space priority
- Jointly pursue open space funds
- Guarantee open space as perpetual
- Maintain public lands as open space
- Develop parks, trails and access sites adjacent to waterways where appropriate
- Support local ranching activities

3.3.2 Northwest Colorado Council of Governments (NWCCOG) 208 Plan Update (2002)

The NWCCOG is working with the Eagle River Watershed Council to establish a local long-term water quality and quantity forum. This report documents Eagle River watershed water quality assessment, water quality issues, watershed improvement projects, land-use regulations applicable to water-quality protection and improvement, wasteload allocations, water quality monitoring needs, water-quality standards and recommendations. Recommended actions were:

Point Source Water-quality Recommendations
- The district consolidation accomplished by the Eagle River Water and Sanitation District is strongly supported by the NWCCOG, and should be used as a model for the development of regional sanitation districts whenever feasible.
- Red Cliff wastewater treatment facilities must be improved to meet wastewater treatment standards.
- Ammonia wasteload allocations need to be carefully monitored with respect to potentially decreasing low stream flows (1E3 and 30E3 conditions).
- As future water and wastewater treatment plant expansions are considered, it is critical that the districts consider the effects of increased diversion on instream flows. Reuse of wastewater should be examined as one method of reducing instream flow diversions. Another consideration should be the location of diversion and return flow structures, which should be located in close proximity to each other.
- The need for a wastewater treatment facility in the Wolcott area is currently being explored by the Eagle River Water and Sanitation District.

Nonpoint Source Water-quality Recommendations
- Policy 1: Water Quality; Policy 2: Water Use and Development; Policy 3: Land Use and Development; Policy 4: Domestic Municipal, and Industrial Wastes; Policy 5: Chemical

Management; in Volume I should be implemented by the appropriate management agencies in the Eagle River watershed to address nonpoint source issues

- Urban runoff and construction activities in Gore Creek and the upper Eagle Valley will continue the need for control of these sources of water degradation as identified in Policy 3 - Land Use and Disturbance - Implementation Recommendations.
- Water augmentation plans for proposals within the basin should be encouraged to provide augmentation water from within the basin and above the point of diversion.
- Municipal, County, and other agency nonpoint source water-quality improvement projects should continue to be supported by local, state, and federal funding.

Watershed Improvement Projects – Future Project Needs

- The establishment of a watershed water quality group, as discussed in the Eagle River Watershed Plan. Other potential projects include further work on Milk and Alkali Creeks, and public education on nonpoint source water-quality impacts and minimization practices.
- Continuation of the USGS Retrospective Analysis.
- Erosion and sediment control (both from construction sites and from I-70, specifically in the Black Gore Creek drainage); instream flow augmentation in the Eagle River.
- Ground-water sensitivity mapping exercise to be used in determining potential for ground-water aquifer contamination.
- Riparian and instream habitat improvement in the Upper Eagle River watershed area.
- Further studies regarding nutrient enrichment of the mainstem of the Eagle River.
- Possible means to improve the dissolved oxygen/temperature issue in the Edwards to Gypsum area.
- GIS project for determining priority ranking for clean-up of abandoned mine tailings and failing mine tailings cribbing.
- Minimum stream flow monitoring and active exercise of the CWCB instream flow rights.

Water-quality Monitoring Needs

- This plan recommends that a committee be established to examine existing monitoring programs, compile, and analyze existing data, provide for monitoring program development and execution, and public information dissemination.
- Specific areas of the Eagle River watershed that warrant continued monitoring include: Gore Creek, where entities in the drainage have expressed interest in establishing a database and acquiring additional information on the state of the creek; the lower Eagle River where fish kills have historically occurred; the Eagle Mine site; potential water quality changes due to increased density of homes on septic systems; stormwater impacts from urbanized areas, and Milk, Alkali, and Ute Creeks for additional nonpoint source sediment control projects.
- Additional physical and biological data are needed to determine the status of Black Gore Creek (Black Gore Creek was subsequently listed on the state's 303(d) list) as to whether it meets the State's guidance as a stream impacted by sediment.
- Milk, Ute, and Alkali Creeks should be added to the state's Monitoring and Evaluation List to determine if these segments are affecting aquatic life as a result of sediment inflow.
- Additional information is needed regarding subsurface hydrology in the Eagle River watershed. Characterization of environmentally sensitive areas for additional management of septic systems and other potential sources of ground-water impacts would provide additional information for appropriate regulation of sources.

Water-quality Standards Recommendations

- The NWCCOG does not currently recommend any additional waterbodies to the list of "Outstanding Waters" designation. If new wilderness areas within the watershed are approved by Congress, NWCCOG recommends investigations of waterbodies within those areas for appropriateness of "outstanding waters" designation.

3.3.3 2002 NWCCOG Regional Water Quality Management Plan: Volume I – Policy Plan & Volume II – Water Quality Program Development

The NWCCOG is the designated regional water-quality management agency responsible for water-quality planning within the Eagle, Grand, Jackson, Pitkin, and Summit Counties' region. The *Guidelines for Water Quality Planning in Colorado* require annual updates of the Areawide Water Quality Management Plans under Section 208 of the Clean Water Act. The purpose of the 2002 208 Plan revision is to satisfy the requirement for an update of the Plan to reflect the progress in plan implementation. Additionally, the Plan is to address the current focus on water-quality planning from a watershed perspective. The 2002 208 Plan revision is structured to satisfy the requirements established under the applicable State guidelines and to satisfy local planning requirements, which dictate a flexible and innovative approach to water-quality planning to avoid future water-quality problems. The 2002 208 Plan is compiled in a two-volume set of technical appendices. *Volume I* is presented in a policy plan format and describes the program recommendations to protect and enhance the level of water quality consistent with the requirements of the Federal Clean Water Act. It is intended to provide the direction for water-quality decisions resulting from activities which have the potential to generate both point and nonpoint sources of water quality degradation in the region. Focus is on six policies, which will lead to maintaining and improving water quality. *Volume II* describes the water-quality program development in a format similar to the specific items contained in Colorado's planning guidelines. It draws on material contained in previous 208 Plan submittals and from technical appendix information. It also provides supporting information for the development and adoption of water-quality management policies currently in practice in Region XII.

3.3.4 Eagle County, Master Plan Update Research Summary, Part II: Environmental Trends & Characteristics – September 2003 (ECCD, 2003)

This Plan was developed to guide growth and development in Eagle County for individuals and developers. It provides a basis for reviewing development proposals and potential capital improvements. Part II of the 2003 Plan provides an overview of wildlife, water quality and quantity, air quality, natural hazards, built environment, and services. A summary of selected issues raised at community meetings, town council work sessions, and field study tours is as follows: protect water quality for fish, other wildlife, and existing domestic uses; protect river ecosystems; river use and management is key to river health; the county should help ensure that all segments of the rivers have funding for instream flows; the county should adopt their own level of water quality, which would have more strength than the states water-quality levels; maintain quality of environmental assets.

3.3.5 Water-Quality and Biological Community Characterization at Selected Sites on the Eagle River, Colorado, September 1997 and February 1998 (Deacon and Spahr, 1998)

The USGS, in cooperation with CDPHE, established five sites in 1997 on the Eagle River to characterize baseline water quality and stream biota. Water-quality and stream-biota data were collected during two low-flow periods along the Eagle River. This study was based on a limited data set from only two sampling periods. The objectives of this study were to (1) characterize the current water quality and biological community at selected sites in the Eagle River; (2) assess relations among nutrient concentrations and stream biota at selected sites; (3) describe changes in the algal community over time at one site; and (4) assess differences in summer low-flow conditions and peak winter recreational-use low-flow conditions. This report presented results of field measurements, and chemical (major ions and nutrients) and biological (benthic algae and macroinvertebrates) sampling during summer 1997 and winter 1998 low-flow conditions.

3.3.6 Low-flow Water-Quality Characterization of the Gore Creek Watershed, Upper Colorado River Basin, Colorado, August 1996 (Wynn and Spahr, 1998)

The Upper Colorado River Basin was selected as a National Water-Quality Assessment (NAWQA) site to evaluate water quality resulting from urban development and recreational land use. A major local concern was how increasing urbanization/ recreation affects the water quality, Gold-Medal trout fishery, and aesthetic values of Gore Creek. Evaluation of spatial characteristics of water quality can provide local water and land managers with information to establish water policy and make land-use planning decisions to maintain or improve water quality. Synoptic sampling was needed to determine the distribution and sources of water-quality constituents at one point in time. This study presented hydrologic background information and an analysis of general water-quality properties and constituents, trace elements, and nutrients collected in water samples during low-flow synoptic sampling of the Gore Creek watershed.

3.3.7 Fish-community Assessment in Gore Creek, Colorado, 1998 (Wynn, 1999)

Gore Creek drains an area south of the Gore Range through the Town of Vail, and joins the Eagle River near Minturn. In cooperation with many agencies, the goal of this monitoring effort was to provide information for the management and protection of water quality and aquatic life in the watershed. A concern was that runoff from urban land uses may affect water quality or stream biology. Results indicated that fish productivity is higher downstream of the Town of Vail and its wastewater treatment facility, but fish diversity is higher upstream of Vail. This effort provided a better understanding of water quality and stream biology and their relation to land uses and natural factors.

3.3.8 Water Quality in the Upper Colorado River Basin, Colorado, 1996-98 (Spahr *et al.*, 2000)

As a result of a USGS NAWQA Program, major findings were reported about water quality in the Upper Colorado River Basin. Water quality was discussed in terms of local and regional issues and compared to the study areas assessed to date. Findings were also assessed in the context of selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms. The comparisons in this report to drinking-water standards and guidelines are only in the context of the available untreated resource. Finally, information about the status of aquatic communities and the condition of instream habitats as elements of a complete water-quality assessment was included in this report.

3.3.9 Gore Creek Watershed, Colorado – Assessment of Historical and Current Water Quantity, Water Quality, and Aquatic Ecology, 1968-98 (Wynn *et al.*, 2001)

As part of this study, the historical and current water-quantity, water-quality, and aquatic-ecology conditions in the Gore Creek watershed were described by the USGS, in cooperation with other agencies. Interpretation of the available water-quality, water-quantity, and aquatic ecology data collected by various agencies since 1968 showed that background geology and land use in the watershed influenced the water quality and stream biota.

3.3.10 Nutrient Criteria Technical Guidance Manual: Rivers and Streams (USEPA, 2000a)

This manual is one in a series of waterbody-specific documents that support the President's Clean Water Action Plan and the National Nutrient Strategy. This document is intended to provide States and Tribes with methods to assess waterbody nutrient impairment and develop ecoregion-specific nutrient criteria. It also provides background information on classification of rivers and streams, selection of criteria variables, design of monitoring programs, building of databases analyzing nutrient and algal data, derivation of regional criteria, and implementation of management practices. Three main components comprise water-quality standards: criteria (scientifically based); designated uses (involving economic, social, and political considerations); and an anti-degradation policy (protecting the level of water quality necessary to maintain existing uses). Alterations in vegetation, sediment balance, or fertilizer use from industrialization, urbanization, or conversion of forests and grasslands to agriculture and silviculture can affect watershed water quality. Cultural eutrophication is one of the primary factors resulting in impairment of U.S. surface waters.

3.3.11 Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Rivers and Streams in Nutrient Ecoregion II (USEPA, 2000a)

In June 1998, the USEPA developed the National Strategy for the Development of Regional Nutrient Criteria. The strategy presents USEPA's intentions to develop technical guidance manuals for four types of waters; namely, lakes and reservoirs, rivers and streams, estuaries and coastal waters, and wetlands. Additionally, the Agency formed Regional Technical Assistance Groups (RTAGs) which include State and Tribal representatives working to develop more refined and more localized nutrient criteria based on approaches described in the waterbody guidance manuals. The distributions of nutrient concentrations in hundreds of streams including the Eagle River in the Southern Rockies Ecoregion are provided in this document. This report also presents the USEPA's current recommended criteria for total phosphorus, total nitrogen, chlorophyll *a*, and turbidity for rivers and streams in Nutrient Ecoregion II (Western Forested Mountains). The USEPA's ecoregional nutrient criteria are intended to address cultural eutrophication – the adverse effects of excess nutrient inputs. The criteria are empirically derived to represent conditions of surface waters that are minimally impacted by human activities and protective of aquatic life and recreational uses.

3.3.12 Data Evaluation Report, Belden Area, Eagle Mine Site, Minturn, Colorado (Dames & Moore, 1997)

This report provides an evaluation of the effects of waste rock piles on water quality in the Belden area at the Eagle Mine site. Data were collected during two full seasons of surface and ground-water monitoring. This three-task study included storm event/snowmelt surface water monitoring to assess the effects of runoff from waste rock piles in the vicinity of Belden and Rock Creek on Eagle River water quality. The second task involved monitoring wells placed in Belden and waste rock piles to estimate metals loading to the Eagle River via ground-water seepage above Belden. The final task was to test Gilman/Belden area waste rock piles to assess the potential of these piles to contribute metals loading to the Eagle River.

3.3.13 Eagle Mine Annual Report – 2002 (NewFields, 2003) and 2003 (NewFields, 2004), Eagle Mine Site, Minturn, Colorado

This annual report provides a summary of environmental data collected during the 2002 calendar year and previous years at the Eagle Mine site. This report also summarized site-related design, construction, inspection, operation and maintenance, and community relation activities conducted in 2002. Surface water monitoring, Eagle Mine water monitoring, ground-water monitoring, revegetation, and CTP surface settlement and erosion monitoring were detailed in this report.

3.3.14 Annual Biological Monitoring of the Eagle Mine Superfund Site Eagle County, Colorado in 2003 (Woodling and Rollings, 2004)

The Colorado Division of Wildlife (CDOW), in cooperation with other agencies, annually monitors the fish and macroinvertebrates of the Eagle River upstream, downstream, and through the Eagle Mine site. The objective of this annual monitoring program is to determine if remedial actions at the mine are improving the Eagle River aquatic ecosystem through and downstream of this series of contaminant sources. The initial sampling protocol was designed to monitor change in the types and numbers of fish and macroinvertebrates attributable to water quality and habitat improvements in the Eagle River from Red Cliff to the Arrowhead Golf Course downstream of Avon, Colorado.

3.3.15 USEPA Superfund Record of Decision, Eagle Mine: EPA/ROD/ R08-93/068 (USEPA, 1993) and EPA/ROD/R08-98/079 (USEPA, 1998)

These documents present selected remedial actions for the Eagle Mine Site, Operable Units 1 (OU-1) and 2 (OU-2), located in Eagle County, Colorado. These documents explain the basis and purpose of the selected remedy for the Site and the final Record of Decision (ROD) for Eagle Mine OU2. The 1998 ROD states that: (1) The State of Colorado, represented by the Colorado Department of Public Health and the Environment, concurs with the selected remedy; (2) The selected remedy is protective of human health and the environment, complies with Federal and State requirements that are legally applicable or relevant and appropriate to the remedial action, and is cost-effective; (3) The remedy utilizes permanent solutions and alternative treatment (or resource recovery) technologies to the maximum extent practicable and satisfies the statutory preference for remedies that employ treatment that reduces toxicity, mobility, or volume as a principal element; and (4) Because this remedy will result in hazardous substances remaining onsite above health-based levels, a review will be conducted within five years after commencement of the remedy to ensure that the remedy continues to provide adequate protection of human health and the environment.

3.3.16 Five-year Review Report for Eagle Mine Superfund Site, Eagle County, Colorado (USEPA, 2000c)

A "five-year review" by the USEPA at all Superfund sites where "remedial actions have resulted in any hazardous substances, pollutants, or contaminants remaining at the site above levels that allow for unlimited use and unrestricted exposure" is required by Federal statute. Although controlled, wastes above these levels do remain at the Eagle Mine Superfund site. The review of the first five years was conducted in cooperation with the CDPHE for this site and is documented in this report. Attached to this USEPA review is a document prepared by Dames & Moore entitled "Five Year Review Report – Eagle Mine Site – Minturn, Colorado."

3.3.17 Biological Survey of Eagle County, Colorado, 2000 Final Report (Fayette *et al.*, 2000)

Eagle County, in northwestern Colorado, is marked by high montane habitats. The Colorado Natural Heritage Program (CNHP) was contracted by several agencies to inventory Eagle County for areas of special biological significance. The primary goal of the project was to identify Eagle County locations that have natural heritage significance. These locations were identified by: (1) examining existing biological data from the CNHP's database, (2) accumulating additional existing information on rare or imperiled plant species, animal species, and significant plant communities, and (3) conducting extensive field surveys. Areas that were found to contain significant elements were delineated as "proposed conservation areas." This report documents areas that were prioritized on the basis of their biological importance.

3.3.18 Biological Survey of Eagle County Colorado: Conservation Plan and Implementation Strategies (Armstrong, 2000)

This plan is a companion document to the CNHP 2000 *Biological Survey of Eagle County, Colorado* inventory report. It was a culmination of a community-based process, designed to help interpret and guide the use of the information assembled in the inventory document, and to help integrate the results of other planning efforts. It should be regarded as a reference document as a guide to conservation action in Eagle County. This plan was intended to help the Eagle Valley Land Trust and the local community interpret and utilize the information documented in the above-mentioned inventory report and to provide a foundation for long-term, community-based conservation action in Eagle County. The four-fold goals of the plan were to assist in the interpretation and use of Heritage data within the context of local planning processes; develop and present a county-wide planning context reference; guide the development of conservation strategies; and explore and develop methods for implementation of conservation action.

3.3.19 Conservation Agreement and Strategy for Colorado River Cutthroat Trout (*Oncorhynchus clarki pleuriticus*) in the States of Colorado, Utah, and Wyoming (CRCT Task Force, 2001)

This Agreement was developed to expedite implementation of conservation measures for Colorado River cutthroat trout (CRCT) in Colorado, Utah, and Wyoming as a collaborative and cooperative effort among resource agencies. The objective of the Conservation Strategy for CRCT is to maintain and restore 383 conservation populations in 1754 stream miles and 18 populations in 652 lake acres in 14 management units within the historic range. The Conservation Strategy includes three primary activities. These are to: (1) protect existing and restored ecosystems; (2) restore degraded ecosystems; and (3) coordinate and plan. Strategies within each activity are outlined in Section 4.9.

3.3.20 Evaluation of Instream Flow Methods and Determination of Water Quantity Needs for Streams in the State of Colorado (Nehring, 1979)

In earlier years, the U.S. Fish and Wildlife Service has performed intensive work in the field of instream flow assessment. Nehring (1979) reports on the Instream Flow Service Group sponsored program for evaluation of selected instream flow methodologies, which included specified methodologies to be used, criteria for selecting streams and reaches to be studies, and a schedule of tasks to be accomplished.

3.3.21 Development of Instream Flow Recommendations in Colorado Using R2CROSS (Espegren, 1996)

R2CROSS is a technique employed by State and Federal agencies to model instream hydraulic parameters thus ensuring that instream flow recommendations reflect the amount of water required to “preserve the natural environment to a reasonable degree” as prescribed by Colorado law. R2CROSS is utilized because it is time- and labor-efficient and can produce results comparable to more costly techniques. This report documents an overview of Colorado’s Instream Flow Program and the R2CROSS spreadsheet program.

3.4 HISTORICAL BACKGROUND

The following section of the ERIA presents an overview of selected historical aspects of the Eagle River watershed that are relevant to existing human influences and ecological conditions. Additional historical information is provided in pertinent sections of the ERIA.

3.4.1 Early Days

Prior to the establishment of mining communities in the late 19th Century, the lands of the Eagle River watershed were summer hunting and fishing grounds for the Ute Indians. Several claims have been made as to the first European exploration of the area. The first documented report occurred in 1845 when Kit Carson led the Fremont party down the Eagle River, then known as the Piney River. The presence of other explorers prior to the Fremont expedition is suggested in a journal entry of John C. Fremont, in his mention of a "William's Fishery" near present-day Edwards and the description of a mysterious "buffalo fish" with a hump on the back of his head. It is likely this fish was either the now endangered humpback chub (*Gila cypha*) or razorback sucker (*Xyrauchen texanus*; Figure 3.3). By 1859, gold had been discovered in Colorado, and prospectors set out on expeditions through the Rocky Mountains in search of major ore deposits (Knight and Hammock, 1965). Although the western half of Colorado had been set aside as a Ute Indian Reservation by the 1870s, the discovery of precious minerals and metals led to revocation of treaties, and relocation of the remaining Ute population to southwestern Colorado and northeastern Utah (Eagle County Planning Commission and Eagle County Planning Division (ECPC & ECPD), 2003).

Figure 3.3: The Federally endangered razorback sucker is native to the Colorado River Basin (photograph courtesy of the CDOW). A fish similar in appearance was observed near Edwards in 1845.

3.4.2 Mining

Shortly after the Leadville strike in 1874, James Denney noted the similarity in the rock formations of Battle Mountain to those in Leadville. In late fall of 1878, a group of men to whom Denney had revealed this valuable information soon discovered the mining significance of Battle Mountain. By April 1879, the first permanent mining camp was established at the foot of Battle Mountain near the confluence of Turkey Creek with the Eagle River, the present day site of the Town of Red Cliff. In the early 1880s, the rush for riches formed mining camps throughout the region, from Tennessee Pass to Brush Creek (Knight and Hammock, 1965). The mined material had to be hauled across the mountains to Leadville for processing to determine the value of the discovered material. A local smelter was essential to profitable mining and by late 1880 the

Belden Mining Company completed the first local smelter in lower Red Cliff near the Beck residence (Knight and Hammock, 1965).

At the time, gold was the primary economic driver of the region and the reason for the original development (Warren and Pedersen, 2003). The mines of Battle Mountain, later named the Gilman mines, produced ore with significant quantities of silver, gold, lead and some copper. Toward the summit of Tennessee pass, Taylor City was successful in the production of gold-silver-iron carbonates. Ores extracted from the surface layers of the mines in Holy Cross and Gold Park contained high values of gold. The Fulford District, located in the southern central portion of the Eagle River watershed, was also a primary producer of gold. By 1883, the mines of Eagle country had produced over 20,000 tons of ore at a total value of more than one million dollars (Knight and Hammock, 1965) (Figure 3.4).

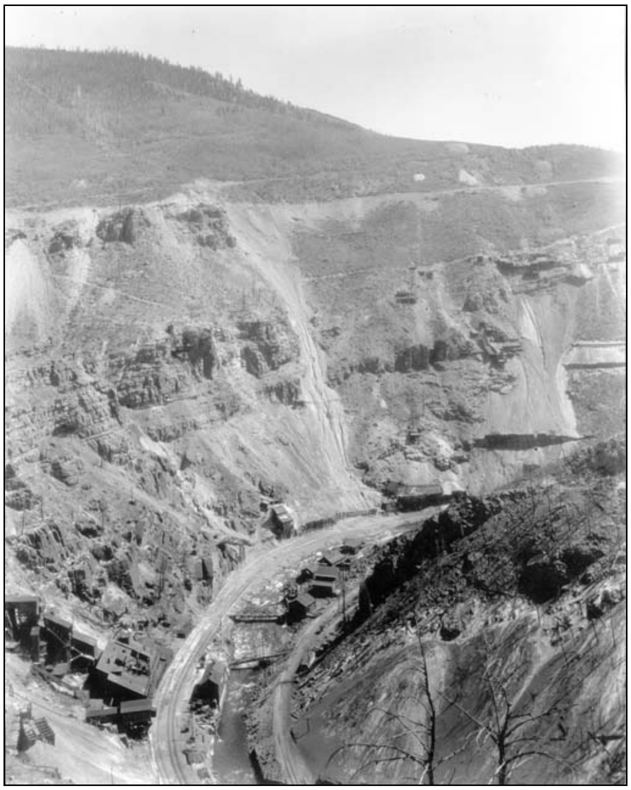


Figure 3.4: Eagle River Canyon at Belden, tracks of the Denver and Rio Grande railroad between 1910 and 1930 (photograph courtesy of the Denver Public Library).

Between the years of 1870 and 1900, the total production of all districts amounted to over 7.5 million dollars (Knight and Hammock, 1965). Despite the figures, the enormous effort expended in the hunt for riches left the majority of prospectors in the Eagle Valley disappointed. The mining boom within the Eagle River watershed did not compare to the bonanzas of other regions of the Rocky Mountains. By 1925, most of the oxidized ores in the Eagle River Valley were exhausted and the mines abandoned (Warren and Pedersen, 2003).

Sulfide ores, still plentiful in the region, were much more difficult to treat and process than the oxidized ores due to the high quantities of zinc and sulfur. The New Jersey Zinc Company, however, had great expertise in the production of zinc, and identified the value of the Eagle mine in continued metal production. Originally known as the Battle Mountain district, the Gilman district became a key player in the economy and workforce of the Eagle Valley. By 1915, New Jersey Zinc Company had acquired the Eagle mine and soon after the Town of Gilman, transforming it into a company town (Warren and Pedersen, 2003). Nearby, Belden was used a shipping hub for the metals. The original treatment of the ore included a roaster and magnetic separation process (Naugle *et al.*, 2003), known as roasting. The process was ineffective, leaving high concentration of leachable metals in the roaster wastes, which were deposited by tramway on the steep canyon slopes and banks of the Eagle River (Figure 3.5; Naugle *et al.*, 2003). An underground flotation mill was constructed by 1929 for the processing of sulfur ores from the Eagle mine. Throughout the life of the Eagle mine, this mill remained the largest underground mill in the world, producing a lead concentrate, a zinc concentrate, and pyritic tailings (Warren and Pederson, 2003). Between 1932 and 1941, the mill was solely used for the production of copper silver ores, and the mining of zinc ores resumed in 1941. The mining of zinc ores was discontinued in 1978, but the mining of copper silver ores continued until 1984. The average assay of the ores included 8.5% zinc, 1.5% lead, 0.9% copper, 228 parts per million (ppm) silver and 1.7 ppm gold.

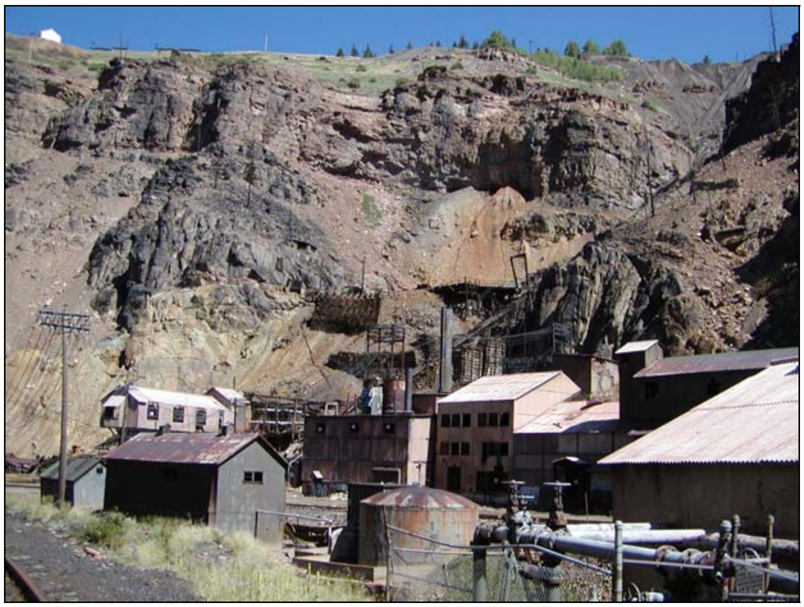


Figure 3.5: Belden tramway area.

Prior to the mid 1940s, the mill tailings were depositing in a site known as the "Old Tailings Pile." After the Old Tailings Pile reached capacity, the tailings were deposited across the Eagle River in the Rex Flats area and further downstream in the Maloit Park area, near the confluence of Cross Creek and the Eagle River. The new tailings pile in the Maloit Park area consisted of a 15-acre water retention pond, the "historic pond," which later became a major source of metals contamination (Naugle *et al.*, 2003).

After the Eagle Mine closed in June of 1984, it was declared a USEPA Superfund site. Large quantities of scattered wastes were hauled to the existing tailings pile location, forming the Consolidated Tailings Pile (CTP) (USEPA, 2000c). The CTP was then capped with a protective clay cover to avoid further highly metallic runoff during rainfall and snowmelt events. The Eagle Mine was plugged, causing hydrostatic pressure to build. As the water level in the mine pool rose, it reached an elevation where it intersected the contact between two geologic units, and the contact was highly fractured. Warren and Pedersen (2003) claimed that the seepage killed fish for 30 miles downstream. Remediation actions required by the USEPA and the State of Colorado have included the installation of a treatment plant at the CTP, pumping and treatment of contaminated water, diversion of uncontaminated water around mine wastes, rehabilitation of contaminated sites, and compliance with biological based water quality standards (USEPA, 2000c). The Superfund cleanup has eliminated several major sources of metals loading to the Eagle River. However, metal loads from the Eagle Mine and other historically mined areas continue to affect water quality within the Eagle River watershed.

Regional mining still occurs today. The American Gypsum Plant in the Town of Gypsum produced over 408,000 metric tons of gypsum in 1999. The plant completed a 2-year expansion in 1999 to increase the annual production capacity to 500,000 metric tons (USGS, 1999). Gypsum is used in the manufacture of wallboard products. Gravel mining is also an active industry in the area, especially within the floodplain of the Eagle River in Edwards and Gypsum. In general, gravel mining within the floodplain often results in the removal of riparian vegetation and alteration of riparian functions (Starnes and Gasper, 2004).

3.4.3 Ranching

Ranching boomed in the early years of Eagle River settlement. Many settlers preferred ranching for its economic stability over the often disheartening and inconsistent outcomes inherent in hard-rock mining. The rise of ranching and farming communities in the region occurred in the 1880s. It consisted of cattle grazing and irrigated hay fields along the river. Soon after cattle ranching began, large herds of sheep were brought into the Eagle Valley. A range war erupted between the cattle ranchers and the shepherds, in which thousands of sheep and some shepherds were killed (ECPC & ECPD, 2003).

The arid climate of Colorado necessarily led ranchers to the practice of irrigation. These settlers, along with miners and water developers quickly recognized the value of Eagle River water. Local transmountain diversion structures date back as far as 1880, with the construction of the Ewing Ditch, the first transmountain diversion in Colorado. This ditch was initially used for placer mining in the Arkansas Basin (Grigg, 2003) and later used for irrigation purposes.

Wolcott was of great importance during the late 1800s due to its central location. The town was a shipping station for cattle from northwestern Colorado. After the completion of a wagon road to Steamboat Springs in 1886 and the advent of the railroad the following year, Wolcott became one of the largest delivery stages on the Western Slope. Livery barns and stockyards were built. Due to the prosperity and location of Wolcott, ranching and livestock provided a reliable income for others in the Eagle River Valley.

The construction of the Moffat Railroad diminished Wolcott's importance as a central shipping point. The railroad industry constructed a rail route over 27 miles of rough terrain across the Continental Divide at Corona Pass (also known as Rollins Pass), eventually reaching Steamboat Springs by late 1908 (Knight and Hammock, 1965).

The onset of World War I increased the demand for livestock, and the number of animals that a rancher was allowed to graze on the lands increased, resulting in overgrazed lands along the river. Around the same time, the first automobiles passed through the valley. The proximity to irrigation water, the cool climate and the mid-level elevation made the Edwards area a leader in vegetable production in Colorado. However, it came to an abrupt end following the Great Depression, leaving ranching as the primary source of stable income in the region (ECPC & ECPD, 2003).

3.4.4 Transportation

Although the first prospectors traveled the trails of the Ute Indians by horse, foot, or wagon to reach the mining camps of the Eagle Valley, major settlement occurred only with the construction of the railroad. Known as the Iron Horse, the rail line of the Denver and Rio Grande Western (D&RGW) Railroad extended to Red Cliff by 1881. The construction of tracks continued down the Eagle River Canyon, but the narrowness of the valley and the precipitous peaks on each side of the river required the placement of fill material within the river and the blasting of solid rock for sufficient rail space (Knight and Hammock, 1965). By March of 1882, the rail line had been completed to Rock Creek and was open to traffic. This significant improvement in the transportation allowed ores to be shipped more efficiently to Leadville for smelting and facilitated the arrival of other prospectors in the region. Pressured by competition from other railroad companies, such as the Union Pacific, the D&RGW recommenced construction of a narrow gauge railroad down the Eagle River Valley in 1887 (Knight and Hammock, 1965). Construction was completed through Gypsum by August of the same year and to Glenwood Springs by October. Although railroads through many early mining camps were abandoned shortly after construction, railroad service through the Eagle Valley continued, and Minturn became an important station between Glenwood Springs and Salida. Transcontinental traffic traveled through the Eagle River Valley via the D&RGW rail, promoting the flow of people and exchange of goods (Figure 3.6).

Figure 3.6: View of engine number 54 on the narrow gauge Denver and Rio Grande railroad tracks above Eagle Park, Eagle County, Colorado ca. 1880 to 1886. Extensive wetlands and the historically meandering channel of the Eagle River are visible in the background (photograph courtesy of Denver Public Library).

Although many small wagon roads existed in the watershed prior to the 1900s, the invention of automobiles in the early 20th century led to the construction of paved roads. In 1960, an extension of I-70 from Denver to Utah was approved, and thirteen years later, the first bore of the Eisenhower tunnel was opened through the continental divide, further connecting the Western Slope with the Front Range via I-70. Construction of I-70 continued west with completion through the Glenwood Canyon in 1993. Construction of the rail and highway systems permanently altered land use within the Eagle River watershed. The confinement of steep valley walls resulted in encroachment into riparian areas and wildlife habitat fragmentation. The expansion of major transportation routes exposed the region to increased rail and car travel, and thus, increased air pollution. Impervious surfaces began to increase relatively rapidly along the Eagle River and Gore Creek, and drainage infrastructure directly conveyed runoff from these areas into surface waterbodies.

3.4.5 Camp Hale

World War II significantly affected the history of the Eagle River Valley when the large glacial valley known as Eagle Park was chosen as a high elevation military camp for training troops in mountain warfare.

On April 10th, 1942, construction of Camp Hale began at Pando, an area on the north end of Eagle Park previously used for lettuce growing and sheep ranching (Figure 3.7). What had once been a remote outpost with a rail station, two houses, and an icehouse, was quickly transformed into one of the largest cities in Colorado (Denver Post, 1942). Construction workers frantically labored to complete the camp that would be used to train soldiers for rough wintry combat conditions in Alaska, New England, Norway, or Italy. Camp Hale's construction required massive land alteration. Material from nearby hillsides and the terminal glacial moraine at the end of the valley was used as fill to cover the expansive floodplain wetlands. Large willow complexes were cleared and wetlands along several miles of the Eagle River were drained. The river itself was relocated, enlarged, and straightened. The main highway was rebuilt, and a city, complete with hospital and schoolhouse, was erected (Denver Post, 1942). Just eight months after construction began, Camp Hale was complete and the first troops had arrived (Figure 3.8).

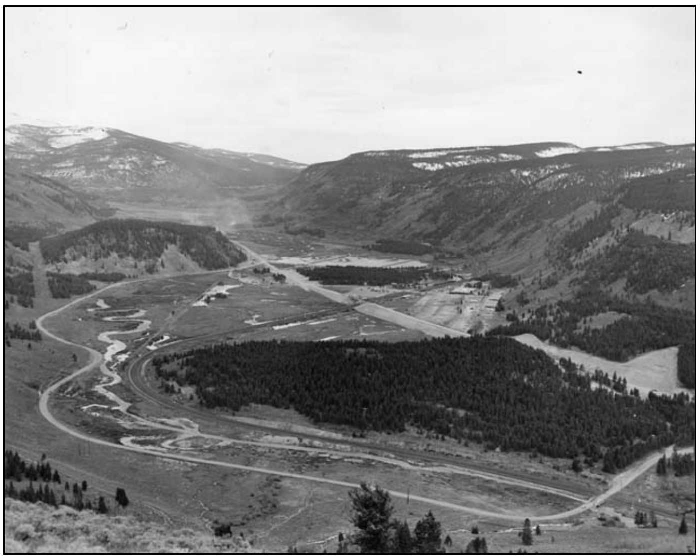


Figure 3.7: Pando and Eagle Park in 1942 (photograph courtesy of the Denver Public Library).

Figure 3.8: The Eagle River was dramatically altered during construction of Camp Hale which included 245 barracks (background) to house 10th Mountain Division troops (photograph courtesy of Denver Public Library).

Camp Hale was constructed for an expected 15,000 troops, 5,000 mules, and 200 dogs over the next several years (Jenkins, 2003).

The installation of a ski tow and the clearing of the primary ski-training grounds facilitated the National Ski Patrol's instruction of the soldiers, many of whom had little to no skiing experience (Figure 3.9). Rock climbing and mountaineering through deep snow at high altitude molded the soldiers of the 10th Mountain Division into an elite force that would later utilize its skills in the Appenine Mountains of Italy in early 1945 (Best, 2003a). The troops' courage and success in battles were critical to the fall of German mountain strongholds.

Figure 3.9: Mountain training consisted of rigorous multi-day ski trips that took soldiers far into the surrounding high country (photograph courtesy of Denver Public Library).

The end of World War II was followed by the deactivation of Camp Hale and the relocation of the 10th Mountain Division to Fort Drum, New York. Under the guise of an atomic testing site, the Central Intelligence Agency (CIA) used Camp Hale to train Tibetan soldiers between 1959 and 1965 following the Communist China invasion (White Crane Films and National Asian American Telecommunications Association (NAATA), 2001). But after nearly 25 years of military use, Camp Hale was demilitarized in July of 1965. Administrators at Fort Carson transferred control of the site to the U.S. Forest Service in 1966. Little structural evidence remains of what was once the largest city in the Eagle River watershed aside from concrete foundation remnants, a straightened river, and commemorative signs.

3.4.6 Rise of Tourism

After returning from the war, 10th Mountain Division veteran Peter Seibert and local rancher Earl Eaton, explored the potential for a ski area in the Gore Range. Upon receipt of the U.S. Forest Service permit in January of 1961, work began on what would soon become the economic foundation of Eagle County. Vail Mountain was open for skiing on December 15th, 1962 (Vail Resorts Management Company, 2002). Over 55,000 skiers visited Vail Mountain the first year; and four years later the Town of Vail was officially established (Vail Resorts Management Company, 2002). Vail Associates purchased ranchland in the Beaver Creek drainage in 1972, and by 1977 Beaver Creek was open for skiing. The ski industry accelerated the rapid development of the I-70 corridor. The opening of golf courses in the region further advanced the tourism industry and offered visitors perennial recreation opportunities. Avon, Vail, and Beaver Creek Village experienced intensive real estate development, primarily along Gore Creek, Beaver Creek, and the Eagle River.

Today, the Eagle River watershed is renowned for its recreational activities, including hiking, fishing, rafting, kayaking, rock climbing, and camping. Over 200,000 visitors participated in recreational activities in the White River National Forest (WRNF) last year (Bob Martin, WRNF Visitor Information, pers. comm., October 7, 2004). At least thirteen golf courses, encompassing over 1,600 acres of land, are located within the Eagle River Valley and suburban development continues to expand down the valley.

The recreational value of the Eagle River watershed is an extremely important cultural and economic resource to the region, yet associated land use changes including forest clearing and urban development have undoubtedly altered its water resources. The rugged mountain terrain dominating the Eagle River watershed forced most urban development to be established within the riparian corridor on alluvial valley floors. The resulting impervious surface cover, such as parking lots, streets, rooftops, and compacted soils, has increased surface runoff across areas that collect metals, nutrients, toxins and other pollutants. Impervious areas, especially those established before stormwater ordinances were implemented, are often directly connected to surface waters via curbs, gutters, and storm sewers, and therefore result in direct delivery of polluted runoff. Concentrated surface runoff from these areas intensifies the magnitude and duration of flows to receiving streams. Snowmaking and irrigation also modify streamflows. Wastewater discharges, nitrogen fertilizers, and automobiles have increased nutrient loading to surface waters.

Thus, from the early mining days along the Eagle River to the current tourism-based economy, the Eagle River watershed has undergone a complex sequence of land use change that has influenced the hydrology, habitat, and water quality of the Eagle River and its tributaries. Detailed descriptions of these changes and the current land use conditions are provided throughout Chapter 4. In recognizing that polluted runoff and impacts to riparian zones resulting from historical and current land use changes affect water quality and habitat, several local government entities have established policies for managing stormwater and riparian zones. These policies are the subject of the final sections of this chapter.

3.5 CURRENT STORMWATER POLICIES IN THE EAGLE RIVER WATERSHED

Municipalities, industrial facilities, and development projects regulated under the Colorado stormwater program must follow the requirements set forth by the Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Commission. Several municipalities, including Eagle County and the Towns of Avon, Eagle, Gypsum, and Minturn have voluntarily established stormwater standards to address water quality concerns (Table 3.1). A brief review of the state stormwater program, which will in some form eventually apply to local governments in the Eagle River watershed, is provided before describing these specific programs.

Table 3.1: Summary of stormwater management requirements in Eagle County. Salient features of model ordinances suggested by the Center for Watershed Protection (CWP) and the USEPA are provided for comparison.

	Application of Ordinance or Code	Permit Procedures and Requirements	Exemptions and Waivers	Stormwater Design Manual	Basic Stormwater Management Design Criteria	Water Quality BMPs	Requirements for Stormwater Management Plan Approval	Stormwater Operation and Maintenance	Enforcement and Penalties	Illicit Discharge Detection Program
CWP and USEPA Recommended Ordinance	5,000 ft^2 or > 1,000 ft^2 of impervious cover	Application procedures and requirements, length of time for permit review outlined	Eligibility for waivers stated	Maryland Department of the Environment 2000 Maryland Stormwater Design Manual Volumes I & II	Site Design Feasibility, Conveyance Issues, Pretreatment Requirements, Treatment Conditions, Environmental Standards, Maintenance Needs, Min Control Requirements, Non-structural Practices encouraged	See "Operation, Maintenance, and Management of Stormwater Management Systems" by *Watershed Management Institute, Inc.*	Preliminary conceptual plan and final plan requirements, performance bond provision, maintenance bond	Design standards, Maintenance Requirements, Inspection outlined	Stop work-order, criminal, civil, and monetary penalties, restoration of the land provision, holds on all occupation permits	Defines illegal discharges and connections, inspection permitted if suspicion is present, MS4 access may be suspended
Eagle County	All commercial and industrial development, planned urban development (PUD), development within 100 ft of water body, 10,000 ft^2 of impervious area	None Specified	None Specified	None Specified	No direct discharge, minimize directly connected impervious area, conveyance of 100-year flow	Detain and treat runoff of the 2-year, 24-hour storm	Stormwater Control Plan and Erosion and Sediment Control Plan required by developer, must identify calculations and maintenance	Design standards outlined	None Specified	None Specified
Town of Avon	25,000 ft^2 of impervious cover or > 50 parking spaces	None Specified	None Specified	Town of Avon Master Drainage Study, September 1994	25-year rainfall event, appropriate methods for calculations, inlet/outlet controls and structure requirements	Detain at least 4 hours of the 10-year, 24-hour storm	Drainage Study, including plan sheet and report of existing and proposed conditions	None Specified	None Specified	None Specified
Town of Eagle	Every development plan and preliminary subdivision plan	Requirements outlined	None Specified	None Specified	Convey runoff to drainage system or maintain historical rate for 10-year storm	None Specified	Drainage Plan, identification of existing channels with 10-year storm calculations, flood plain, and breach points. Vicinity map and maintenance plan.	Maintenance Plan required	None Specified	None Specified
Town of Gypsum	Drainage systems for development	None Specified	None Specified	None Specified	Section 4.0 of Town Code. Offsite and major drainage systems must convey 100-year peak Q. Minor systems must convey 25-year peak Q, drainage system requirements, methods for calculation outlined	None Specified	Drainage Analysis and Design to be approved by Town of Gypsum	None Specified	None Specified	None Specified

3.5.1 State of Colorado

In November of 1990, the U.S. Environmental Protection Agency (USEPA) released its final regulation on the control of municipal, construction and industrial stormwater discharges. The Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Division (WQCD) manages the stormwater program for the State of Colorado in accordance with the National Pollutant Discharge Elimination System (NPDES) section of the Clean Water Act Amendments of 1987. The primary objective of the program is to reduce the pollutant loading to streams, rivers, and lakes resulting from residential, commercial, and industrial stormwater runoff. The Colorado stormwater program has been implemented in two phases through the Colorado Discharge Permit System (CDPS) and is currently operating under Phase II. Municipal and industrial facility stormwater systems regulated under the CDPS Phase I and Phase II programs must adhere to applicable stormwater discharge permit regulations. No stormwater management is required by the State of Colorado for those municipalities, construction projects, and industries that are not included in Phase I or Phase II permitting. However, the State encourages voluntary participation in stormwater management programs.

3.5.1.1 Phase II Stormwater

Phase II of the CDPS program, which amended the previous State regulation based on Phase I, became effective in March 2001. The second phase broadened the application of the CDPS program to include several smaller municipalities, industrial facilities, and construction projects. The primary concern of the municipal program is to eliminate sources of pollution directed to the MS4s, which are used to collect and convey stormwater. Under Phase II, small municipalities (<100,000 population) in urbanized areas are considered with simpler application and permit requirements than large municipalities (>100,000 population). While certain municipalities are required to have permit coverage, the WQCD determines whether or not permit coverage for other municipalities is compulsory. The designations for permit coverage are:

- All municipalities having an urbanized area with a population greater than 50,000 are required to obtain a permit.
- Those municipalities outside of urbanized areas with populations of 10,000 to 50,000 and population densities of 1,000 per square mile or greater are evaluated by the State to determine if permit regulation is required.
- Municipalities outside urbanized areas having considerable contributions to stormwater discharges and pollutant loading of connected municipalities must obtain a permit.
- Any municipality outside of an urbanized area with a population less than 10,000 and a population density of less than 1,000 per square mile may be evaluated by the State for permit coverage.

Phase II of the stormwater program requires that all construction projects that disturb one or more acres of land obtain a permit. The construction permit may only be waived if the rainfall erosivity factor is less than five for a project under five acres in size. The rainfall erosivity factor is a measure of the erosive force and intensity of precipitation events. The waiver is based on construction activity occurring in an area, or during a specific period of time, where the potential for rainfall is low, and thus, less likely to cause considerable disturbance. Under Phase II, the industrial permit program expanded its waiver for permit coverage to include all industrial activities (construction excluded) that do not have any industrial materials or activities exposed to stormwater. However, the temporary waiver that exempted industrial facilities owned and operated by small municipalities expired in March 2003. All industrial activities owned and operated by small municipalities regulated under Phase II, inclusive of construction operations, gravel pits, and wastewater treatment plants with a capacity greater than 1 million gallons per day (MGD), require an industrial stormwater management permit. No municipality within the Eagle River watershed was required to obtain a municipal stormwater management permit under Phase II of the CDPS program.

3.5.2 State Permit Requirements

Requirements for construction permits are the same regardless of the size of the construction disturbance (CDPHE, 2002a). Through the completion of a Stormwater Management Plan (SWMP), construction dischargers are required to control and remove the pollutant sources with the use of structural and non-structural Best Management Practices (BMPs). Typical construction pollutant sources include sediment, fuel, and other onsite chemicals and materials. Common BMPs used to eliminate these sources include silt fences, sediment ponds, vehicle tracking controls, good housekeeping, inspection and maintenance schedules, and personnel training.

Municipalities under the Phase I and Phase II permits are required to meet a minimum of 6 actions to more effectively manage stormwater. These measures include:

1. Public Education and Outreach on Stormwater Impacts
2. Public Involvement/ Participation
3. Illicit Discharge Detection and Elimination
4. Construction Site Stormwater Runoff Control
5. Post-Construction Stormwater Management in New Development and Redevelopment
6. Pollution Prevention/ Good Housekeeping for Municipal Operations

Best Management Practices are typically incorporated into these 6 steps to maintain optimal water quality. The CDPS WQCD does not provide design storm criteria for the development and implementation of water quality BMPs. However, all structural and non-structural water quality BMPs are generally designed to capture pollutants to the "maximum extent practicable" (Nathan Moore, CDPS WQCD, pers. comm., July 8, 2004), but practicability for various pollutants is not linked with specific design criteria.

Currently, no municipality in the Eagle River watershed is required by the State to begin implementing a stormwater program under Phase II for discharges associated with MS4s. Although the Towns of Vail and Red Cliff do not currently operate under any MS4 stormwater management, other programs in the Eagle River watershed vary considerably in the extent to which they voluntarily comply with Phase II criteria. The Town of Vail, however, is proactively initiating a process of meeting the six municipal criteria. Because construction and industrial permits under Phase I and Phase II of the CDPS do apply to the municipalities in the Eagle River watershed, construction activities in all municipalities within the Eagle River watershed that disturb at least 1 acre of land (or are part of a larger development plan that will disturb at least 1 acre of land) are required to obtain permit coverage under a CDPS permit for stormwater discharges associated with construction activities (CDPHE, 2002b). CDPES *industrial* stormwater permits prohibit non-stormwater discharges and entail the control and removal of stormwater pollutant sources through the execution of a SWMP. This plan includes the use of BMPs for stormwater treatment and reduction of pollutant sources. The SWMP must identify any sources of pollution that could potentially affect the quality of stormwater discharges. The permit requires semi-annual inspections, annual reports, monitoring reports, and annual fees.

3.5.3 Eagle County

The drainage standards of the Eagle County Land Use Code (Section 4-650) define the stormwater runoff guidelines for all proposed development within Eagle County's jurisdiction. The purpose of the standards is to minimize water quality degradation and its effect on the environment and to reduce flooding damage from urban runoff. The standards apply to all commercial and industrial developments, sub-developments and PUDs, property development within 100 ft of a body of water, and developments generating 10,000 ft^2 or more of impervious surface area. Techniques that are not mentioned within the standards may be applied upon approval of Eagle County.

The County prohibits all direct discharge into a body of water, and each developing entity must comply with one of three management practices, including the implementation of a vegetative surface, on-site treatment, or a conveyance structure. The standards entail the minimization of impervious areas, which are directly connected to the body of water. Fifty percent of all developed impervious areas must drain over grass buffer strips before flow is directed through a stormwater conveyance system. If additional stormwater treatment (i.e., constructed wetlands, infiltration device, sand filters) is connected below the grass buffer strip, this requirement may be reduced. All developed lands draining to a buffer strip must not exceed a maximum slope of 10%. The buffer strip must be uniform in slope and may not exceed 5%.

A permanent stormwater detention facility is required for all developments meeting the application standards set forth by the County. Such a facility must be designed to remove pollutants from stormwater, to maintain historic peak flows, to reduce the possibility and effects of extreme flooding, and to prevent the erosion of downstream channels. In the treatment of pollutants, 90% trap efficiency is required for all particles having a diameter equal to or greater than 0.005 mm during a 2-year, 24-hour storm. Peak flows must be reduced to undeveloped peak flows for all storms with a magnitude equal to or greater than the 25-year, 24-hour storm. All permanent stormwater detention facilities are required to protect against excessive damage and casualties from large flooding events by designing for the reliable routing of the one hundred year flood. Discharge into a channel must use a natural drainage way as a receiving stream unless the County agrees that no reasonable location exists. The developing entity is required to protect channels located downstream from the point of discharge from amplified channel scour, bank instability, erosion, and sedimentation from the 25-year storm.

Erosion and sedimentation control standards apply to any disturbance within 100 ft of a stream, residential developments disrupting 0.5 acres of land or more, commercial and industrial developments, and subdivisions and PUDs. Each applicable development must comply with a number of regulations. First, all construction activities must be phased as to minimize the soil degradation effects. All water protection structures, including sediment traps, are established prior to the commencement of construction. If disturbance areas will be exposed for more than fourteen days or during winter snowmelt, the soil surfaces must be roughened, mulched, seeded and mulched, or otherwise protected against erosion. Those construction disturbances located within 50 ft of a body of water or on slopes exceeding 20% must protect exposed soils with hydromulch, nets or mats. Permanent vegetation is required on construction sites that are not developed for one year or longer. After project completion, 75% of site must be covered by vegetation within one growing season.

Slope stability is a required course of action prior to, during, and following construction. The recommended slope stability method for areas subject to grading with side slopes less than or equal to 3:1 is permanent vegetation. Slopes steeper than this must be stabilized by any method deemed appropriate by the County. Construction within or adjacent to any water body is required to provide both bed and bank stability through stream isolation. All new channels, ditches, and stream receiving water are also protected against erosion.

Stormwater must be managed to avoid severe erosion during construction by diverting runoff away from exposed soils. If the slope length and gradient are not minimized, slope drains may be required to convey runoff. Sediment build up on adjacent properties are minimized through the use of silt fences, hay bales, or sediment traps. Streets are protected through the implementation of construction or street bases. Sediment detention facilities are required for sites whose contributing drainage area, including off-site drainage, exceeds five acres. The facilities, which may include ponds, infiltrations devices, or other management practices, must sufficiently treat stormwater runoff for a 2-year, 24-hour storm. If sediment detention ponds are included in the sediment control design, a 90% trap efficiency is required for particles having diameters of 0.005 mm or greater. If filtration or infiltration methods are utilized, the trap efficiency may be reduced.

Sediment ponds that will be removed following re-vegetation of the disturbed area must safely capture and discharge runoff for a 25-year, 24-hour storm at a release rate equal to that of pre-development. Permanent ponds must be designed for the safe passage of the one hundred year flood.

All de-watering of construction sites must be monitored for total suspended solids. Releases from the de-watering activities cannot initiate erosion. Every construction site must be monitored after rainfall or snowmelt events, at a minimum of once each month. Any problems demonstrating the need for further erosion protection are acted upon in a timely manner. County officials will receive inspection logs on a monthly basis and may visit the site regularly for review of the inspection log.

3.5.4 Town of Avon

The Town of Avon has pollution control standards for both temporary and permanent modifications to the natural state of an area. Temporary pollution control standards are in place for all development that disturbs the existing conditions of the ground surface. Permanent pollution controls are required for sites with fifty or more parking spaces.

While temporary pollution control is required for all disturbed land, a temporary pollution control plan must only be submitted to and approved by the Town of Avon if any of the following conditions exists: (1) more than one-half an acre will be disturbed during construction, (2) fifty or more parking spaces will be constructed, or (3) slopes of the construction site exceed 15%. Such a plan must be inclusive of physical controls and management practices to minimize the extent and period of disturbance. The developer should phase the project such that only the active portion of the site is exposed. Once construction is completed for individual areas, the developer should either use temporary or permanent vegetative cover to restore the disturbed area. All disturbed areas use hay bales and silt fences at the downstream limit of the construction to restrict the flow of sediment. Further methods of temporary controls may include seeding, check dams, or sediment basins. More extensive measures of temporary pollution control are mandated for larger construction projects. Temporary devices are monitored for effectiveness throughout construction and removed upon project completion. Existing drainage structure must remain clear of sediment and debris related to the construction through the length of the project.

Permanent pollution control methods, designed to treat the 2-year, 24-hour storm, may include physical structures or management practices with the objective of improving water quality by separating out sediment and oils from runoff waters. Best Management Practices, as outlined in the *Urban Storm Drainage Criteria Manual* (Urban Drainage and Flood Control District, 1992), are implemented to limit the amount of offsite pollution. Development that contains impervious surface cover is graded to encourage the flow of runoff water over grass-covered surfaces. A detention pond may also be designed to contain and treat runoff. The pond must be designed to detain runoff for at least 4 hours of a 10-year, 24-hour storm event, and must have a spillway or outlet structure for the 100-year event. A skimming baffle or grease trap is an additional requisite of the design.

3.5.5 Town of Eagle

The Town of Eagle Land Use Code mandates every development and preliminary subdivision to include a drainage plan certified by a Professional Engineer, subject to approval by the Town Engineer (Section 4.13.040). The design must restrict storm runoff to the pre-developed rate for the ten-year design storm. If this is not feasible, then the plan must include a storm drainage system to direct runoff to a reasonable offsite drainage channel. The required drainage plan information is outlined in the Town Code. There are no additional stormwater collection regulations other than those stated within the code.

The Town calls for erosion and sediment control plans when the proposed development includes a subdivision or when the Town Officials consider it necessary for Development Permit, Building Permit, or Grading Permit for excavation and fill activities greater than 250 cubic yards. Such a plan maintains the natural drainage flows to deter erosion in existing channel and adjacent properties and to avoid damage to natural vegetation and topsoil. The erosion and control plan must be suitable for the soil types and land uses characterizing the proposed development. Sediment detention facilities are incorporated into the design to reduce the degradation and sedimentation of natural and artificial channels. The transfer of dust, mud, and debris beyond the public right-of-way needs to be minimized in the development process.

For the control of erosion and sedimentation, the Town provides a list of control practices to be followed during development (Land Use Code, Section 4.13.050). Significant practices include trapping of sediment in runoff through the use of debris or sediment basins, fencing, silt traps, or other approved method to ensure stabilization. Surface water is directed away from cut and fill slopes, and all exposed areas deemed critical are covered with vegetation or mulching during construction. To minimize the degradation and aggradation effects of adjacent lots, cut slopes must have a slope less than 2:1 unless a variance in granted. If water is to be passed through an adjacent property, permission from landowner is required. Watering of exposed soil is enacted to control dust during development. The number of entrances from the right-of-way must be minimized, and all entrances constructed must protect against mud tracking through the use of gravel placement. Finally, the developer is required to minimize the time in which construction is completed.

3.5.6 Town of Gypsum

Development within the town must have a drainage system such that no public or private property within and downstream of the development is negatively impacted by runoff, erosion, sedimentation, and debris flow. Positive drainage (no ponding) for all drainage structures must drain to natural flow ways or other positive conveyance of runoff. Drainage structures, roadways, and site grades provide the passage of flow from a 100-year design storm without impairment to any private or public structures, buildings, roads, or property.

It is the obligation of the developer to examine and provide mitigation, where necessary, and the appropriate drainage capacity for the 100-year storm. The developer investigates detention storage for debris flow, along with maintenance and cleanup conditions. A Colorado Registered Professional Engineer must prepare and submit all drainage systems in accordance with the Town of Gypsum. The Town of Gypsum is responsible for the review and approval of the design and drainage analyses.

The primary drainage passage for any proposed development must effectively transport the peak flow discharge of the 100-year storm without allowing flow to pass the determined right-of way and easements. Off-site drainage from a 100-year storm must maintain the pre-development peak flow discharge, and must flow through structures within the site and not over street surfaces. Twenty-five year drainage systems consist of all connections distributing water to the primary drainage channel and are required to facilitate the flow from a 25-year storm event, and be structurally reliable under flow produced by a 100-year storm. Following development, the peak discharge associated with a 25-year storm cannot exceed the pre-development peak discharge of an event of the same magnitude. If the peak discharge requirements cannot be met for either the 100-year or the 25-year storm, the developer has the option to direct flow to detention storage or through a system with direct output to either Eagle River or Gypsum Creek which meets the peak flow requirements without causing damage to private or public property.

Developments subject to debris flow require analysis by a geotechnical engineer with experience in debris flow management to determine a bulk loading factor and gradation analysis of the estimated debris matter associated with a 100-year storm event. Appropriate structures or facilities are required to prevent the passage of debris material through screens with a maximum allowable opening of four inches. The facilities transport the water and debris passing the screens to the surface for efficient cleanup. During a 100-year storm, at least 50% of all debris flow must be retained by the screens. No debris flow is directed through any underground conveyance system.

The Town of Gypsum also requires both temporary and permanent erosion and siltation control for land development and infrastructure construction. During construction, a temporary erosion control plan must be submitted. The plan must demonstrate the diversion of clear and offsite water from areas under excavation and onsite drainage structures. Silt fences and hay bale check dams are used to control velocity and sediment flow. Hay bale check dams protect all storm drainage structures from sediment accrual. All other permanent structures subject to erosion as a result of the construction must be temporarily protected until a permanent method of erosion control is implemented. Silt fences must protect all public or private lands adjacent to the disturbed areas. Temporary erosion control methods remain in operation until the Town of Gypsum approves of their removal.

Permanent erosion control methods are submitted for approval by the Town of Gypsum. These methods must be designed to provide for the stabilization of surfaces subject to erosion by water or wind. Typical control measures include synthetic reinforced matting for vegetation and flexible channel lining systems. The design must contain a provision to control velocities of onsite surface drainage systems to maintain the 100-year storm event flood flow such that the maximum sustainable erosion velocity of the particular structure is not reached. Drainage structures are protected from erosion by high velocity flows, and all erosion protection should be designed to require little maintenance.

3.5.7 Town of Minturn

The Town of Minturn follows Eagle County stormwater management regulations (Russ Martin, pers. comm., October, 2003).

3.5.8 Town of Red Cliff

Like other Towns in the Eagle River watershed, Red Cliff is not included under Phase I or Phase II of the CDPS program. No stormwater management practices are currently required (Russ Martin, pers. comm., October, 2003).

3.5.9 Town of Vail

Vail currently requires no stormwater management. However, a draft stormwater ordinance addressing the requirements of the CDPS Phase II permit is currently being completed and under review (Bill Carlson, Environmental Health Officer/Planner, pers. comm., July, 2003).

3.5.10 Edwards

Edwards is an unincorporated region of the watershed, and therefore falls within the jurisdiction of Eagle County and is required to follow all County stormwater regulations.

3.6 CURRENT RIPARIAN ZONE POLICIES IN THE EAGLE RIVER WATERSHED

Multiple riparian zone or ‘setback’ policies are currently in place within the Eagle River watershed (Table 3.2). As with the stormwater policies described above, Eagle County regulates development within riparian areas while incorporated towns within the county implement riparian zone policies on an individual basis. These incorporated towns within the Eagle River watershed include Avon, Eagle, Gypsum, Minturn, Red Cliff, and Vail.

Table 3.2: Summary of riparian zone policies in the Eagle River watershed.

Government	Setback Width Requirement	Allowable Structures / Activities within Setback
Eagle County Land Use Regulations	The 100-year floodplain or 50 ft from the high water mark, whichever is greater.	Footpaths, bridges, fences, irrigation structures, pump houses, and flood control and bank stabilization devices. Agricultural uses of land permitted. No projections into setback.
Town of Avon	30 ft from the mean annual flood high water mark within a proposed subdivision.	Footpaths, bridges, irrigation structures, flood control and erosion devices, and approved underground utilities.
Town of Eagle	50 ft from the high water mark of any live stream.	Bridges, paths for non-motorized use, fences, irrigation structures, flood control and erosion protection devices, approved underground utilities.
Town of Gypsum	No set distance, Community developed map used for determination of Riparian zones, no new development within 100-year flood plain.	All development requires approval by Town Board.
Town of Minturn	30 ft from high water mark, determined by 2-year debris flow.	Footpaths, bridges, fences, irrigation structures, flood control and erosion devices, approved underground utilities.
Town of Red Cliff	30 ft from high water mark, determined by 2-year debris flow.	Footpaths, bridges, fences, irrigation structures, flood control and erosion devices, approved underground utilities.
Town of Vail	30 ft from the center of the creek or stream channel, as indicated by the Town Comprehensive Plan Base Maps, 50 ft from the center of Gore Creek.	None indicated.

3.6.1 Eagle County

The Eagle County Land Use Regulations restrict new development within the 100-year floodplain or a 50-foot setback on each side of any river or live stream measured horizontally from the high water mark, whichever is greater. A live stream is essentially defined under the definition of a "stream" in the Regulations (Article 2) (Joe Forinash, Eagle County Planner, pers. comm., July 8, 2004), as any "watercourse having a natural source and terminus, banks and channel, through which waters flow at least periodically," with the exception of man-made irrigation ditches. The high water mark is generally defined as the waterline visible on the edge of a river, stream, or other body of water such that the natural soil and vegetation have a distinct character. The discharge that determines the high water mark typically has a recurrence interval of 10 years or less. For the purposes of the regulation, the 100-year floodplain is inclusive of both the flood fringe and the flood way (Bob Narracci, Eagle County Planning Manager, pers. comm., October 7, 2003). All zones in this area are protected in their natural state (Joe Forinash, Eagle County Planner, pers. comm., July 8, 2004), with the exception of footpaths, bridges, fences, irrigation structures, pump houses, and flood control and bank stabilization devices. No projections are allowed into the 100-year floodplain or the specified setback. Projections pertain to structural architecture features, such as decks, cantilever, and roof overhangs. The Board of County Commissioners can set a greater setback to better protect a stream and all associated riparian areas. On several occasions, the Board has exercised its discretionary powers to set stricter standards (Bob Narracci, Eagle County Planning Manager, pers. comm., September 24, 2003).

Eagle County's Regulations prevent the storage or use of potentially buoyant, flammable, explosive, and injurious materials that may cause harm to human, animal, and plant life during a flood. However, the use of chemicals and fertilizers within riparian zones is not prohibited. The Regulations allow general farming, pasture, grazing, outdoor plant nurseries, horticulture, viticulture, truck farming, forestry, and sod farming within the riparian zone. Certain PUDs do contain specific guidelines limiting the use of fertilizers and chemicals in wetland areas, specifically relating to single-family residential lots and golf course management.

In addition to the Eagle County Land Use Regulations, the *1996 Eagle River Watershed Plan*, an ancillary document to the *Eagle County Master Plan* (ECCD, 2003), recommends that all structures, grading, paving and land disturbance be located outside of the 100-year floodplain or the riparian zone of all live waters, whichever is greater. The riparian zone as defined in the document is a 75-ft distance, measured horizontally, from the high water mark. To further protect the riparian zones, the *1996 Eagle River Watershed Plan* recommends requiring greater setbacks than those stated. In regards to vegetation, the Plan proposes that only those vegetative disturbances that include environmentally sound weed control and improvements to the riparian corridor be permitted in the zone. Other development, including approved trails, recreation access sites, bridges, fences, irrigation and diversion structures, and flood control and erosion devices, may be permitted provided that there is little or no disturbance to the riparian areas, or that the disturbances can be mitigated. The *1996 Eagle River Watershed Plan* suggests that approved underground utilities only be located in the protected areas in the case that no alternate locations will suffice, that there is minimum or no disturbance to protected areas, and that all other required permit and approvals are obtained.

The *1996 Eagle River Watershed Plan* was adopted as a policy statement under the Eagle County Master Plan. The recommendations in the *1996 Eagle River Watershed Plan* regarding riparian zones are considered in the planning process. However, the *1996 Eagle River Watershed Plan* is not a legally binding document, and the standard setback used in development is that provided under the Land Use Regulations (Joe Forinash, Eagle County Planner, pers. comm., July 8, 2004). In the Land Use Regulations, the riparian area is defined as between the "water's edge of aquatic ecosystem and upland areas, whose soils allow for or tolerate a high water table and provide sufficient moisture in excess of that otherwise available locally so as to provide a more moist habitat than that of contiguous floodplains and uplands (Article 2)." If the riparian area extends beyond the specified setback distance of 50 ft from the high water mark, consideration would be given to extending the setback for that particular region (Joe Forinash, Eagle County Planner, pers. comm., July 8, 2004).

3.6.2 Town of Avon

According to the Avon Land Use Regulations (Title 17: Zoning), a stream setback provision defines the riparian buffer zone. A setback is defined as a 30-foot strip of land from the mean annual flood high water mark on each side of any live stream within a proposed subdivision. All properties within the Town of Avon are considered as a part of a subdivision (Tambi Katieb, Town of Avon Planner, pers. comm., July 8, 2004). With the exception of footpaths, bridges, irrigation structures, and flood control and erosion devices, the land is to be protected in its natural state. Underground utilities may be placed within the stream setback should no reasonable alternatives exist, the Town Council approves the plans, and the disturbed area is re-vegetated.

3.6.3 Town of Eagle

The requirements for development adjacent to live stream and rivers are outlined in the Town of Eagle Land Use Code (Section 4.04.100.H.2). The Town Code follows the Eagle County Land Use Regulations closely, prohibiting new construction and improvements within a 50-ft setback area from the high water mark, defined as the waterline at the point of high discharge with a recurrence interval of 10 years, of any live stream, with the exception of bridges, paths for non-motorized use, fences, irrigation structures, and flood control or erosion protection devices. Additionally, the Planning Commission and Town Board may permit underground utilities if no reasonable alternative locations can be found, and all construction disturbances are revegetated. The Eagle Ranch PUD Guide, a zoning code for the particular development, requires a 50 foot setback from minor streams and a 100-ft building setback from Brush Creek.

3.6.4 Town of Gypsum

The Town of Gypsum has no set regulation specifying required distances for riparian buffers. Instead, the Town uses a master plan map, which indicates Riparian Zones. The zones were determined by a series of town meetings open to the public. Within the Riparian Zones, little development is allowed, unless approved by the Town Board. In general, the town allows no new development within the 100-year floodplain.

3.6.5 Town of Minturn and Town of Red Cliff

Both the Town of Minturn and the Town of Red Cliff follow the same planning regulations. The setback from rivers and creeks is a 30-ft zone, measured horizontally from the high water mark (generally determined by the 2-year debris flow). The stated land is protected in its natural state except for footpaths, bridges, fences, irrigation structures, and flood control and erosion protection devices. Additional protection of a river or creek may require an extended setback width, as determined by the Town. Following the Eagle County regulations, underground utilities can be placed within the setbacks given that there is no feasible alternate location, that the Town Council approves them as a conditional use, and that revegetation follows all construction.

3.6.6 Town of Vail

Based on the Vail Town Code (Section 12-14-17: Setback from Watercourse), the required minimum setback from a creek or stream is 30 ft from the center of the creek or stream channel. The Town Comprehensive Plan Base Maps indicate the river and creek channel centers. An exception to this regulation is the setback for Gore Creek, which maintains a minimum setback distance of 50 ft from the center of the creek.

3.6.7 Comparison with USEPA and Center for Watershed Protection (CWP) Recommendations

The USEPA and CWP have developed model ordinances for the protection of riparian buffer zones (Appendix J). An investigation was performed to compare the current setback ordinances in the Eagle River watershed to guidelines set forth by the USEPA and CWP. Through application of the three-zone approach, the USEPA recommended minimum stream buffer width is 100 ft. Eagle River watershed municipalities employ a fixed setback approach varying in width from 30 to 50 ft. No common methodology for measuring buffer widths is used among the seven municipalities. Although allowable structures and activities are addressed in several of the ordinances (Table 3.2), no specifications exist regarding agricultural and livestock uses, timber harvest, and vegetation removal and treatment, all critical factors of an effective riparian management plan. Although the USEPA and CWP outline public understanding as a key component in building support for riparian ordinances, no municipal public education initiatives concerning riparian zones are currently active in the Eagle River watershed.

The CWP suggests that incentives such as density grants or conservation easements be used to encourage community compliance. Density credits can be used to compensate developers and landowners for land use by buffers, providing greater flexibility in setbacks, frontage distances, or minimum lot sizes. Conservation easements allow a landowner to donate the use of the buffer as a land trust for charitable contribution as an income tax saving or to a local government for property tax adjustment on the land within the buffer zone. Example programs utilizing incentive programs are discussed in Appendix J. No Eagle River watershed municipalities currently offer incentives to landowners for observance of riparian zone standards.

Furthermore, the USEPA and CWP recommend enforcement of riparian ordinances through monitoring and maintenance, and suggest the use of a monetary penalty for noncompliance. No known monitoring initiatives to ensure adherence to setback ordinances are active in the Eagle River watershed. A large body of scientific research has demonstrated the importance of riparian zones to the ecological integrity of stream networks. Success in protecting the functions and values of riparian zones in the Eagle River watershed depends on the clarity of ordinance language, restrictions of potentially harmful activities, public education, monitoring, and enforcement of ordinances.

CHAPTER 4

Analysis of Watershed Characteristics

"Although the river and the hillside waste do not resemble each other at first sight, they are only the extreme members of a continuous series and when this generalization is appreciated one may fairly extend the 'river' all over its basin and up to its very divide. Ordinarily treated the river is like the veins of a leaf; broadly viewed it is the entire leaf." – W. N. Davis

A comprehensive evaluation of the Eagle River watershed was performed to identify vital management concerns. Watershed processes that actuate energy and material fluxes, including sediment supply, hydrologic regime, organic and chemical inputs, and light/heat inputs, were examined in order to establish a large-scale understanding of basin conditions. The approach of the investigation focused on the identification of watershed-scale patterns in major stressors and alterations. The following sections present the results of the evaluation and discuss notable features that contribute to the current conditions of the watershed. First, the prevailing state of land and water use was addressed, as well as projected changes. This was followed by an overview of the allocation of water rights and a more detailed exploration of major diversions. Hydrologic temporal patterns of stream flow in the basin were analyzed, inclusive of an in-depth investigation of instream flows. An examination of the water quality was completed, and the state of the watershed was further assessed through a study of basin geomorphology, riparian areas, and biological resources.

4.1 LAND USE

An examination of current land use within the Eagle River watershed was performed to relate land-use patterns to physical processes and current ecological conditions of the watershed. As in the historical development of the basin, the specific type of economic system within each region shapes the current land-use patterns. While the economy of the Eagle River watershed is increasingly based on tourism, especially in Vail and Avon, some mining, ranching, and farming activities still exist.

Industrial mining is still occurring in the Eagle River watershed with the American Gypsum Eagle Mine and Plant in the Town of Gypsum, just north of the Eagle River. Sand and gravel mining also occurs to support the construction and development activities in the Eagle River watershed. Large excavation pits are visible along the Eagle River in Edwards and Gypsum. Mined materials remain important for local construction activities within the basin and for the distribution of gypsum wallboard products throughout the nation. Nevertheless, mining is increasingly less prominent as a source of income (ECCD, 2003).

Once a leading provider for the region's economy, agriculture has been steadily decreasing for at least the past 20 years. The numbers of acres of land used for irrigation within the watershed has decreased considerably within the last few decades. According to the USGS Water Use Study in the Eagle River watershed, the area of irrigated land dropped 58% from 23,000 acres to less than 10,000 acres. This dramatic change of land use has affected the quantity of water that returns to the river late in the irrigation season, possibly altering the quantity and timing of low flows, as discussed in Section 4.4.10.

The current economy of the Eagle River watershed is driven by tourism and real estate development. The Eagle River and its tributaries provide residential communities with a variety of recreational activities, including fishing, hiking, wildlife watching, canoeing, kayaking, rafting, along with numerous other leisure activities. The highest intensity of land development is, not surprisingly, within the river corridor. While skiing is the chief tourism interest in Eagle County, a rise in the golfing industry is noticeable (ECCD, 2003) and indicative of a growing tourism season.

Due to the rapid development that occurred over the last 50 years in the basin, the issue of changing land use has become a common concern. A study completed in October 2002 by the Eagle County Planning Department determined the total number of dwelling units currently built (23,085) and those that would be allowed in the future (45,020) based on the current zoning standards (ECCD, 2002). Figure 4.1 depicts the current intensity of land development by the number of dwelling units per acre of land.

A Geographical Information System (GIS) was used to examine land cover within the entire watershed, subbasins, and set distances from the Eagle River and its major tributaries. The most recent National Land Cover Data (NLCD) from 1992 are available for the Eagle River watershed through the USGS Land Cover Characterization Program (Vogelmann *et al.*, 2001). New NLCD imagery for the entire United States from 2001 is currently scheduled for release in 2006 (Homer *et al.*, 2004).

Caution must be used in applying these data at smaller scales due to errors associated with the quality of the Landsat data, mapping error, time differences in source imagery and reference data acquisition, definition related to land use, and spatial uncertainty (USGS, 2004a). In addition, considerable development of the watershed has occurred since 1992. The NLCD, nonetheless, conveys an overall sense of land-use patterns in the watershed and within the riparian corridor.

Figure 4.2 illustrates the land cover within the entire Eagle River basin. Horizontal distances of 30 and 100 m on each side of stream segments were chosen to evaluate land-cover patterns within the riparian corridor. Results indicate that even though the highest percentage of land cover is attributed to upland forest, the riparian corridor is experiencing the greatest development. Figures 4.3 through 4.5 depict the development on the mainstem of Gore Creek, from the confluence with Black Gore Creek to the confluence with the Eagle River, within specific buffer distances.

Within 30 m of each side of Gore Creek, 35% of the land has been developed. This percentage decreases to 7% within 100 m of either side of the river. When compared with the entire Gore Creek watershed, the percentage of estimated development is further decreased to only 2%. Figure 4.5 illustrates the allocation of land cover throughout the entire Gore Creek watershed.

This same procedure was performed for different subbasins in the watershed (Table 4.1). Graphs summarizing the distribution of land use by percentage are included in Appendix B.

A major factor arising from development and the changing land uses of the region is an increase in impervious area, which consists of rooftops, roadways, parking lots, and driveways, or any surface that impedes the natural course of water to the subsurface. As water infiltrates the surface and slowly seeps through the subsurface, soil and vegetation act as filters for pollutants and nutrients, preventing them from entering the surface waters at high concentrations. The creation of impervious land cover obstructs rainfall and snowmelt from infiltrating the soils and creates runoff that directly enters surface watercourses without filtration or retention of pollutants. This process can result in water quality degradation if proper land-use management techniques are not adopted. Conversion of precipitation delivery pathways from infiltration and subsurface flow into surface runoff also reduces base flows to streams and rivers (Rose and Peters, 2001).

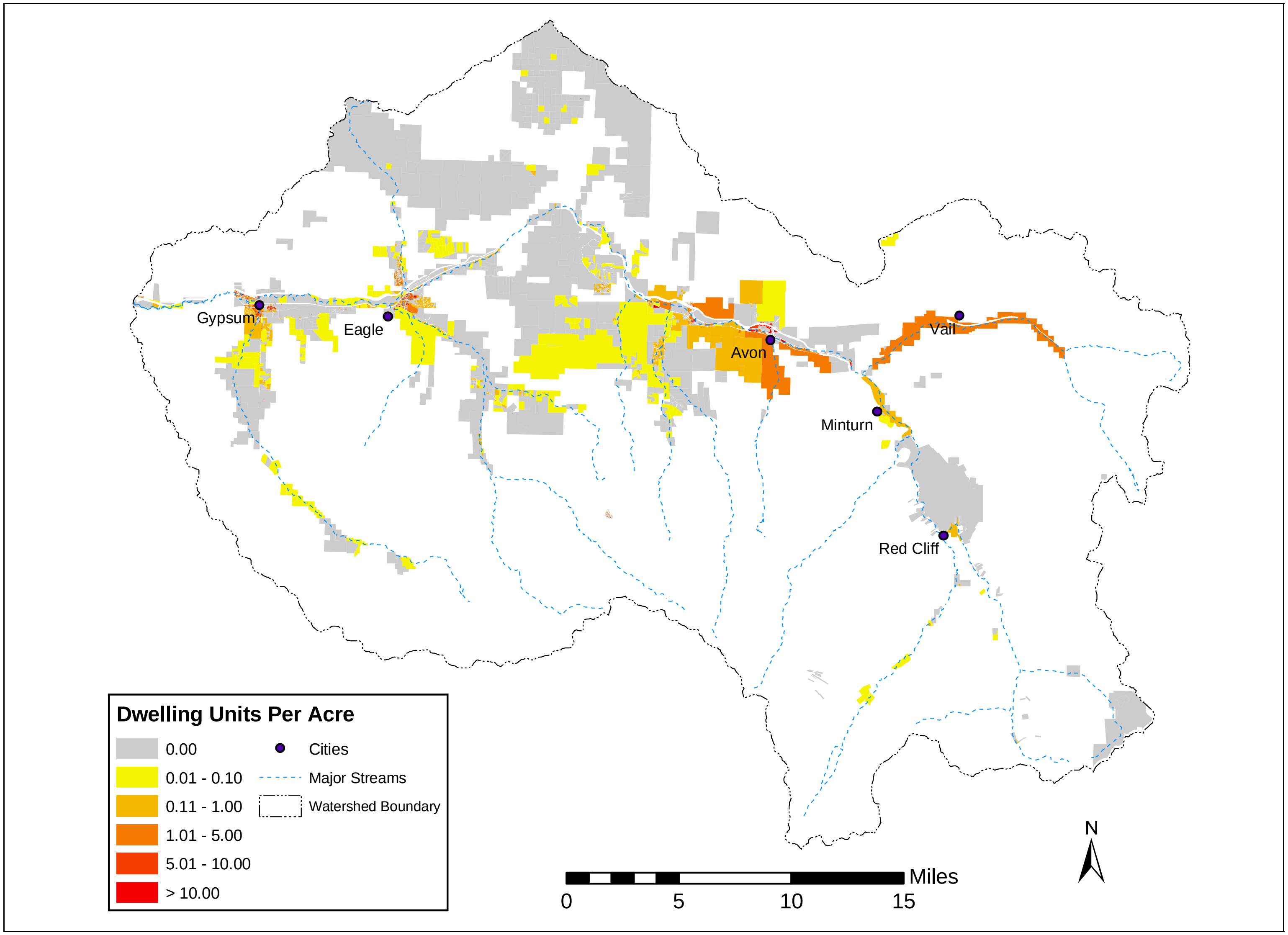


Figure 4.1: Current Dwelling Unit Intensity Map, based on the current number of dwelling units per acre (source: ECCD, 2002).

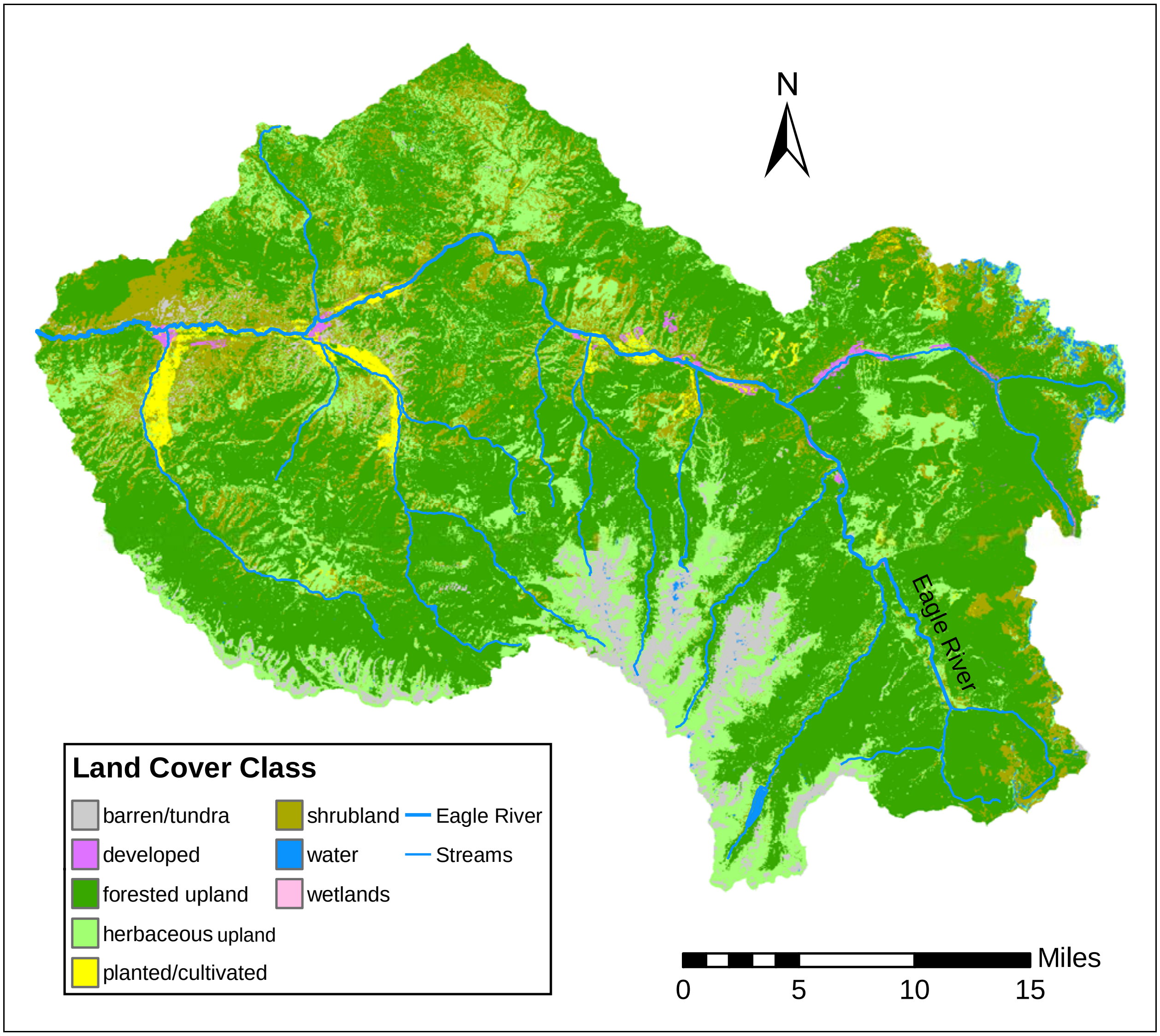


Figure 4.2: Land cover in the Eagle River watershed based on 1992 National Land Cover Data (Vogelmann *et al.*, 2001).

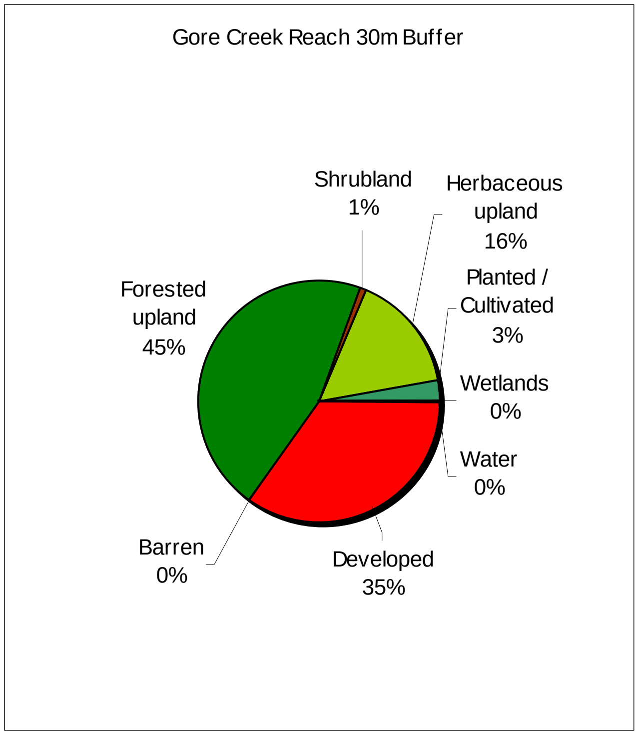


Figure 4.3: Land-cover distribution within a 30-m buffer zone of the main stem Gore Creek based on 1992 National Land Cover Data (Vogelmann *et al.*, 2001).

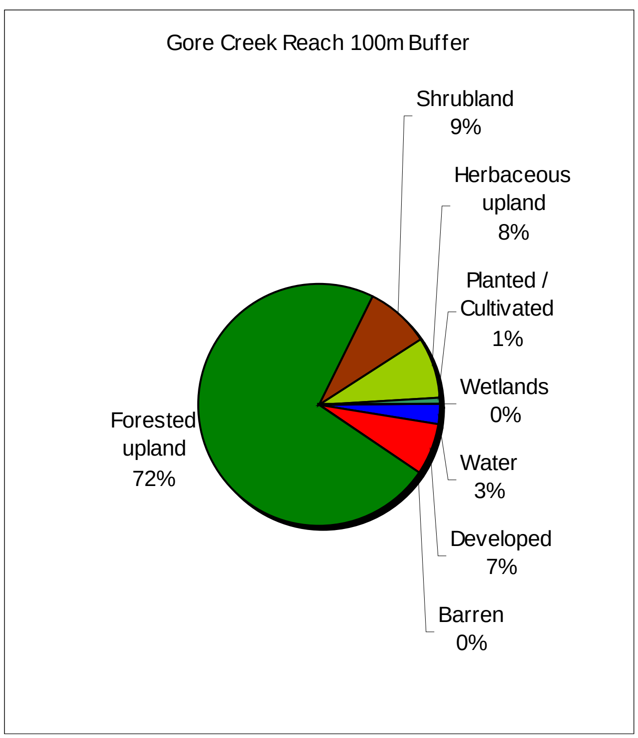


Figure 4.4: Land-cover distribution within a 100-m buffer zone of the main stem Gore Creek based on 1992 National Land Cover Data (Vogelmann *et al.*, 2001).

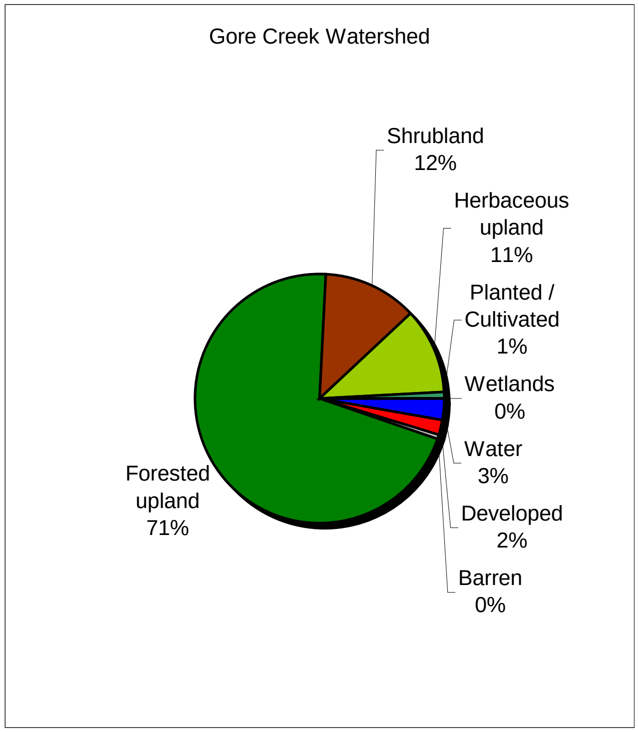


Figure 4.5: Land-cover distribution within the entire Gore Creek watershed based on 1992 National Land Cover Data (Vogelmann *et al.*, 2001).

Table 4.1: Percent of developed land for different subbasins and regions within the Eagle River watershed within different buffer distances based on 1992 National Land Cover Data (Vogelmann *et al.*, 2001).

		Percent of Land Classified as Developed		
		30-m Buffer	100-m Buffer	Watershed
Basin or Subbasin	Eagle River	1%	1%	1%
	Upper Eagle River	3%	3%	1%
	Eagle River above Lake Creek	3%	3%	1%
	Eagle River above Gore Creek	1%	1%	< 0.5%
	Gore Creek	7%	7%	2%
	Homestake Creek	< 0.5%	< 0.5%	< 0.5%
Main Stem Only	Eagle River below Edwards	1%	2%	N/A
	Eagle River between Edwards and Minturn	4%	14%	N/A
	Gore Creek	35%	7%	2%

Imperviousness is often used as an indicator of stream health and the potential impact of urbanization on the landscape (Schueler, 1994). Effects associated with increased impervious cover include increased runoff, pollutant loading, and stream temperature, and decreased stream stability and biodiversity (Benke *et al.*, 1981; Schueler, 1994). Research has established that considerable stream degradation can be evident at low levels of imperviousness in some contexts. Many studies have identified an apparent threshold at which stream biotic integrity and/or geomorphic stability reach a degraded state (Klein, 1979; Booth and Reinelt, 1993; Schueler, 1994). This threshold varies from region to region depending on stream type and biological measure(s) used.

The percentage of impervious cover in the Eagle River watershed ranges from 0.9 to almost zero. When the focus of the analysis is reduced to a buffer zone surrounding the river, the percentage of impervious cover increases dramatically. To estimate imperviousness within the riparian corridor, typical imperviousness values were assigned to each land-cover type representing development. The values chosen to represent the various land-cover classes (Table 4.2) were based on the Natural Resources Conservation Service TR 55 (NRCS, 1986) recommended percent impervious values.

Table 4.2: Value of % Imperviousness used to represent the NLCD classifications for developed land cover.

NLCD Classification	% Imperviousness
Low-intensity Residential	30%
High-intensity Residential	65%
Commercial/ Industrial/ Transportation	70%

Percent imperviousness was estimated in specific sub basins, the riparian corridor, and the entire watershed (Table 4.3). The watershed identified in the analysis as the Upper Eagle Watershed represents the sub basin at the confluence of Gore Creek and the Eagle River. Regions classified as sub basin or basin included a 30- or 100-meter width on each side of the main stem and the tributaries. Main stem-only segments included a 30- or 100-meter width on each side of the main stem of the specified river or stream, but excluded the tributaries. Imperviousness values determined for each region represent conservative estimates of percent imperviousness given that imperviousness values associated with compaction and non-'developed' land cover were not included in this analysis.

Table 4.3: Imperviousness percentages for different regions in the watershed based on 1992 National Land Cover Data (Vogelmann *et al.*, 2001).

		Percent Imperviousness		
		30-m Buffer	100-m Buffer	Watershed
Basin or Subbasin	Eagle River	0.6%	0.5%	0.2%
	Upper Eagle River	1.3%	1.2%	0.3%
	Eagle River above Lake Creek	1.2%	1.2%	0.4%
	Eagle River above Gore Creek	0.4%	0.3%	0.1%
	Gore Creek	3.2%	3.1%	0.9%
	Homestake Creek	0.0%	0.0%	0.0%
Main Stem Only	Eagle River below Edwards	0.4%	0.9%	N/A
	Eagle River between Edwards and Minturn	2.7%	5.4%	N/A
	Gore Creek	13.7%	3.1%	0.9%

The results of the analysis demonstrate that the highest imperviousness within the basin occurs within the riparian corridors of the Eagle River and its tributaries. Due to the steep topography of the Eagle River watershed, this region is often the most feasible option for development due to the efficacy of construction and access. The riparian corridor is the region of the watershed that is most critical to ecological integrity, and like many other mountainous watersheds, is also the zone of greatest development pressure (Figure 4.6). Although the effects of imperviousness on stream biotic integrity vary with the connectedness of the impervious surfaces and best management practices, this analysis indicates that existing impervious areas alongside the Eagle River and its major tributaries are an important factor to consider in the management of water quality in the Eagle River watershed.

Figure 4.6: Land use change focused in the riparian corridor of Beaver Creek.

4.1.1 Future

Rapid growth is expected to continue in the watershed. A study to explore potential future land use was performed based on previous work by Eagle County. Along with the current dwelling unit analysis, the Eagle County Community Development (ECCD) Department completed a future dwelling unit estimation. The Dwelling Unit Analysis (ECCD, 2002) results provided estimates of the maximum number of dwelling units for each land unit or residential development based on current zoning. The future development intensities at maximum buildout for the Eagle River watershed were created from this information (Figure 4.7). The map indicates that the current locations of highest intensity are expected to intensify in the future, with the exception of Minturn and Vail. Rural regions having little or no development under current conditions are expected to increase to less than 1 dwelling unit per acre at buildout. The projected future locations of highest intensity will remain alongside the main stem of the Eagle River and its tributaries with intensity decreasing as distance from the river increases.

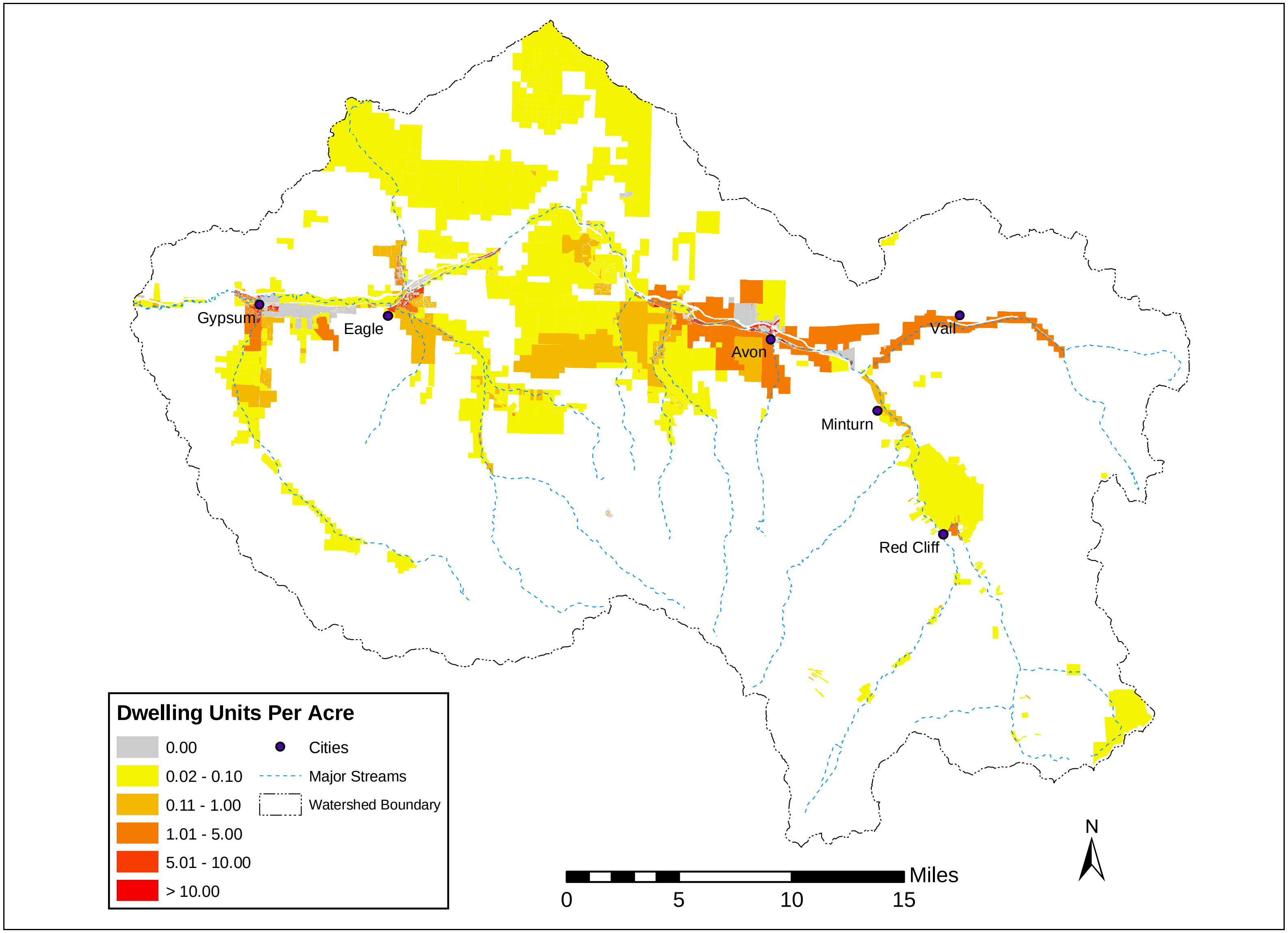


Figure 4.7: Future Dwelling Unit Intensity Map, based on the total number of potential future dwelling units per acre under current zoning (compare to Figure 4.1) (source: ECCD, 2002).

The Dwelling Unit Analysis is based on the assumption that zoning would not change within Eagle County in order to approximate maximum buildout. However, it is not uncommon to request a zoning upgrade in order to increase the number of dwelling units that can be built per acre. Therefore, future intensities may be greater than the Future Dwelling Unit Analysis Map indicates.

Geospatial data depicting future land-use projections other than the Dwelling Unit Analysis are not currently available. Thus, a comparable future estimate of imperviousness was not obtainable. Regardless, it is predicted that even at maximum buildout, the increase in future impervious cover values of the *entire basin* will not change substantially. However, with an increase in development pressure on the streamside zone, the imperviousness of the riparian corridor will increase, as will its influence on water quality.

4.1.2 Population Projections

Evaluation of past population growth statistics and future projections are helpful in estimating likely trends in future development, and can provide watershed managers with a framework for anticipating future development needs and potential environmental consequences. The population histories of the towns and unincorporated regions of Eagle County are shown in Table 4.4. While 98% of the Eagle River watershed falls in Eagle County, a small percentage of Eagle County, including the Town of Basalt, is located in the Colorado and Roaring Fork river basins.

Table 4.4: Historical census data for Eagle County (source: U.S. Bureau of Census).

	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
EAGLE COUNTY	3,608	2,985	3,385	3,924	5,361	4,488	4,677	7,498	13,320	21,928	41,659
Avon	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	640	1,798	5,561
Eagle	124	186	358	341	518	445	546	790	950	1,580	3,032
Gypsum	n/a	n/a	164	165	245	345	358	420	743	1,750	3,654
Minturn	n/a	241	298	400	596	509	662	706	1,060	1,066	1,068
Red Cliff	256	383	347	544	715	556	586	621	409	297	289
Vail	n/a	n/a	n/a	n/a	n/a	n/a	n/a	484	3,555	3,716	4,531
Unincorporated	3,219	1,940	2,033	2,326	3,075	2,460	2,312	4,058	5,434	10,637	21,572

In Eagle County, the population increased 90% from 1990 to 2000 (U.S. Bureau of Census), making it the fourth fastest growing county in the state. The percent of change within each area between 1980 and 2000 was computed and is presented in Table 4.5.

Table 4.5: Percent change in population in Eagle County between 1980 and 2000.

	1980	2000	% Change
EAGLE COUNTY	13,320	41,659	213%
Avon	640	5,561	769%
Eagle	950	3,032	219%
Gypsum	743	3,654	392%
Minturn	1,060	1,068	1%
Red Cliff	409	289	-29%
Vail	3,555	4,531	27%
Unincorporated	5,434	21,572	297%

The highest population growth in Eagle County does not necessarily correspond to the locations of the greatest number of dwelling units per unit area. The highest population growth between 1980 and 2000 occurred in the towns of Avon and Gypsum. The greatest number of dwelling units per unit area is currently in Vail and Beaver Creek, as shown in the Dwelling Unit Analysis Report. Looking at a shorter-term scale, the population growth from 2001 to 2002 followed a similar pattern (Table 4.6).

Table 4.6: Percent change in population in Eagle County between 2001 and 2002 (source: U.S. Bureau of Census).

	July 2001	July 2002	% Change
EAGLE COUNTY	43,497	45,819	5.3%
Avon	5,712	6,081	6.5%
Eagle	3,112	3,359	7.9%
Gypsum	3,980	4,584	15.2%
Minturn	1,106	1,120	1.3%
Red Cliff	296	299	1.0%
Vail	4,606	4,832	4.9%
Unincorporated	22,621	23,412	3.5%

The Colorado Division of Local Government (CDLG, 2003) used an economic-demographic projection system to forecast population growth for individual counties in Colorado at 5-year intervals (Table 4.7).

Table 4.7: Eagle County population projections (source: CDLG).

Year	Population	% Change
2000	43,354	
2005	49,601	2.7%
2010	56,816	2.8%
2015	64,436	2.5%
2020	72,157	2.3%
2025	79,673	2.0%
2030	86,842	1.7%

The total historical and expected future populations for Eagle County are shown jointly in Figure 4.8. The CDLG estimates that the population of Eagle County will double within the next 30 years. However, the population growth is projected to be less than what it has been in the past 10 years.

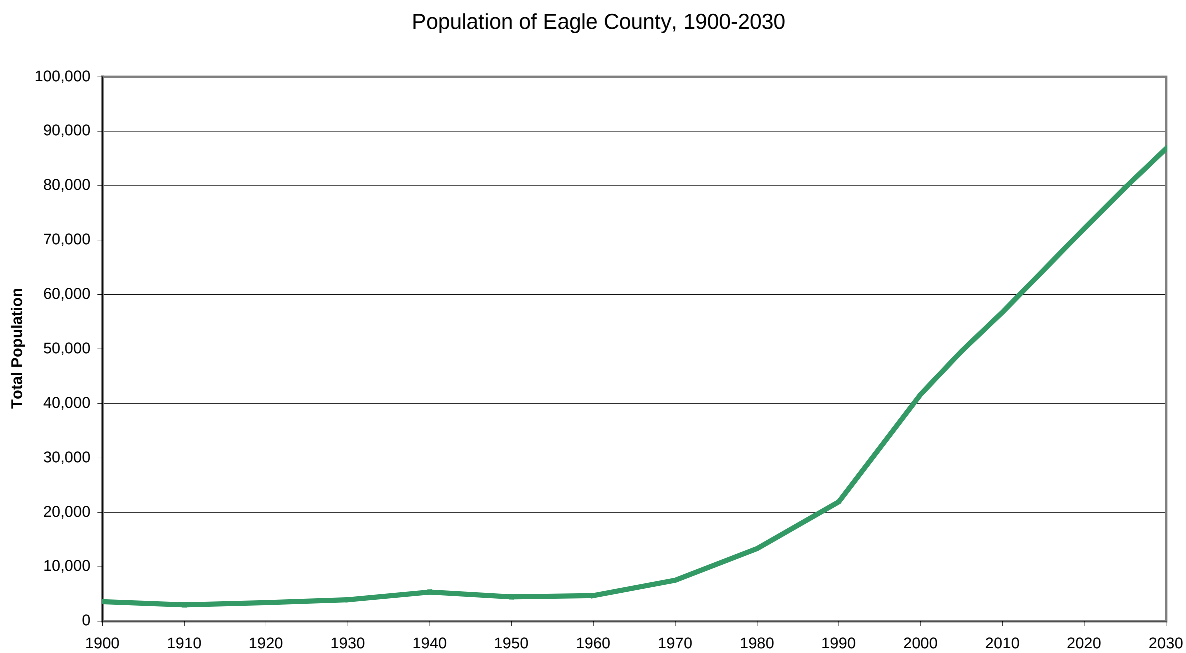


Figure 4.8: Population of Eagle County from 1900 to 2030 based on historical data and projections (sources: U.S. Bureau of Census and CDLG).

Watershed managers can use the population forecasts to estimate future domestic water needs for users in the Eagle River basin. An acre-foot of water is approximately 326,000 gallons, and is often estimated as the amount needed to satisfy the annual domestic needs of a family of four (Kenney, 2001). Water is used for domestic needs on a regular basis, with higher demands occurring during the peak tourist months of December through March, when river flows are frequently lowest. Based on the current projected population in 2030 of 87,000 persons, approximately 22,000 acre-feet of water will be needed to satisfy the domestic needs of the permanent population of Eagle County. In 1995, domestic water use accounted for 50% of the total withdrawals for public supply or approximately 4,600 acre-feet per year (USGS, 1995).

By 2030, at least 5 times this quantity will be necessary to meet the needs of domestic users. With a domestic consumptive use loss of 30% (USGS, 1995), an estimated 6,500 more acre-feet per year will be lost to consumptive use from domestic needs alone by 2030. Although this only reduces the total yield leaving the basin by less than 2%, the required domestic needs associated with increased population affect the magnitude and spatial distribution of streamflow throughout different regions of the basin, as well as the proportion of flow resulting from wastewater treatment effluent.

4.2 WATER USE

The United States Geological Survey (USGS) has compiled nationwide water use estimates at 5-year intervals since 1950. Water use data for the Eagle River watershed were available for the years 1985, 1990, and 1995, but not for 2000. Sources of the data and the accuracy of the estimates vary for each of the water use categories. The USGS data were gathered from numerous governmental agencies, and were derived from field reconnaissance, evaluation of measured or estimated data, and through the use of coefficients, accounting methods, and models (Solley *et al.*, 1998). The estimates of water use are expressed as average daily quantities. For irrigation, which is only delivered at particular times of the year at varying rates, the actual rates of application are much greater than what is shown in the report as average daily quantities (Solley *et al.*, 1998). It is also important to note that the USGS water use data only include water use within the basin, and do not account for transmountain water use. Each category of water use includes an estimate of consumptive use.

4.2.1 Public Supply

Public supply water use refers to both ground and surface water that is withdrawn by public and private suppliers for delivery to commercial, domestic, industrial, and thermoelectric power users (Solley *et al.*, 1998). The difference between the water supplied and the water delivered represents losses associated with the distribution system, filter back flushing, and public uses such as firefighting, public parks and swimming pools, and street washing (Solley *et al.*, 1998). Figures 4.9 and 4.10 illustrate the source and delivery of the public water supply in the Eagle River watershed.

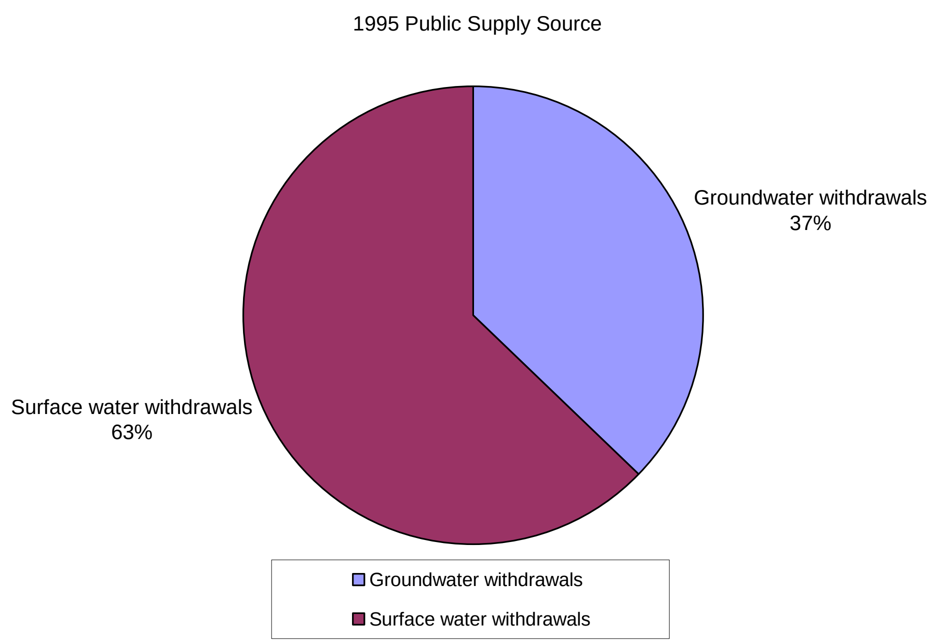


Figure 4.9: 1995 Public supply source in the Eagle River watershed.

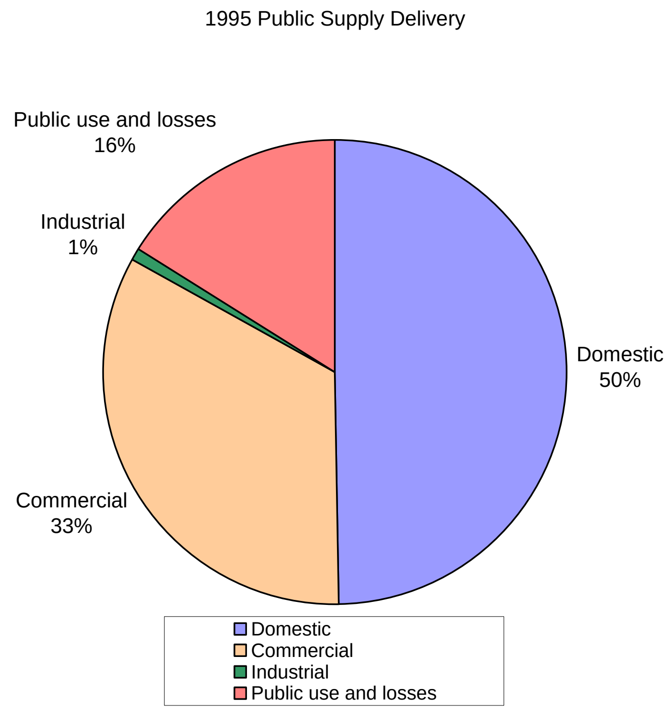


Figure 4.10: 1995 Public supply deliveries in the Eagle River watershed.

The quantity of water withdrawn for public supply in the Eagle River watershed in 1995 was estimated at an average rate of 8.1 MGD, which is 44% more than the withdrawal rate estimated from the previous analysis in 1990 (see Table C.1 in Appendix C). Groundwater contributed to 37% of the public supply source and surface water contributed to 63%. The distribution of the deliveries included 50% domestic, 33% commercial, 1% industrial, and 16% to public use and losses. The public supply served nearly 22,000 people, which is 99% of the total population, and represents an increase of 31% from 1990. Total public supply withdrawals averaged 370 gallons/day for each person served, compared to state average of 210 gallons/day per person served and the nationwide average of 179 gallons/day per person served (Solley *et al.*, 1998).

4.2.2 Domestic Use

Domestic water use includes all water associated with household uses, including drinking, bathing, cooking, washing clothes, flushing toilets, and watering lawns (Solley *et al.*, 1998). Four million gallons per day were withdrawn for domestic water use in the Eagle River Basin in 1995, 0.02 MGD of which was self-supplied through groundwater withdrawals. The 1995 total domestic water use has decreased about 5% since 1990, representing a difference of 0.21 MGD. Domestic consumptive use accounted for 1.2 MGD, also a 5% decrease from 1990.

The slight decrease in domestic water use and domestic consumptive use may be attributable to climatic differences and lawn watering habits. In 1990, 20 inches of snow water equivalent (SWE) were recorded at Vail, as opposed to 1995, when 31 inches of SWE were recorded. Further investigation of the Vail climate station data identified 41 rainy days and a maximum daily average temperature of 78 degrees Fahrenheit during the peak lawn-watering season (June through September) in 1990. However, in 1995, the number of rainy days increased to 52 days and the maximum daily average temperature was only 70 degrees Fahrenheit. When combined, these results suggest that more soil moisture was available during the peak lawn-watering season in 1995 than in 1990. Decreased domestic consumptive use from 1990 to 1995 may largely reflect this difference.

4.2.3 Commercial Use

Commercial water use includes deliveries to commercial facilities, including motels, hotels, golf courses, restaurants, and office buildings, in addition to military and civilian establishments (Solley *et al.*, 1998). Between 1990 and 1995, commercial water use in the Eagle River watershed doubled, from 1.5 MGD to 3.0 MGD. Commercial use consisted of 0.31 MGD of self-supplied groundwater and 2.7 MGD delivered from the public supply. An estimated 450,000 gallons per day were used for commercial consumptive use, an increase of 96% from 1990.

4.2.4 Industrial Water Use

Industrial water use refers to water used by manufacturing companies for cooling, processing, and washing products. Such industrial uses may include the manufacture or refining of steel, chemicals, paper, and petroleum (Solley *et al.*, 1998). In the Eagle River watershed, only one facility was considered for industrial water use in 1995. Total withdrawals for industrial use were 0.27 MGD: 0.06 MGD from public supply delivery, 0.15 MGD from self-supplied groundwater withdrawal, and 0.06 MGD from self-supplied surface water. Consumptive uses associated with industrial water use included 0.1 MGD. Industrial water use remained unchanged from 1990 to 1995.

4.2.5 Irrigation Water Use

Irrigation is by far the greatest consumptive use of water in the western United States (Figure 4.11). This category of water use consists of water conveyed to farms and horticulture fields, in addition to self-supplied water for the irrigation of public and private golf courses (Solley *et al.*, 1998). Publicly supplied irrigation of golf courses is considered under the commercial use category. The USGS categorizes all irrigation water as self-supplied, even though it may originate from other irrigation companies or districts (Solley *et al.*, 1998). In 1995, the total water withdrawal for irrigation use in the Eagle River watershed was approximately 66 MGD, a decrease of 30% from 1990, and a decrease of 58% since 1985.

Figure 4.11: Irrigation is the leading inbasin consumptive use in the Eagle River watershed.

Figure 4.12 presents the disposition of irrigation water in the Eagle River watershed in 1995. According to the USGS water use database, only 20% of irrigation water is lost to consumptive use. Thirty percent of the irrigation water is lost in conveyance, defined as the loss of water "in transit from a pipe, canal, conduit, or ditch by leakage or evaporation," (Solley *et al.*, 1998). Some of this water may return to ground water through percolation of the soil or material lining the ditch or canal. A considerably high quantity, 50% of the irrigation water, returns to the surface or groundwater after its discharge from the point of use. This quantity is termed the return flow.

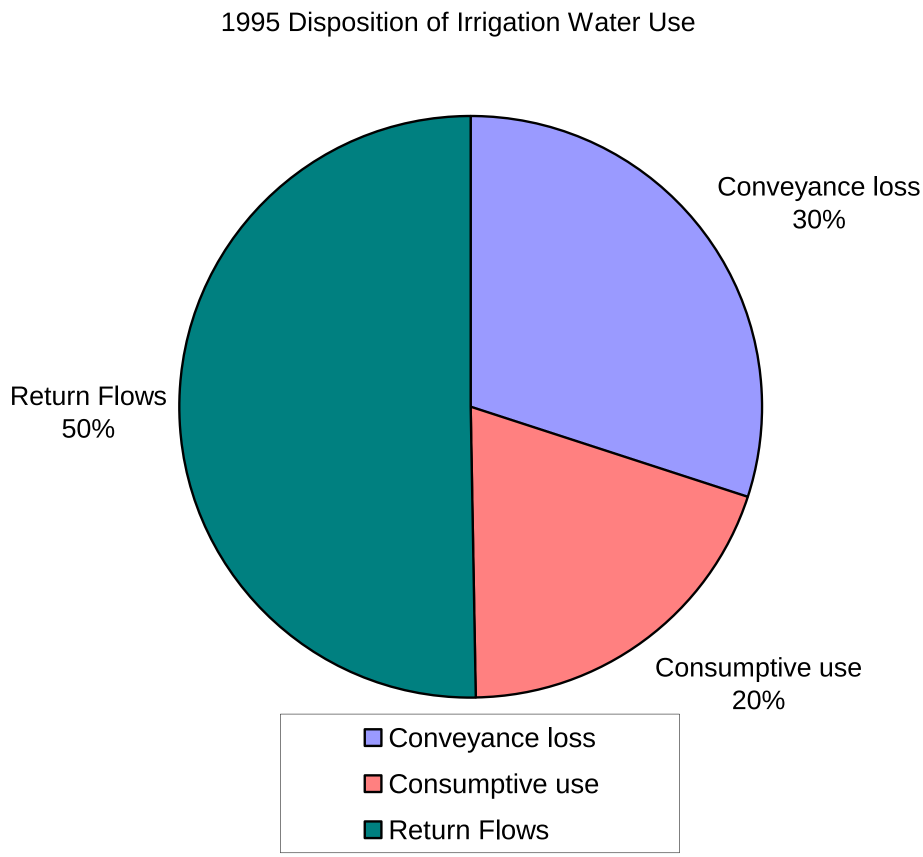


Figure 4.12: Disposition of irrigation water use in the Eagle River watershed in 1995.

The area of land irrigated in the Eagle River Basin decreased from 23,000 acres in 1985 to approximately 10,000 acres in 1995, a decrease of 58% across 10 years, averaging a decrease of 5.8% a year. In 1995, irrigation consumptive uses averaged 13 MGD, a decrease of 52% since 1990. Return flows dropped from 92 MGD in 1985 to 33 MGD a day in 1995, a decrease of 64%. Figure 4.13 illustrates the decline in the irrigation water use, consumptive use, and return flows from 1985 to 1995.

An obvious downward trend is present in the basin for irrigation water withdrawals, return flows, and consumptive use. Conveyance loss is not included in Figure 4.13 because a portion of the water lost through conveyance returns to the river, and the remaining water is lost through evaporation. Currently, no methods are available to measure the distribution of water lost through conveyance. The potential effect of decreased irrigation withdrawals is further discussed in Section 4.4.10.

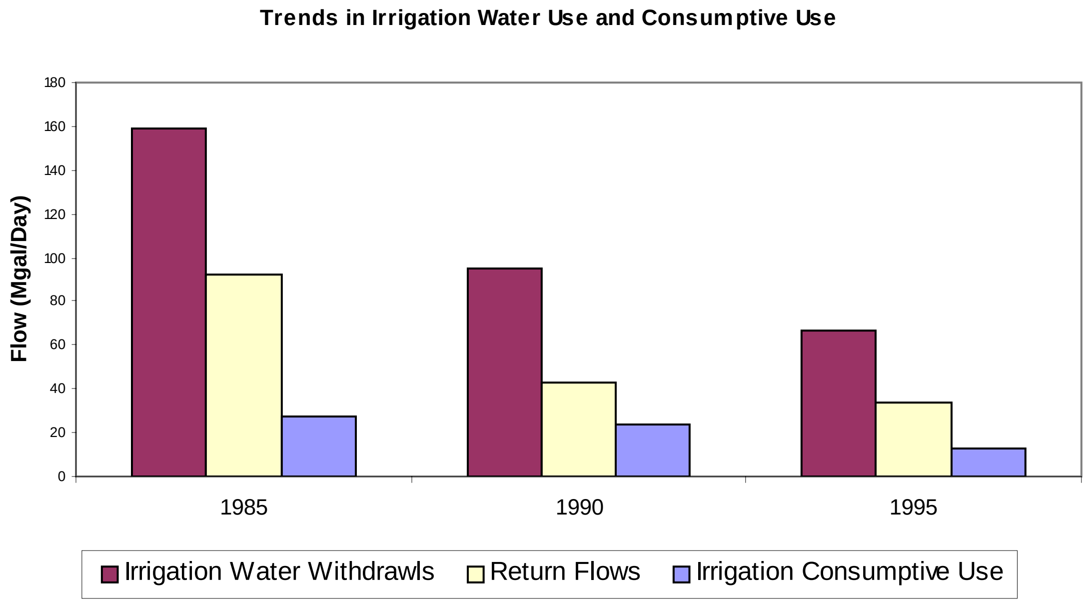


Figure 4.13: Decline of irrigation water use and consumptive use in the Eagle River watershed from 1985 to 1995.

4.2.6 Livestock Water Use

Livestock water use is comprised of water used for livestock, feedlots, fish farms, and other farm needs (Solley *et al.*, 1998). In the Eagle River watershed, the livestock category only referred to water associated with the production of red meat, poultry, eggs, meat, and wool. Based on the number and types of animals in the basin, total water withdrawal from the basin was estimated as 0.16 MGD, a decrease of 6% from 1990. All water used to support livestock was estimated as being used to extinction.

4.2.7 Mining Water Use

Mining water use is considered as water used for the extraction of naturally occurring minerals, including solids, liquids, and gases (Solley *et al.*, 1998). All activities associated with mining, including milling, quarrying, and other operations are incorporated in this category. Mining use in the Eagle River Basin included self-supplied groundwater withdrawals only, at a rate of 0.07 MGD in 1995, an increase of more than 130% from 1990. All of the water withdrawn for mining activities in the watershed is considered consumptive use.

4.2.8 Wastewater Treatment

Wastewater releases and return flows from treatment plants contribute to the water use within the Eagle River watershed. In 1995, eight facilities were recognized in the basin, seven of which were public and one considered “other.” Publicly owned facilities treat wastewater from multiple types of users, including domestic, commercial, and industrial. Treatment facilities in the “other” category are typically privately owned and include commercial and industrial plants that receive and treat their own wastes. In 1995, about 5 MGD were reported as average total return flow rates from the seven public treatment plants, an increase of

13% from 1990. Return flows are released directly into stream channels and are not considered in estimates of consumptive use.

Reclaimed wastewater is defined by the USGS as treated wastewater effluent that has been diverted for beneficial use before reaching a natural waterway. With conservation of such high importance to the western United States, the technique of utilizing reclaimed wastewater for such purposes as irrigation of golf courses and public parks and industrial use is becoming more popular. No reclaimed wastewater was released by public facilities in 1995.

Reclaimed wastewater can be useful for supplying water needed for various purposes and freeing up freshwater that can be used for other beneficial uses. Although no basin-wide wastewater reclamation projects are currently operational in the Eagle River watershed, the Eagle River Water and Sanitation District (ERWSD) implements several small programs with local contractors and businesses. In addition to irrigating all ERWSD land with reclaimed wastewater, the three wastewater treatment plants under their jurisdiction (Vail, Avon, and Edwards), provide reclaimed wastewater to contractors for dust control and concrete mixes and to landscape companies for hydroseeding purposes (Bob Trueblood, ERWSD, pers. comm., 7/2/04). Hydroseed is an inexpensive method for planting a new lawn through the use of a variety of grass seeds mixed with water, fiber, and fertilizer. Opportunity exists in the Eagle River watershed for additional wastewater reclamation projects.

4.2.9 Consumptive Use

Consumptive use analysis is essential for estimating how human activities can influence flow levels in rivers and streams. Decreased flows due to consumptive use within the basin may contribute to the decline of biodiversity in aquatic ecosystems, especially during low flow conditions. The importance of flow regime to sustainable aquatic ecosystems is clear and well supported, as further discussed in Section 4.4. From an examination of consumptive use, it is also possible to reconstruct the historical hydrograph of the river and determine human alterations to the natural flow regime.

All available data from two databases were used to analyze consumptive use in the basin. The USGS water use database provided consumptive use broken down by the general water use categories as estimates of average daily rates for the years 1985, 1990, and 1995. The Colorado Decision Support System (CDSS) StateCU (Consumptive Use) Model was used to analyze the monthly average consumptive use. The CDSS data were presented as estimates of average monthly values for the time period of 1986 to1990.

4.2.10 USGS

Consumptive use data from the USGS water use database were defined as the water withdrawn from the system that is lost through evaporation, transpiration, incorporation into crops or products, consumption by humans and livestock, or otherwise removed from the local water system. Data for consumptive use were available in millions of gallons per day (MGD) associated with each water use. Table 4.8 is a compilation of the consumptive use data from the USGS. Unlike the CDSS, this information does not include water withdrawn from the watershed for transmountain diversions.

Table 4.8: USGS consumptive use for 1985, 1990, 1995.

Consumptive Water Use	Units	Year		
		1985	1990	1995
Commercial	MGD	0.25	0.23	0.45
Domestic	MGD	0.75	1.3	1.2
Industrial	MGD	0	0.1	0.1
Mining Use	MGD	0.03	0.03	0.07
Livestock (stock) Use	MGD	0.13	0.17	0.16
Irrigation Use	MGD	28	24	13
Total Consumptive Use	MGD	29	25	15
Total Consumptive Use	acre-ft/ yr	32,000	29,000	17,000

A downward trend in the total inbasin consumptive use is notable. The majority of the consumptive use is associated with irrigation. Since the number of irrigated acres changed so drastically between the years 1985 and 1995 (Figure 4.6), consumptive use has followed a similar trend. The distribution of consumptive use for 1995 is shown in Figure 4.14.

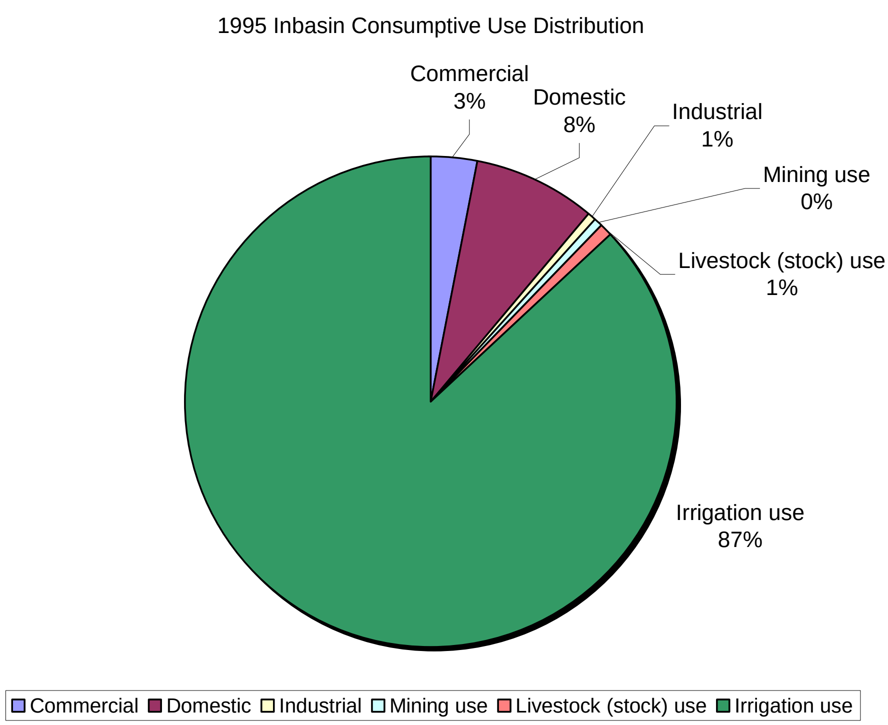


Figure 4.14: Distribution of consumptive use in the Eagle River watershed for 1995 (source: USGS water-use database).

Without the incorporation of transbasin export, irrigation is by far the leading contributor of consumptive use in the basin with 87% of the basin total, followed by domestic consumptive use with 8% of the total. Commercial consumptive use accounts for 3% of the total while livestock and industrial use each account for 1%. The consumptive use due to mining is negligible. As irrigation lands continue to decrease in number and the population of the region continues to climb, domestic consumptive use will most likely increase unless additional conservation techniques are employed.

4.2.11 Colorado Decision Support System (CDSS)

The consumptive use data can be used to approximate the natural hydrograph that would occur in the absence of the consumptive use withdrawals. The CDSS data were chosen for this purpose because the values account for transbasin diversion and were available by month. For the purposes of the CDSS, consumptive use is considered any water leaving a managed water system of a given region by human activities. The StateCU model includes a graphical user interface that provides estimates of municipal, irrigation, livestock, reservoir, export, mineral resource, stockpond, thermal electric, fish and wildlife, and recreational consumptive uses within a specific area. The analysis for Eagle County had no consumptive use associated with the latter four categories. In addition, the export data within StateCU only included the Wurtz Ditch as being an export within Eagle County. Therefore, to provide accuracy in the analysis, the Ewing Ditch, Columbine Ditch, and Homestake Tunnel were added into the dataset to determine overall consumptive uses in the Eagle River watershed. The irrigation portion of the data was run separately through the model. Only the irrigation structures within the Eagle River watershed were included in the analysis. The data were provided as average monthly values for the years 1986 to 1990. After running the model and adjusting the data to represent all transbasin diversions in the Eagle River watershed, the consumptive use related to each categorical activity was determined, as shown in Table 4.9. This analysis differs from the USGS dataset because it includes the export data.

Table 4.9: CDSS monthly average consumptive use in acre-ft for the years 1986 to 1990 (sources: CDDS StateCU model, CDDS HydroBase published data).

Consumptive Water Use (in acre-ft)	Month of the Year												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Livestock	21.3	19.2	21.3	20.6	21.3	20.6	21.3	21.3	20.6	21.3	20.6	21.3	250.4
Reservoir	0	0	67.8	165.6	313.2	414.6	432.8	295.8	240.2	127.4	18.6	0	2076
Municipal	64.3	58.1	77.2	87.1	102.9	161.8	205.8	167.2	112	90.1	74.7	64.3	1265.7
Mineral Resource	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	33.6
Irrigation	0	0	0	751	1903	3552	3612	3414	1692	545	0	0	15473
Columbine Ditch	0	0	0	0	309	993	185	37	0	0	0	0	1524
Ewing Ditch	0	0	0	9	251	402	122	44	15	0	0	0	853
Wurtz Ditch	0	0	0	18	814	1188	249	45	0	0	0	0	2314
Homestake Tunnel	2094	2123	2189	1592	2304	1168	2241	2700	4551	1306	954	598	23820
Total Consumptive Use in Watershed	2182	2203	2359	2645	6021	7903	7072	6727	6634	2092	1071	686	47609
Average Yield at Eagle River Below Gypsum	14046	12737	11071	10118	8904	10714	20443	66853	98833	33976	15348	11445	276634

Figure 4.15 demonstrates that the transmountain diversions within the watershed are causing 60% of the consumptive use in the basin, followed by irrigation with 32%. The combined municipal and reservoir consumptive use account for 7% of the total while livestock and mineral resource consumptive use is responsible for less than 2% of the total.

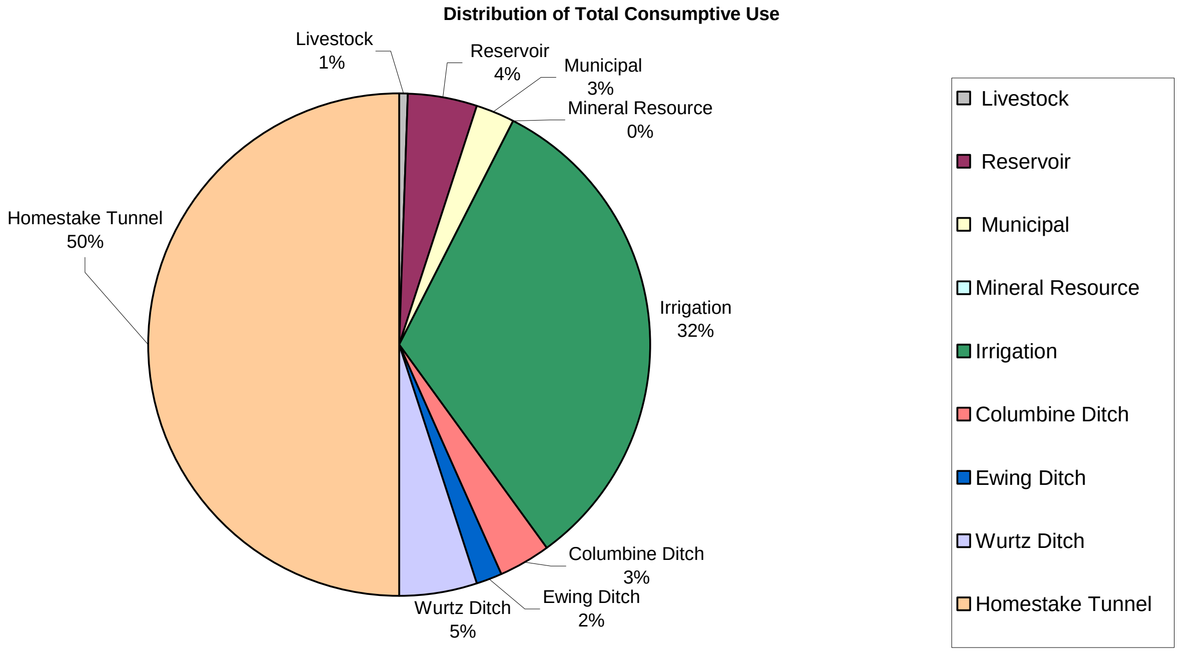


Figure 4.15: Total distribution of consumptive use (including exports).

The locations of the consumptive use are widely spread throughout the basin. Irrigation consumptive use is primarily present in the lower portion of the watershed. Reservoir evaporation is most detectable in the Upper Eagle watershed, and municipal consumptive use is greatest in the towns and unincorporated areas nearby the river. Consequently, the most appropriate USGS stream gage to use in the analysis was the downstream-most gage in the basin, Eagle River below Gypsum. From this gage, the average monthly streamflow yield values were determined between the years 1986 and 1990. The natural hydrograph was generated by adding the values of consumptive use to the monthly streamflow yield values. The resulting hydrograph represents the expected average monthly values, expressed as average volumetric flow rates of water, which would have occurred in the absence of consumptive use during this period (Figure 4.16).

Although upon first glance, it appears that there is not much of an effect from consumptive use on the hydrograph, there is, in fact, a significant change, especially considering the size of the watershed. A paired t-test was used to determine that the pre- and post-consumptive use flow data were significantly different at the 95% confidence interval. The gage under consideration incorporates all of the tributary and runoff flow in 944 square miles of the 972 square mile watershed. Therefore, consumptive use effects are more pronounced at upstream locations, especially the effects of transmountain diversions in the upper Eagle River and Homestake Creek.

The analysis of consumptive use indicates that consumptive water withdrawal is modifying the flow regime in the Eagle River watershed. The following section of the report explores specific changes in the flow regime throughout the watershed in much greater detail.

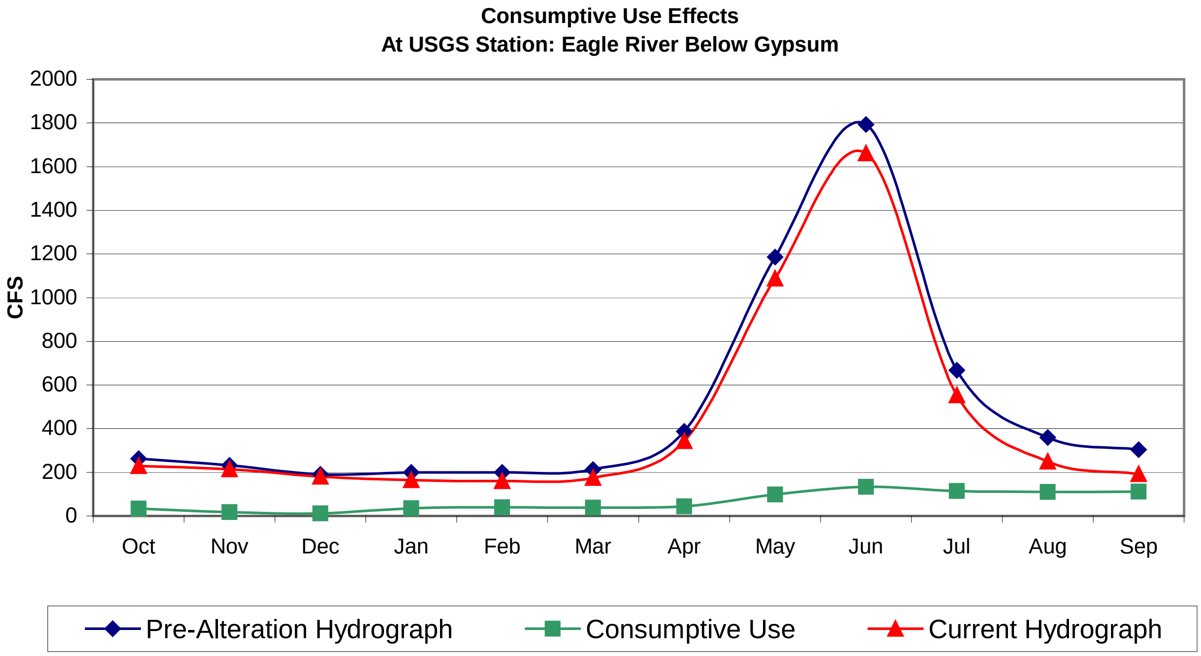


Figure 4.16: A comparison of the natural hydrograph and the current hydrograph of the streamflow at the USGS gage Eagle River below Gypsum.

4.3 WATER RIGHTS

Water rights in the Eagle River watershed date back to the late 1800s. As farming and cattle ranching increased, so did the demand for water. Municipal rights were later decreed for water users in the Eagle River watershed and on the Front Range. The rights were apportioned as storage or rate rights. Many of the rights were also limited by season. For example, irrigation water was typically allocated during the months of April through October.

In Colorado, water rights are classified as absolute or conditional rights. An absolute right is one that has been assigned to a beneficial use. A conditional right, however, is one that is fixed in priority by the court despite the lack of the completion of the appropriation. This ensures that the water that was available at the initiation of a project will still be available for the water right holder after the completion of the project. Every six years, the holder of the conditional water right must prove to the court that progress has been made toward the completion of the project for which the water right is adjudicated. Upon project completion, the court will change a conditional right to an absolute right with a priority date of the initial right. A brief summary of some relevant aspects of Colorado water law is presented in Appendix D of the ERIA.

The Colorado Decision Support System (CDSS) Hydrobase is a database of all of the water rights and water resource structures in Colorado (http://cdss.state.co.us). According to CDSS, over 3,000 water rights and over 1,700 structures, including headgates, dams, reservoirs, and wells, exist in the Eagle River watershed (Figure 4.17). More than 1,000 of the structures are headgates for water diversion. Table 4.10 illustrates the quantity of rights by volume and by rate broken down as absolute or conditional for each tributary and the main stem Eagle River.

Water rights within the basin, in terms of sheer volumes, are allocated far beyond the actual capacity of the main stem and it tributaries as shown in Table 4.10. At the Gypsum gage, the average annual yield is 410,000 acre-ft, compared to the total water rights in the basin, which represent nearly 650,000 acre-ft per year. As described in Section 4.2.9, the total consumptive use *within* the basin is estimated to be only 17,000 acre-ft per year.

A comparison of streamflow versus the quantity of water allocated through water rights is complicated by the timing and quantity of return flows throughout the watershed. Return flows represent the quantity of water conveyed back to surface water or groundwater after being used for a specific purpose. Therefore, all water that is not consumed, lost in conveyance, or stored is expected to return to a surface or groundwater source. Irrigation return flows are most likely occurring in highest quantities between late summer and March, while domestic return flows are distributed throughout the year based on water and wastewater treatment effluent patterns. Comparing yield with water quantities allocated through rights is difficult because of the timing associated with the irrigation rights, the levels of seniority in rights, and the differences in rights by rates and rights by storage. For example, reservoirs are given rights by storage, but water rights diverted from the reservoirs are rate rights. Both are included in the above summary.

Rights on the Colorado River generate additional complexity in identifying the potential for water shortages in the Eagle River and its tributaries. When senior water rights downstream of the Eagle River on the main stem of the Colorado River are not met, a "call" is made and upstream junior rights are put on hold. Just downstream of Dotsero, the Shoshone Power Plant, shown in Figure 4.18, has an original appropriation date of 1902 with a decreed capacity of 1,250 cubic feet per second (cfs), which was increased to over 1,400 cfs in 1929 (CDSS, 2004). When this right is not met, the water rights of junior users in the Eagle River watershed are suspended. This enhances the consistency of the base flow rate through the Eagle River.

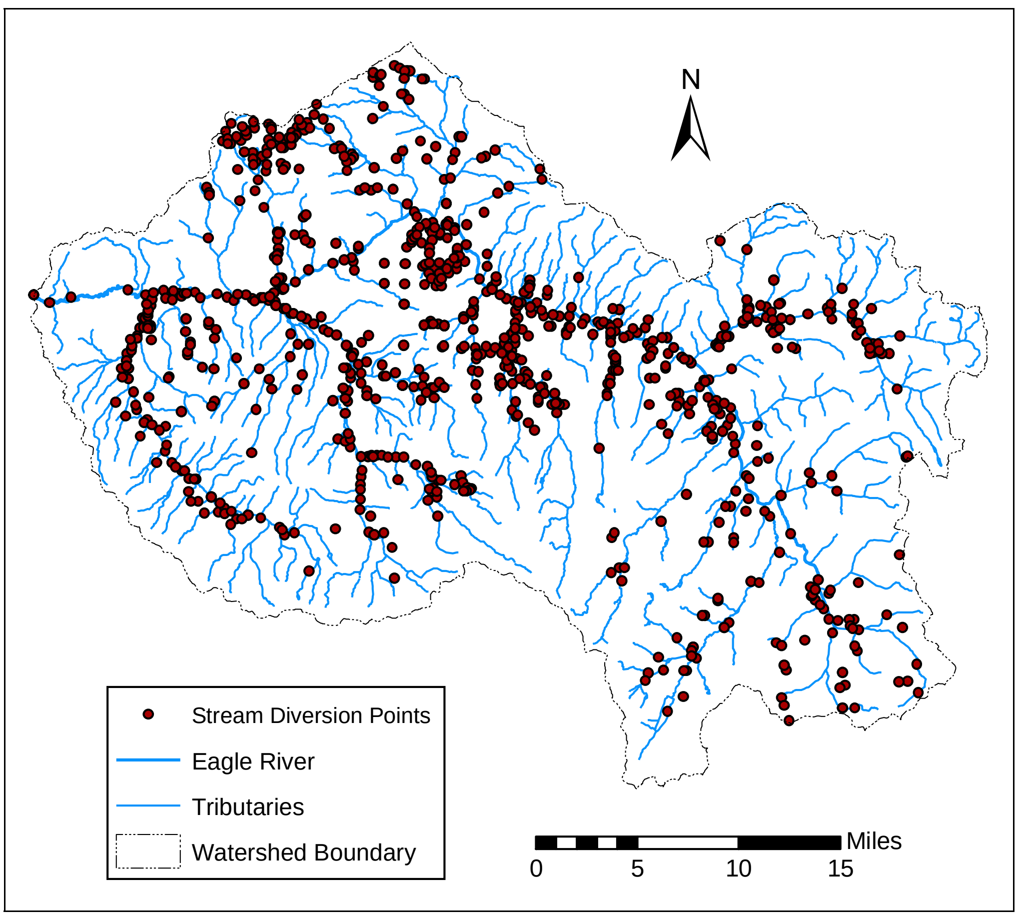


Figure 4.17: Eagle River watershed stream diversion points.

Table 4.10: Water rights in the Eagle River watershed categorized as either rates or volumes and as conditional or absolute (source: CDSS, 2004).

Stream/River Name	Total Absolute Rate (cfs)	Total Absolute Storage (acre-ft)	Total Conditional Rate (cfs)	Total Conditional Storage (acre-ft)
Alkali Creek	21.07	343.60	41.11	350,000.29
Beard Creek	4.59	0.20	2.07	2.50
Beaver Creek	99.43	226.00	8.00	0.00
Berry Creek	12.29	0.00	0.00	0.00
Bishop Creek	0.00	0.00	0.00	0.00
Brush Creek	418.18	937.06	174.17	9,305.22
Buck Creek	2.00	0.00	0.00	0.00
Castle Creek	14.29	7.11	10.34	7.00
Cataract Creek	1.00	0.00	90.00	0.00
Cross Creek	84.50	2,185.00	994.00	0.00
Eagle River	1,070.04	3,910.39	3,777.15	495.48
Eby Creek	39.54	1,132.54	1.35	47.14
Elk Creek	0.00	0.00	0.00	0.00
Fall Creek	22.00	1,824.00	280.00	0.00
Game Creek	3.05	0.00	0.00	0.00
Gore Creek	195.84	430.56	1,271.93	920.85
Grouse Creek	41.44	8.00	10.50	0.00
Gypsum Creek	279.77	1,188.64	50.96	600.00
Holland Creek	4.72	0.00	2.29	67.00
Homestake Creek	744.48	44,777.70	2,459.83	219,425.00
Jones Gulch	0.00	0.00	144.00	0.00
June Creek	9.26	38.00	2.67	0.00
Lake Creek	169.90	1,834.02	53.29	30.82
Long Creek	0.00	0.00	0.00	0.00
McCoy Creek	13.43	0.00	5.00	500.00
Milk Creek	62.29	300.00	3.12	0.00
Nontributary	0.19	0.00	0.03	0.00
Nottingham Creek	7.83	0.00	0.00	0.00
Peterson Creek	0.00	0.00	90.00	0.00
Piney Creek	103.50	0.00	725.00	0.00
Red Canyon Creek	0.00	0.00	1.00	5.00
Reese Creek	0.00	0.00	0.00	0.00
Rock Creek	1.00	0.00	0.00	0.00
Rule Creek	0.50	0.00	0.00	0.00
Sheep Gulch	0.00	0.00	20.00	0.00
Short Creek	0.00	0.00	0.00	0.00
Smith Ditch	0.80	0.00	0.00	0.00
Spring Creek	10.97	10.00	6.90	48.00
Squaw Creek	21.42	1.33	4.31	7.27
Stone Creek	42.81	5.19	2.33	0.00
Talmage Creek	6.30	5.57	6.00	36.30
Traer Creek	1.20	0.00	0.00	0.00
Travis Creek	3.57	0.00	4.24	24.00
Turkey Creek	20.51	0.00	0.07	3.00
Two Elk Creek	4.00	0.00	0.00	0.00
Unknown Tributary	0.02	0.00	0.00	0.00
Ute Creek	0.20	0.00	0.00	65,975.00
Warren Gulch	0.13	0.00	0.00	0.00
Whiskey Creek	2.53	0.00	0.00	55.20
Willow Creek	6.00	36.90	0.22	0.00
Yoder Creek	1.00	60.00	0.00	0.00
Total	**3,547.59**	**59,261.81**	**10,241.89**	**647,555.08**

Figure 4.18: Shoshone Dam (courtesy of http://rockymountainscenery.com/glenwood/).

4.3.1 Diversions

4.3.1.1 Major Reservoirs

There are several large reservoirs used for recreation, irrigation, snowmaking, flow augmentation, domestic water supply, and industrial purposes within the Eagle River basin. These reservoirs are all shown in Figure 4.19.

Constructed between 1963 and 1967 as part of the Homestake Project, the Homestake Reservoir is the oldest major reservoir in the Eagle River Basin (Figure 4.20). It is managed and owned by the cities of Aurora and Colorado Springs, with equal share in cost and water yield. Homestake Reservoir has a capacity of 45,000 acre-ft.

The two Black Lakes Reservoirs were built on Black Gore Creek in 1993 by the Colorado Department of Wildlife and Vail Valley Water District on the west side of Vail Pass (Figure 4.21). With an estimated combined capacity of 300 acre-ft, they are used to augment flows and replace water diverted for snowmaking.

The Eagle Park Reservoir is owned and operated by the Eagle Park Reservoir Company with a decreed capacity of 5,300 acre-ft (Figure 4.22). Along with the Robinson Reservoir, it was originally built to supply water for industrial purposes, and retain tailings from mine waste. Eagle Park Reservoir has been rehabilitated for water supply.

Other water storage facilities include Nottingham Lake, Sylvan Lake, and Lede Reservoir. Located in the Town of Avon, Nottingham Lake has a 100 acre-ft capacity and is primarily used for recreation. Sylvan Lake provides 500 acre-ft of storage for the Town of Eagle. Lede Reservoir is a privately owned irrigation water storage facility on National Forest Land south of Gypsum. The Town of Gypsum has historically leased some water rights from the owner of the Lede Reservoir. The facility is also used for public recreation (*1996 Eagle River Watershed Plan*; CDSS, 2004). An additional 130 acre-ft reservoir that stores water for snowmaking use at Beaver Creek Resort is located on Beaver Creek Mountain. Each year, Vail Resorts typically draws 1,000 to 1,200 acre-ft of water from the Eagle River and its tributaries for snowmaking purposes.

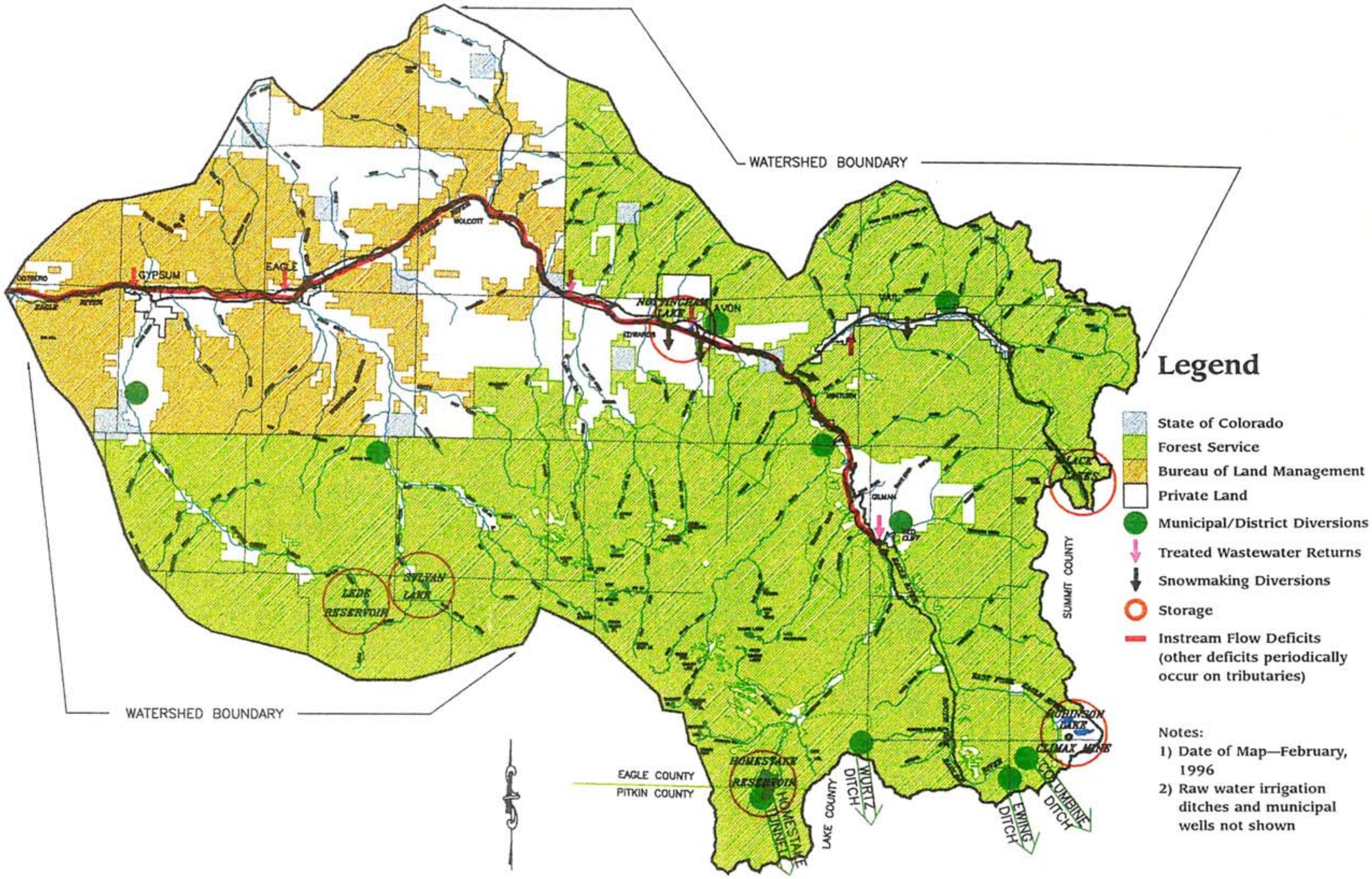


Figure 4.19: Eagle River watershed water quantity issues (*1996 Eagle River Watershed Plan*).

Figure 4.20: Homestake Reservoir; conditional storage rights totaling nearly 220,000 acre-ft exist in the Homestake drainage basin.

Figure 4.21: Black Lakes, June 18th, 2004.

Figure 4.22: Eagle Park Reservoir with Robinson Reservoir in the background.

4.3.1.2 Transmountain Diversions in the Eagle River Watershed

There are four transmountain diversion structures that export water from the Eagle River watershed. Although the denotations of diversion structures are often used interchangeably, there is a difference between transmountain diversions and transbasin diversions. A transbasin diversion applies to a diversion structure that transports water to another watershed, which ultimately flows to the same ocean, while a transmountain diversion exports water from one slope of the Continental Divide to another (Winchester, 2001). In the Eagle River basin, four transmountain diversions transport water to the east slope. Their locations are shown in Figure 4.19.

The interbasin transfer of water in Colorado, the oldest diversion to the Arkansas River Basin, and the oldest diversion still in use in the Eagle River watershed is the Ewing Ditch (Winchester, 2001; Grigg, 2003). Located off of Piney Creek, the Ewing Ditch transports water to Tennessee Creek in the Arkansas River basin. The 1.5 mile long ditch was constructed in 1880 for placer mining in the Arkansas Basin and has an appropriation date of June 1, 1906. The water right was adjudicated on November 13, 1911 with a decreed capacity of 18.5 cfs from April 18th to October 28th (CDSS, 2004). The diversion point is located at an elevation of approximately 10,500 ft and intercepts water from a drainage area of 2,400 acres. In 1955, the Pueblo Board Water Works purchased the Ewing Ditch and changed the use from irrigation to municipal (Winchester, 2001). The 10-year average annual diversion yield from 1992-2001 was 1,092 acre-ft. In 2002, the diversion yield was 192 acre-ft (CDSS, 2004).

The next major transmountain diversion system, the Wurtz Ditch (Figure 4.23), was built in 1929 for the irrigation of land in the Arkansas River basin. The Wurtz ditch intercepts water in the South Fork of the Eagle River and diverts it to the Tennessee Creek in the Arkansas basin. The ditch has an appropriation date of June 8th, 1929 and a decreed a right of 85.0 cfs from April 18th to October 28th, not to exceed a volume of 4,083 acre-ft in any one year. The right is currently owned by the Pueblo Board of Water Works, which modified the use from irrigation to municipal in 1993. The 10-year average annual diversion yield from 1992-2001 was 2,863 acre-ft. In 2002, the diversion yield was 647 acre-ft (CDSS, 2004).

Figure 4.23: Wurtz Ditch flowing from headgate during summer, 2003.

The Pueblo Board of Water Works also owns the Columbine Ditch, constructed in 1931 for supplemental irrigation uses. Located approximately 13 miles north of Leadville, the Columbine Ditch exports water from the headwaters of the East Fork of the Eagle River to Chalk Creek in the Arkansas River basin. The water rights through the Columbine Ditch total an absolute net rate of 60 cfs from April 28th to October 21st. The rights were appropriated on June 21st, 1930 and adjudicated on October 3, 1946. In 1993, the beneficial use was changed from agricultural to municipal and other uses. The 10-year average annual diversion yield from 1992 to 2001 was 1,831 acre-ft. In 2002, the diversion yield was 780 acre-ft (CDSS, 2004)

The largest export from the basin occurs through the Homestake Tunnel, which was part of the Homestake Project constructed in 1965. The project collects water from several tributaries along Homestake Creek, including the Middle Fork Homestake Creek, the East Fork Homestake Creek, and Homestake Creek. The waters are stored in the reservoir for conveyance through the 5.2-mile long Homestake Tunnel into the Turquoise Reservoir in the Arkansas River basin (USGS, 2004b). The cities of Aurora and Colorado Springs own the water rights and transfer the water to the South Platte River basin through the Otero Pump Station. The rights have an appropriation date of September 22nd, 1952 and an adjudication date of July 23rd, 1958 for a decreed capacity of 700 cfs through the Homestake Tunnel. The 10-year average annual diversion yield from 1992 to 2001 was 30,610 acre-ft, or 42 cfs. In 2002, the diversion yield through the tunnel was 26,510 acre-ft, or 37 cfs (CDSS, 2004).

The total transmountain 10-year average export yield is approximately 36,400 acre-ft, or 9% of the average yield from the entire Eagle River basin. These diversions markedly affect peak flows in some areas, as shown by the pre- and post-impact hydrographs presented in the next section. While the quantity of these diversions is relatively large, the timing of the diversions generally provide for the maintenance of low flows. Most transmountain diversion from the watershed occurs during the spring snowmelt period. The Ewing, Columbine, and Wurtz Ditches export 95% of their combined total annual export during the months of May, June, and July. Homestake Tunnel diverts about 60% of its annual diversion during March and April (CDSS, 2004).

The transmountain diversions represent 100% consumptive use losses. The potential for impact to environmental and recreational benefits of the Eagle River and its tributaries has created growing tension among Front Range and Western Slope water users. In addition to increased basin demand, Aurora and Colorado Springs will likely tap more conditional water rights within the basin. Currently, the two cities have 83,000 acre-ft of total water rights through the Homestake Project, 43,500 acre-ft of which have been made absolute (Colorado River Water Conservation District (CRWCD), 2003b).

In 1993, former Eagle County Commissioner Dick Gustafson organized a meeting of water rights holders to discuss potential solutions to the problem of competing water demands for Eagle River water and to support the protection of its environmental and recreational value (Kenney, 2001). This informal collaboration of technical experts and political authorities, known as the Eagle River Assembly, helped craft the Memorandum of Understanding (MOU) that approaches a policy of a "joint use water project in the Upper Eagle River" (MOU, 1997) to effectively meet the water demands of the participants while minimizing environmental impact. MOU signatories include the cities of Aurora and Colorado Springs, the Vail Consortium, the Colorado Water Conservation District, and the Cyprus Climax Metal Company.

Until now, the MOU has coordinated the enlargement of reservoirs and the reclamation of an old tailings pond, currently known as Eagle Park Reservoir. As part of the MOU, Aurora and Colorado Springs capped the amount of additional water that could be removed from the watershed to 20,000 acre-ft on a 25 year rolling average basis, and if available, up to 23,000 (Kenney, 2001). For every one acre-ft in excess of the 20,000 acre-ft exported from the basin, one-acre ft of water must be provided to the inbasin users of the Eagle River watershed at no additional charge. The amount of conditional rights owned in the basin by the two cities is almost four times greater than the capped amount in this agreement. Alternatives are currently under investigation to withdraw additional water for the benefit of both out-of basin and inbasin uses. The alternatives include an additional reservoir project north of Wolcott, a Climax reservoir alternative, underground water storage at Camp Hale, and the utilization of Ruedi Reservoir.

Also notable is the agreement among the partners of the MOU for Aurora and Colorado Springs to provide 500 acre-ft of water available for snowmaking by Vail Resorts during the low flow winter months in exchange for an additional 800 acre-ft of storage during the summer high flows (CRWCD, 2003b). This critical timing of the inbasin diversion is of great concern to the ski industry that requires withdrawals during late fall and winter, when streamflows are lowest.

The City of Denver has been in discussion with the Eagle River Assembly regarding its undeveloped rights in the Eagle River watershed, which amount to more than 100,000 acre-ft per year (Smith, 2003; Eagle River Watershed Plan, 1996). The latest round of discussions suggests that if Denver agrees to cap its diversions from the basin, permitting local use of the water, 5,000 acre-ft of water could be obtained without delay, and Denver would reserve the right to develop an additional reservoir near Wolcott (Smith, 2003).

4.3.1.3 Inbasin Diversions

Unlike transmountain and transbasin diversions, inbasin water diversions return to the river, except for consumptive uses. The timing and location of inbasin diversions can be critical to sustaining the ecological integrity of the river. While minimum flow rights have been adopted to maintain sufficient survival flows for fish, the seniority of the inbasin diversions takes precedence over instream flow rights. During October through April, local irrigation use is typically not occurring in the watershed, but snowmaking, domestic, and commercial water uses are peaking. The reach-specific effects of inbasin diversions on winter base flows are difficult to assess at a basin-wide scale. Domestic and commercial uses of the water result in fairly rapid return flows. However, return flows from snowmaking do not occur until spring snowmelt. Nevertheless, between the removal of the water and its return to the river, there is an effect on streamflow levels and the quality of aquatic habitat due to the inbasin diversions. An electronic database of inbasin diversions is available as Electronic Appendix M.

4.4 HYDROLOGY

4.4.1 Overview

This section of the ERIA identifies key issues related to the flow of surface water and results of analyses related to climate and flow regime. For the purposes of this report, the flow regime is defined as the magnitude, duration, timing, frequency, rate of change, and variability of streamflow at different locations in the drainage basin.

The pathways that water takes from its origin in the atmosphere, across the landscape, and into the stream channel network directly influence the nature of the flow regime. Precipitation may either evaporate directly back into the atmosphere, accumulate as snowpack, runoff over the land surface, or infiltrate into the soil. Relatively impermeable strata or bedrock tend to exist below upper soil horizons and direct flow downward along hillslopes. The amount of water that runs off or infiltrates into the groundwater table depends on soil permeability, surface roughness, and precipitation intensity. The typical flowpaths that water takes as it flows across the landscape are depicted in Figure 4.24.

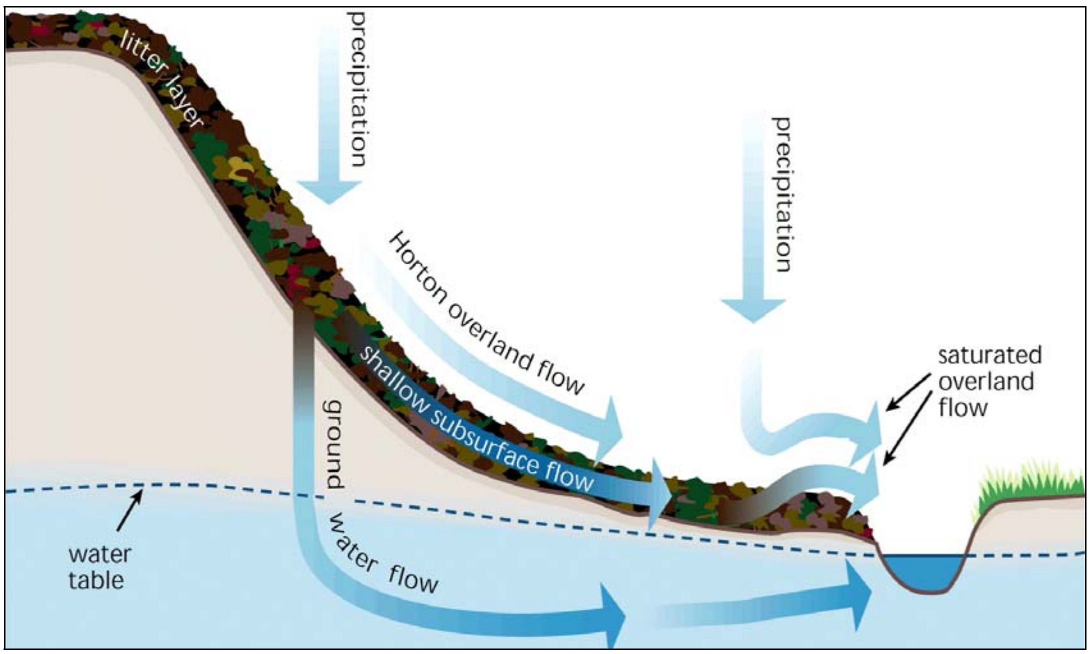


Figure 4.24: Schematic of hydrologic flow paths (Federal Interagency Stream Corridor Restoration Manual, http://www.nrcs.usda.gov/technical/stream_restoration).

Surface flow velocity is typically several orders of magnitude greater than subsurface flow. Overland flows are rare in undisturbed forested watersheds, but are common after wildfires and in urban areas. Water that has infiltrated into the soil or shallow groundwater system seeps slowly downward, often intersecting the stream channel network and thus contributing to streamflow. Subsurface flows occur continuously throughout the year, resulting in streamflow during dry periods.

There are many ways that human activities may alter the way that water flows across the landscape, such as storing and/or redirecting streamflow, introducing impervious surfaces, and compacting the soil. This section of the ERIA seeks to quantify the influences historical and current human activities, especially the construction of water supply reservoirs and diversion structures described in previous sections, have on the hydrology of the Eagle River watershed.

The highest profile issues in the Eagle River watershed regarding water quantity are related to the occurrence of low flows and drought conditions, and the concomitant effects on water quality, habitat for aquatic life, and implications for population growth and development. An increasing amount of pressure is being placed on the limited amount of water resources available within the watershed, while the demand for transmountain exports to Front Range water rights holders grows. The following subsection of the ERIA provides explanations of the various aspects of streamflow regimes and their ecological significance.

4.4.2 Flow Regime

"Streams and rivers are naturally dynamic and variable, both in their physical character and their ecological relationships. The seasonality of high and low flows and the natural swings between wet and dry years create and maintain a diversity of habitat types (both in and outside the channel) that benefit a wide range of species, including fish. Human management of streams and rivers typically alters natural patterns of flow variability, resulting in new environmental conditions, which are often unfavorable to native aquatic and riparian species and to long-term ecosystem integrity," (Poff, 1999).

In pursuing the objectives of the ERIA, it is necessary to describe the historical flow regime of the stream channel network, and compare that "natural" state to the present state in order to assess the extent of human influence. The characterization of the natural flow regime is dependent on the definition of the term "natural." Of course, the natural state could not be usefully defined as the condition of the flow regime prior to European settlement, because data needed to quantify that condition are not available. It was, however, practical to describe streamflow conditions before and after major modifications to the basin hydrology, especially the closure of dams and construction of diversion structures. Therefore, the working definition of the term "natural" used in the ERIA is the state of the flow regime of the Eagle River that existed prior to the development of transbasin diversions in the upper Eagle Watershed in 1929, and on Homestake Creek before the construction of Homestake Reservoir in 1965.

The five key elements of flow regime are the magnitude, frequency, duration, timing, variability, and rate of change of streamflow. It is a 'master variable' that is directly related to the diversity of habitats and species that are present in aquatic and riparian ecosystems (Poff *et al.*, 1997). Therefore, modifications to the natural flow regime of a stream or river often result in altered ecological processes. The aforementioned water resource developments have influenced both high and low flows, as well as the timing of flows and variability of streamflows.

4.4.3 High Flows

High or flushing flows are important to maintain aquatic habitat. Streamflows flush fine sediment from the channel substrate, providing gravel bed habitats needed by aquatic insects and fish for reproduction. When flows necessary to move sediment are significantly reduced, fine particles can become trapped between gravels. This results in a cover of fine grains over fish eggs, which can prevent access to sufficient oxygen and removal of metabolic waste and can entomb fry (Whiting, 2002). Benthic invertebrates, such as mayflies, caddisflies, and stoneflies, are dependant on flushing flows to support optimal substrate conditions. Studies have shown that as the quantity of fine particles on the bed increases, the density of invertebrates, amphibians (Furniss *et al.*, 1991; Welsh and Ollivier, 1998), and game fish often decreases. A sizeable reduction in peak flow magnitude due to diversion or the installation of a dam can lead to sediment accumulation, degrading the habitat for fish and macroinvertebrates. In other instances where sediment supplies are not replenished by tributaries or other sources, trapping of sediment by dams can lead to an increase in the bed particle size, which often results in bed armoring. The modification to the packing of particles in a riverbed as a result of moderate streamflow alterations can result in ecological degradation (Whiting, 2002).

Further ecological benefit is attributed to high flows in the ability to sustain ecosystem productivity and diversity (Poff *et al.*, 1997). Flood disturbances will often scour floodplain soils, which promotes the germination of species that require wetted, barren surfaces free from competition (Scott *et al.*, 1996). High flows create new habitats and food sources for invertebrates and fish by importing woody debris and organic materials from the floodplain. Even in locations lacking a clearly defined floodplain, high flows maintain riparian communities through flooding of the banks and zone adjacent to the river (Hupp and Osterkamp, 1985). For additional information on these processes see Section 4.8.

4.4.3.1 Base and Low Flows – Definition of Criteria

Base flows generally represent the normal flow that occurs prior to and following runoff from precipitation events or snowmelt. For the purposes of this study, the base flow was defined as the average daily flow occurring between September 15th and March 31st. Base flows are important to the maintenance of spatial corridors of connectivity, which exist laterally, longitudinally, and vertically, within a river or stream (Ward and Stanford, 1989). Maintenance of minimum base flows promotes the transfer of energy, matter, and organisms through interaction with the hyporheic zone (the region of stream bed and banks where surface and ground waters mix), the riparian corridor, and upstream and downstream river reaches. The survival of fish and invertebrates is dependent on the existence of flowing water that allows movement and provides sufficient current for oxygenation of the waters. Conversely, there are some ecological benefits to decreased flows. For example, certain riparian vegetation species require flows to fall below a specific flow level for successful recruitment. However, the primary ecological concern of low flows is that they do not fall to a level detrimental to the ecological integrity of the system.

Low-flow characteristics are of great importance in the Eagle River watershed due to their relationship to ecological integrity, recreational activity, and increasing human water needs. As detailed in Table F.2 in Appendix F, metrics of minima values are associated with an ecological significance. The 1-day minima are influential to the balance of competitive, ruderal (or weedy), and stress-tolerant organisms (Richter *et al.*, 1996). Particular species with high tolerance will be able to withstand a more significant modification to the 1-day minima, especially a reduction, than various sensitive species. Minima 3-day means are associated with the creation of sites for plant colonization (Richter *et al.*, 1996).

The 7-day minima are important to the structuring of aquatic ecosystems by abiotic vs. biotic factors (Richter *et al.*, 1996). Abiotic factors are non-living physical and chemical factors that affect an organism's ability to survive and reproduce. Such factors include light intensity, temperature, type of substrate, levels of acidity, alkalinity, and pollutants, and water availability. Every abiotic factor plays an important role in determining the type and density of organisms within a specific environment. Biotic factors are living matter that directly or indirectly affects an organism's environment. These may include organisms, their wastes, body parts, and interactions with others (e.g., parasitism, predation, and disease). A change in the average 7-day minima indicates that the abiotic features have been modified for the environment of a particular species and may have affected the limiting factors for native species. Unable to survive in the new conditions, certain fish and macroinvertebrates will no longer be present in the region or may be out competed by non-native species.

A decrease in the annual minima of the 30-day means indicates an alteration of physical habitat conditions. The annual minima of the 90-day means are indicators of the amount of soil moisture stress in plants (Richter *et al.*, 1996). While there is variability in the size of the impact of the minima flow metrics, each enables a distinct evaluation of the modification to the natural flow regime and associated ecosystem.

4.4.3.2 Timing and Duration – Definition

The timing of flows is significant to the life cycles of many aquatic and riparian ecosystems. Life cycles of various species are timed in such a manner as to avoid specific low or high flows. Certain fish species depend on cues from high flows to initiate transitions in the life cycles, such as spawning, egg hatching, rearing, and migration upstream or downstream (Poff *et al.*, 1997). The natural flow patterns of a system impede non-native species invasive success. The timing and duration of flows for cottonwood recruitment must occur such that flows recede at a rate that allows their roots to grow with the decline of the water table. The duration of flooding of riparian species will prevent or permit the successful establishment based on levels of tolerance. Duration of low flow events is extremely important to the macroinverterate and fish assemblage within a river, where prolonged low flows would preclude the persistence of less tolerant species.

4.4.3.3 Variability – Definition

Streams that are highly homogeneous in environmental conditions tend to have fewer co-occurring species than those with more diverse environmental conditions (Theinemann, 1954). Variable streamflows create a multitude of diverse habitat conditions. In flowing water environments characterized by high fluctuations in current velocities and discharges, more species can co-occur than in environments characterized by less variation in velocity and discharge. Generally, benthic invertebrate richness and diversity increases across heterogeneous substrates due to the stability of larger particles, refuge from flood events, protection from predators, and the ability of varied sized streambed materials to act as natural catchments for organic material.

Understanding the natural flow regime and the influence that human activity has had upon it necessitates simultaneous consideration of trends in precipitation and other climatic factors. The amount, timing, and distribution of precipitation events are fundamental elements of the hydrologic cycle. The analysis provides a general estimation of the conditions that would be present in the absence of human influence. Therefore, the following subsection describes an investigation of the climatic records and an interpretation of how climate affects streamflow in the Eagle River watershed.

4.4.4 Meteorological Characterization

In evaluating the climatic factors that drive the hydrologic functions of the Eagle River watershed, precipitation, snowfall, temperature, and evapotranspiration data were collected from various sources to assess conditions within the watershed over the period of record. This section presents a brief overview of the major climatic characteristics, and documents the sources of climate data and the methods used to interpret them.

The climate of the Eagle River drainage basin varies from semi-arid at the watershed outlet at Dotsero, to alpine above treeline in the mountains. The lower reaches receive only about half of the annual precipitation as the upper elevations, and higher temperatures in the lower watershed areas drive higher evapotranspiration losses relative to the forested highlands. The watershed as a whole receives the vast majority of its runoff-producing precipitation in the winter in the form of snowfall, which accumulates to form snowpack in the upper elevations. Increased solar radiation in spring raises air temperatures, which causes the snowpack to melt, thereby recharging soil moisture deficits and generating most of the streamflow for the year.

4.4.4.1 Precipitation

The objectives of the analysis of the available precipitation data were to quantify average monthly and annual conditions within the basin and detect trends in the data that may account for any changes in streamflow that have been observed. Daily precipitation and snowfall data were available from the National Climatic Data Center (NCDC), daily snowpack data from the Natural Resource Conservation Service (NRCS) snowpack telemetry (SNOTEL) sites. Mean monthly values were acquired from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) database. PRISM is an analytical tool that uses point data, a digital elevation model, and other spatial data sets to generate gridded estimates of monthly, yearly, and event-based climatic parameters, such as precipitation and temperature.

As illustrated by Figure 4.25, a strong precipitation gradient exists between the lower reaches of the watershed and the headwaters, primarily due to orographic lifting, where moisture-laden clouds release precipitation as they are pushed over the mountains. This accounts for much of the variability in snowpack, soil development, and vegetation characteristics. Runoff-generating precipitation events in the lower reaches tend to be localized, high-intensity convective thunderstorms, which may erode exposed soils, and may cause localized flash-flooding in the lower stream reaches. Although these types of rain events may be locally intense, they do not contribute as much to total annual runoff as snowmelt.

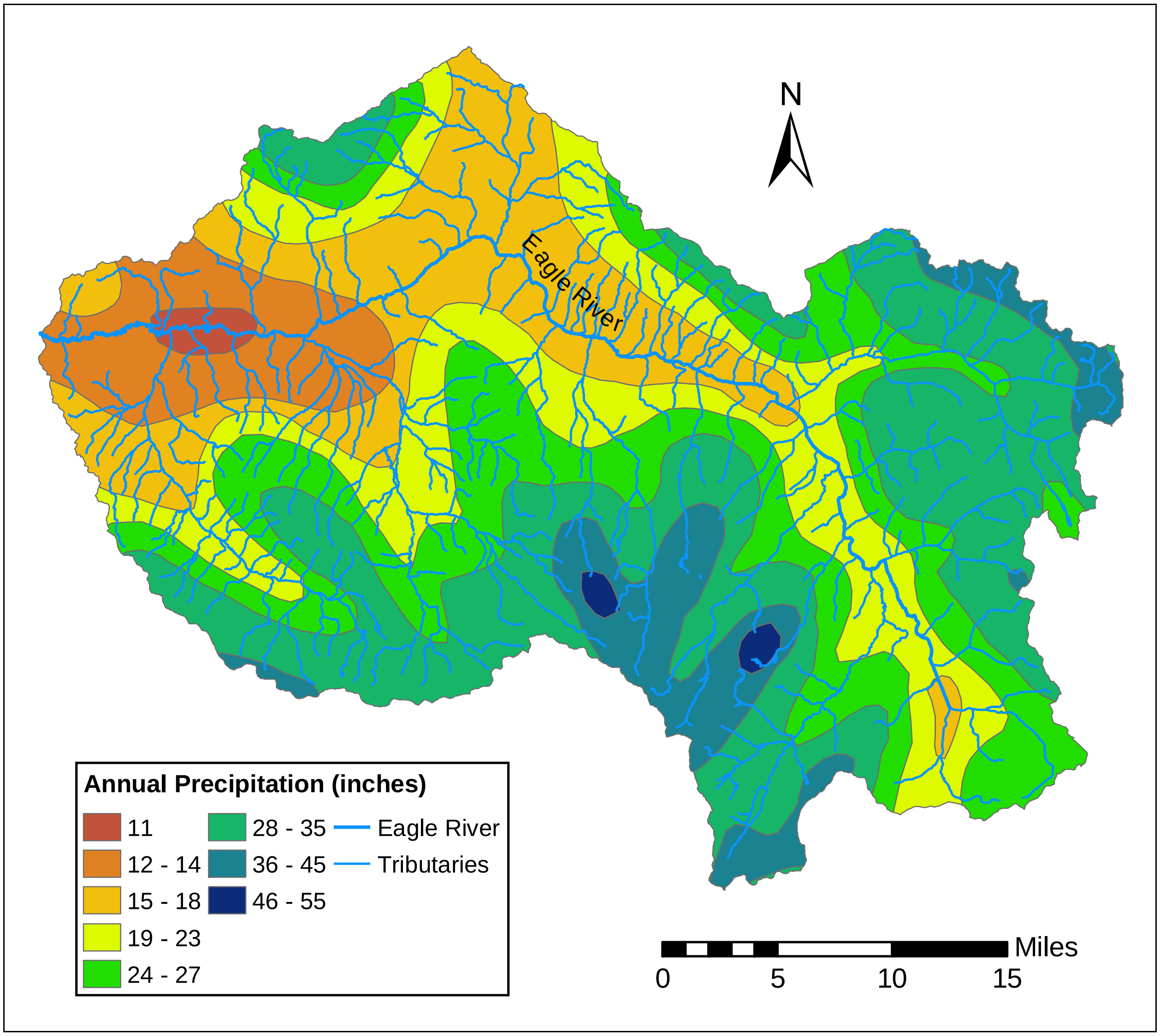


Figure 4.25: Distribution of mean annual precipitation (inches) in the Eagle River watershed.

The amount of snow that falls on a given day that becomes snowpack is highly variable, as is the amount of water present within the snowfall. The best indicator of actual snow available for spring runoff is the amount of Snow Water Equivalent (SWE) present in the snowpack at the end of the winter. SWE can be thought of as the depth of water that would theoretically result if one were to melt the entire snowpack instantaneously.

Snowpack measurements made at the Vail SNOTEL site were available from 1979 to 2003. This period of record does not overlap with the timing of all of the documented changes in land and water use that have occurred, but it does include the period after the completion of the rehabilitated Eagle Park and Black Lakes reservoirs in the mid-1990s, and a period including a major decrease in agricultural land use. The mean annual maximum snowpack depth for the period before the Black Lakes reservoir was completed in 1993 was 27.4 inches of SWE, whereas afterward that value was slightly lower at 25.3 inches of SWE. The mean annual maximum snowpack depth since the completion of the Eagle Park reservoir in 1998 was 20.6 inches SWE. The drought conditions that have prevailed over the short time since the reclamation of the Eagle Park Reservoir have made meaningful comparisons of pre- and post-reservoir hydrographs essentially impossible.

A snowfall monitoring station has been active at Dillon since 1909. A regression analysis of the monthly total snowfall values from Vail and Dillon was performed, and it showed fair correlation ($R^2 = 0.35$) between snowfall at the two sites. Because the period of record for the climate station at Vail was notably limited, the Dillon dataset was used as a surrogate for actual snowfall data from the Eagle River watershed to detect trends in snowfall during the post-European settlement period.

The average annual snowfall depths at Dillon before and after the closure of Homestake Reservoir in 1967 were also calculated. Prior to completion of the reservoir the average annual snowfall was 143 inches, whereas after completion of the reservoir the average annual snowfall was 117 inches. This change in total snowfall accumulation at Dillon suggests that a similar trend could have occurred in the Eagle River watershed, and may explain some of decreased average discharge values in the Eagle River watershed during the period after the reservoir was completed.

Statistical analyses (Sen, 1968; Mann, 1945) were used to determine the trend in annual snowfall depths from 1948 to 2002, the period of record for discharge measurements made at the watershed outlet near Gypsum. The statistical analysis showed a downward trend of 1.6 inches of snowfall during that period, significant at the 95% confidence interval. A similar analysis of the SNOTEL data collected at Vail from 1979 to 2003 showed a downward trend of 0.4 inches of SWE during that period, significant at the 90% confidence interval.

4.4.4.2 Temperature

The amount of water available for streamflow is a function not only of precipitation, but also of the amount of water lost to evapotranspiration, which is primarily driven by temperature. Therefore, the temperature records for the Eagle River watershed were also analyzed to detect trends in time and space. Figure 4.26 presents the highest and lowest average monthly temperatures, which generally correspond to the lowest and highest elevations in the basin, respectively (Hobbins *et al.*, 2001).

Because Figure 4.26 represents the complete range of average daily temperatures, values for all elevations of the watershed will fall somewhere between these extremes. The lowest elevations are subject to above-freezing temperatures almost year-round, thus there is little potential for snowpack accumulation there.

Average monthly temperatures near Vail, at an elevation of 8,250 ft, are presented in Figure 4.27. Most of the sub-alpine region, where snowpack accumulates, will be subject to average daily temperatures above freezing between April and November. Thus, spring snowmelt runoff begins in late April or early May. Snowpack accumulation typically resumes in November. Below freezing average temperatures prevail throughout most of the year in the uppermost portions of the watershed, resulting in snowfields on the highest peaks that sometimes persist throughout the entire year.

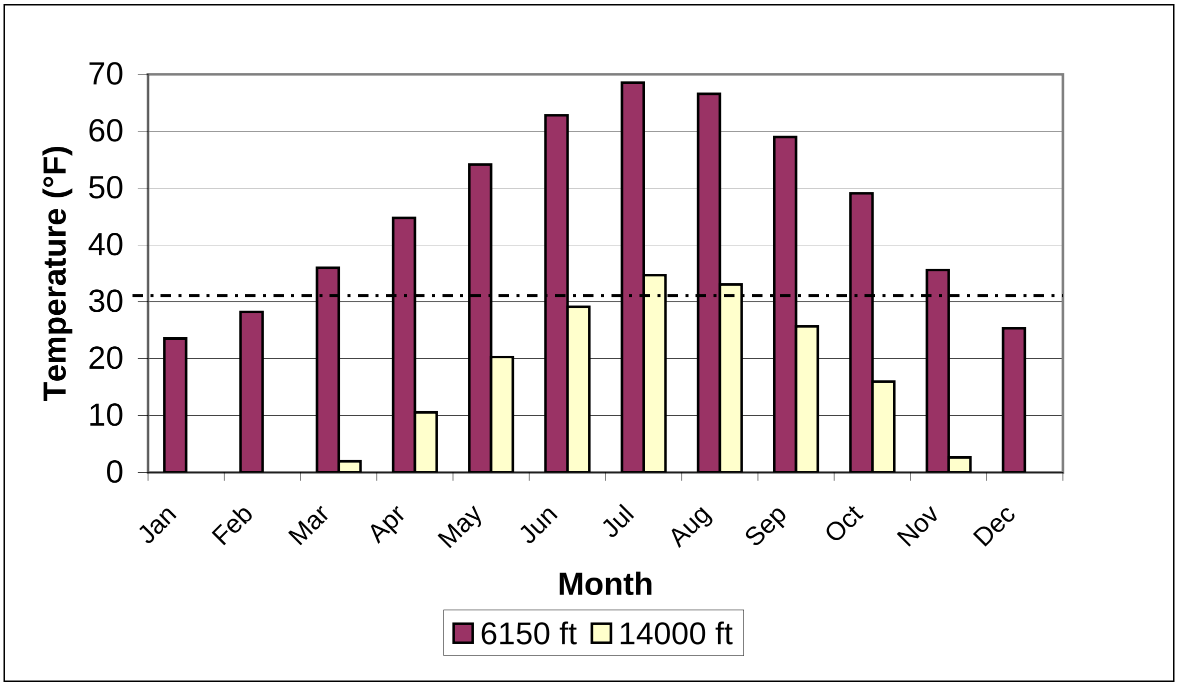


Figure 4.26: Range of monthly average temperatures in the Eagle River watershed (negative values omitted).

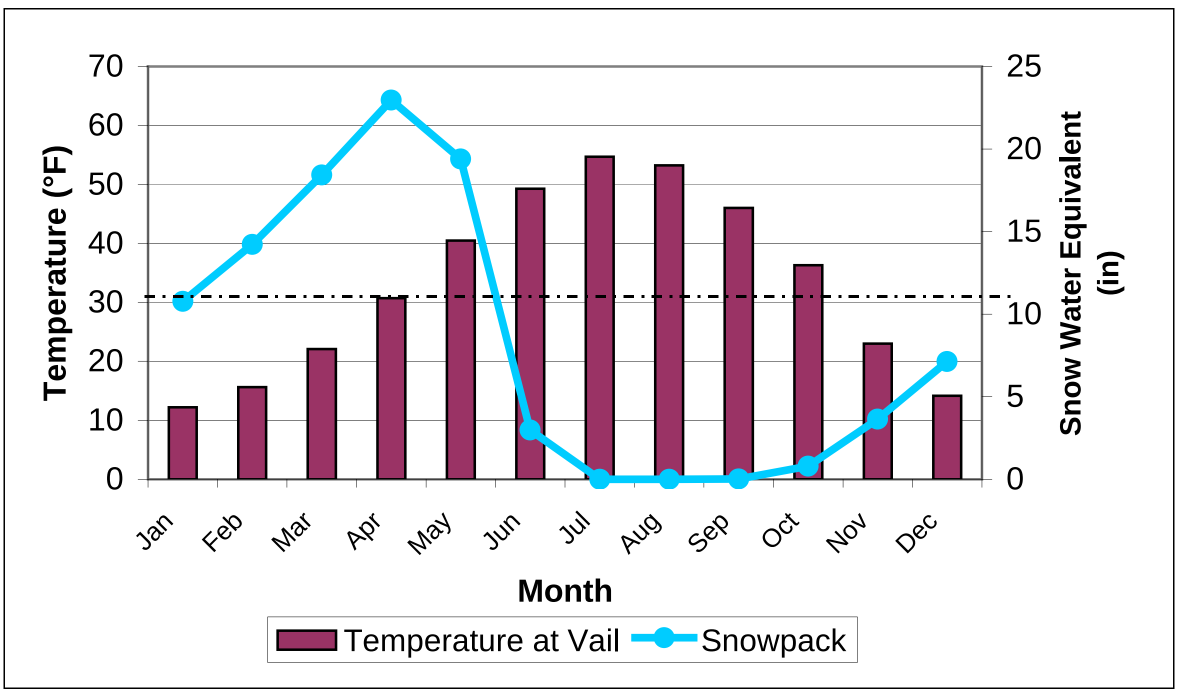


Figure 4.27: Average monthly temperatures and snowpack at Vail.

The rate of evaporation of surface water and transpiration of shallow groundwater by plants are driven by air temperature, solar radiation, convection, humidity, and other factors. The lower portions of the watershed are subject to appreciably higher temperatures than the upper sub-alpine region, of the watershed and have higher evapotranspiration losses than the upper regions. Distributed monthly mean potential evapotranspiration data for the Eagle River watershed were computed by Hobbins *et al.* (2001). Figure 4.28 presents the distribution of potential evapotranspiration throughout Eagle River watershed.

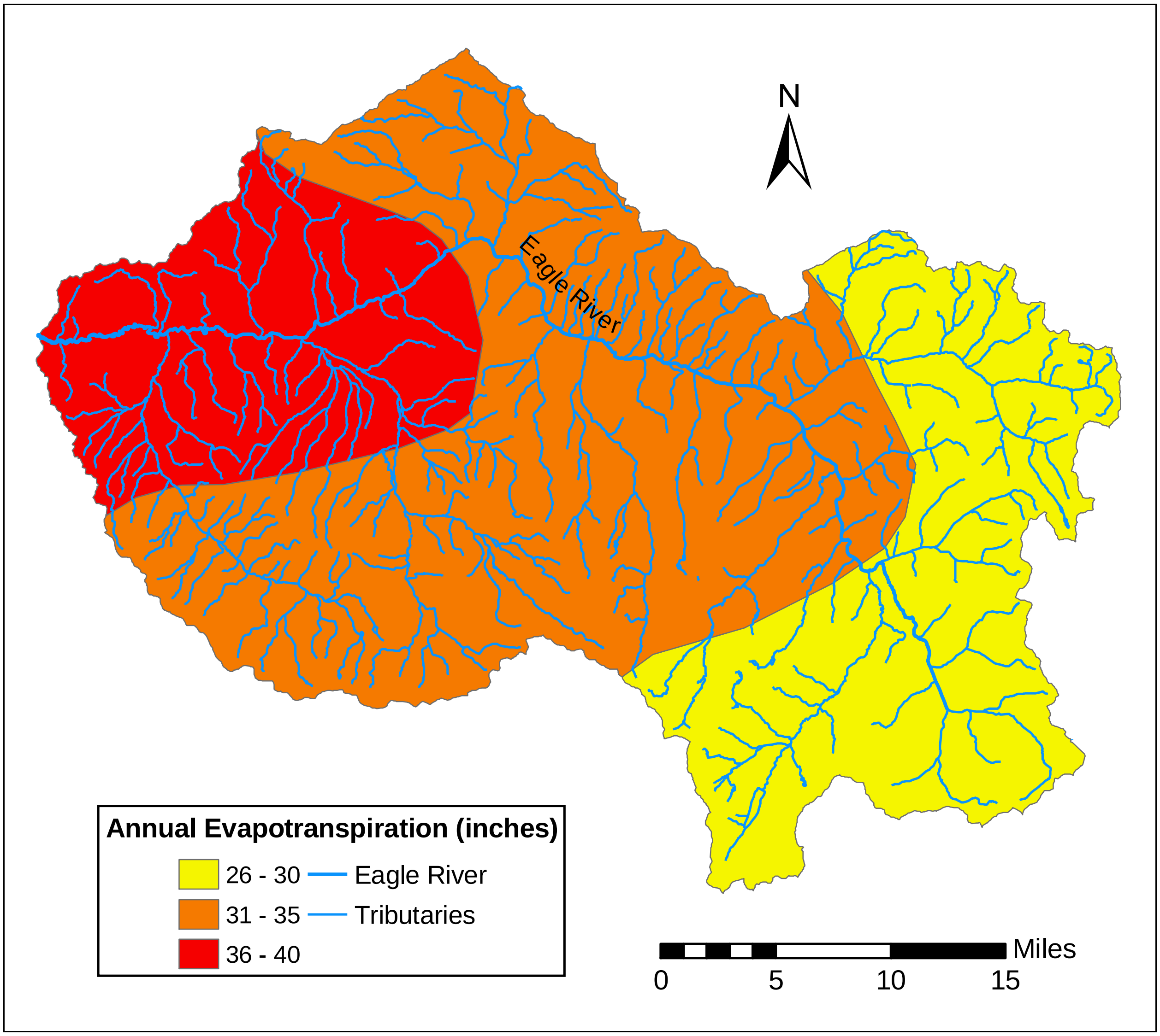


Figure 4.28: Annual potential evapotranspiration in the Eagle River watershed based on kriged monthly mean values (Hobbins *et al.*, 2001).

4.4.5 Streamflow

This section presents the culmination of the work performed to determine historical conditions within the Eagle River watershed and to quantify human influences related to streamflow. The hydrographs of the Eagle River and its tributaries generally have a base flow that occurs between September and March, increased flows occurring during snowmelt in April and early May, peak flows in May and June, and a recession of flows in July and August.

Annual hydrographs often present discharge values over the course of the water year, October 1st to September 30th. Figure 4.29 is a hydrograph of the flows in the Eagle River near the basin outlet below Gypsum during water year 1949. The hydrograph from 1949 was selected because the annual mean streamflow for that year was close to the median annual streamflow for the period of record, and 1949 was the earliest year for which climate data were available. The available climate data were used to determine if sudden small increases in flow could be attributed to rain events. Please note that discharge values in Figure 4.29 are plotted on a logarithmic scale, which emphasizes the variability of low flows and minimizes the expression of change in high flows.

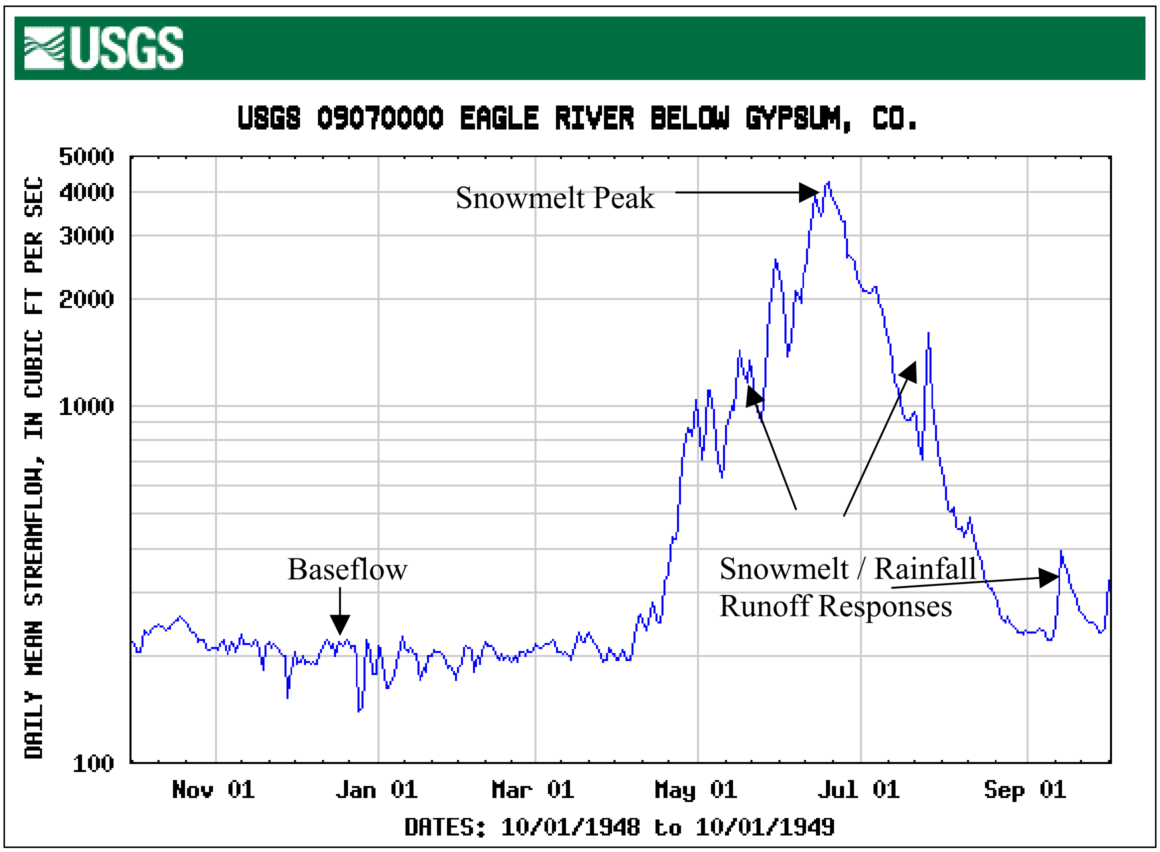


Figure 4.29: Annual hydrograph of the Eagle River below Gypsum for water year 1949.

Data from thirty-five gaging stations operated by the U.S. Geological Survey (USGS) were available to characterize streamflow throughout the Eagle River watershed (Figure 4.30). Some records were deemed insufficient for analyses, due to either a short period of record, location far removed from reservoirs and diversion structures, or both. Table 4.11 presents the name and period of record of each station with flow records that predate major reservoir construction. Check marks indicate if the gaging station is located below a given structure. Gaps in the periods of record are noted. Figure 4.30 shows the locations of the gaging stations in the basin. The only one downstream of and pre-dating the diversions to the Arkansas River Basin is the Red Cliff station.

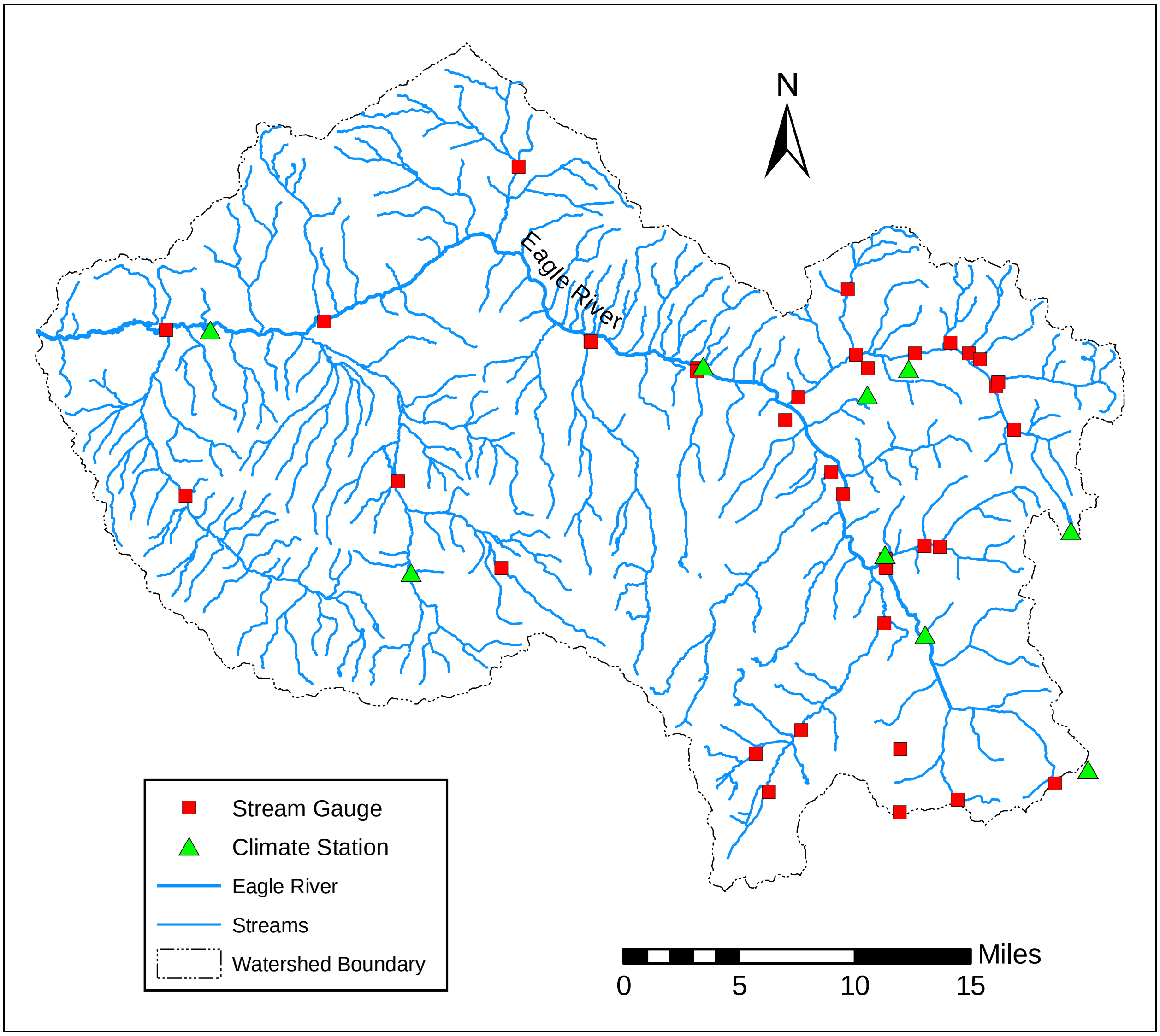


Figure 4.30: Locations of 35 gages used for hydrologic analysis of the Eagle River watershed.

Table 4.11: List of USGS gaging stations used in the pre- and post-analysis of the Eagle River watershed.

Gage	Period of Record (Begin | End)		Down-stream Homestake Reservoir	Down-stream Black Lakes	Down-Stream Eagle Park	Down-stream Wurtz & Columbine Ditches
USGS 09066000 BLACK GORE CREEK NEAR MINTURN, CO	10/1/1947	9/30/2002		√		
USGS 09066050 BLACK GORE CREEK NEAR VAIL, CO	10/1/1973	10/2/1979		√		
USGS 09067005 EAGLE RIVER AT AVON, CO	10/1/1988	9/30/1999	NR	√	√	NR
USGS 09070000 EAGLE RIVER BELOW GYPSUM, CO	10/1/1946	9/30/2002	√	√	√	NR
USGS 09064600 EAGLE RIVER NEAR MINTURN, CO	10/1/1989	9/30/2002	NR		√	NR
USGS 09066310 GORE CREEK, LOWER STATION, AT VAIL, CO	8/18/1988	9/30/1999		√		
USGS 09064000 HOMESTAKE CREEK AT GOLD PARK, CO	10/1/1947 7/19/1972	9/30/1954 9/30/2002	√			
USGS 09064500 HOMESTAKE CREEK NEAR RED CLIFF, CO	10/1/1910 10/1/1944	9/30/1918 9/30/2002	√			
USGS 09063000 EAGLE RIVER AT RED CLIFF, CO	10/1/1910 10/1/1944	9/30/1925 9/30/2002				√

NR = no record

Two USGS stations have been located on Black Gore Creek. The gage named Black Gore Creek near Minturn is currently located approximately 4.5 miles downstream of Lower Black Lake. For a brief period of time, the gage Black Gore Creek near Vail was located just upstream of the confluence with Gore Creek. The former gage was probably described "near Minturn" because its period of record predates the establishment of the Town of Vail.

4.4.6 Annual Yield

The total volume of water that is discharged from a basin in a given year is called the annual yield and is typically expressed in acre-ft per year. The annual yield from the Eagle River watershed upstream of Dotsero was calculated for each year over the period of record of the USGS gage on the Eagle River below Gypsum. This was done to quantify the average volume of water leaving the basin via streamflow, and identify trends, if any, in annual yield at the basin outlet. Figure 4.31 presents the annual yield from the Eagle River watershed from 1948 to 2002. Regression analysis of the annual yield values revealed a slight downward trend, but the trend is not statistically significant at the 95% confidence level. Although a change in yield is apparent after the completion of Homestake Reservoir in 1967, climate records indicate no significant decrease in snowfall during the period from 1967 to 1977, but the yield appears to be markedly lower during that period.

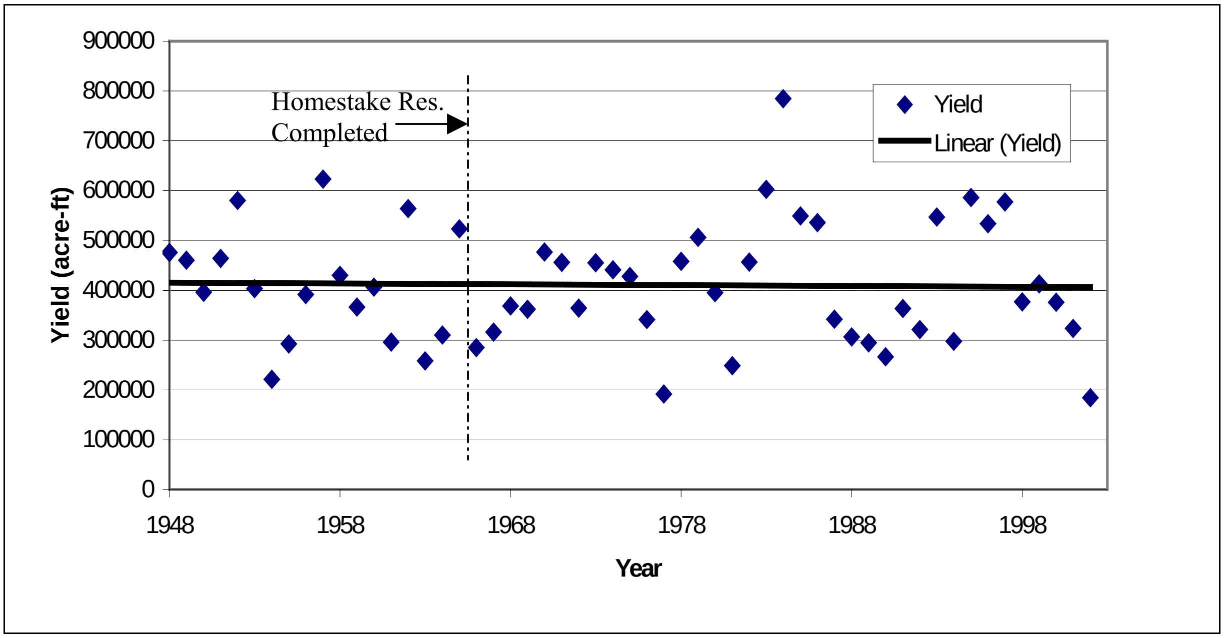


Figure 4.31: Annual yield from the Eagle River watershed at the USGS gage below Gypsum.

The amount of water available for streamflow is primarily a function of the depth of snowpack present at the beginning of spring runoff. Figure 4.32 presents a comparison of snowpack depth at Vail and the annual yield from the Eagle River at Gypsum.

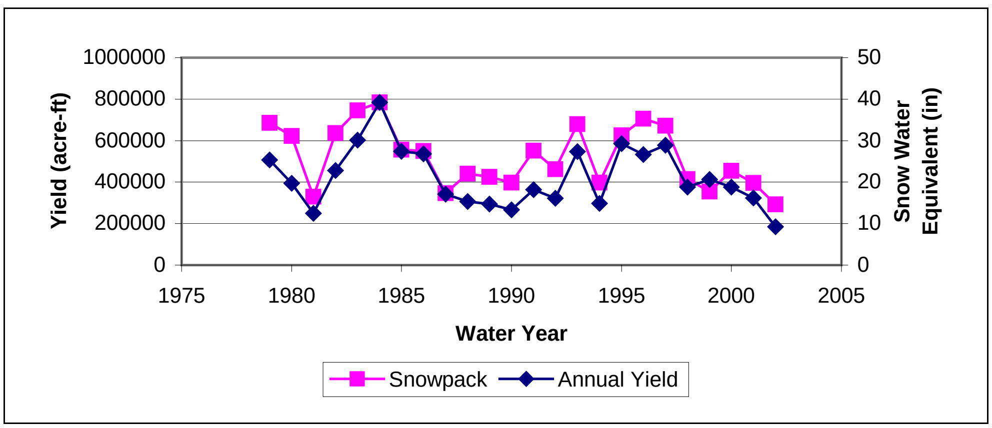


Figure 4.32: Comparison of snowpack at Vail and annual yield below Gypsum.

The ability to detect a change in the flow regime is dependent on the spatial separation of impacts and observations. The closer the observations are to the flow modification, the more pronounced the effects will be. For this reason, effects of dam construction and transmountain diversions are not obvious at the basin outlet. Figure 4.33 represents the daily flows across the period of record for the USGS gage Eagle River below Gypsum. The axis labeled "Julian Day" corresponds with the typical day of the year, such that day 1 represents January 1st; and day 365 represents December 31st.

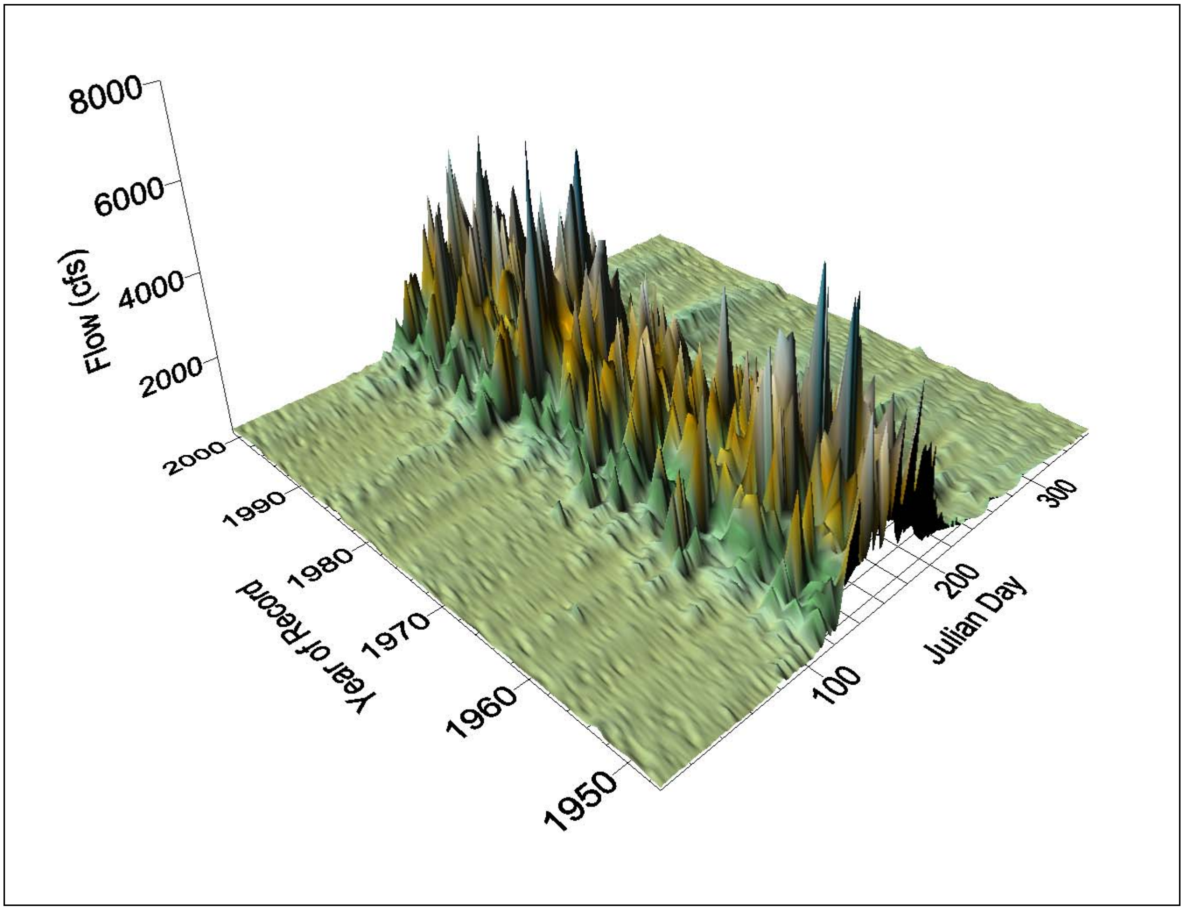


Figure 4.33: Period of record at USGS gage on Eagle River below Gypsum.

Given the inherent variability in the flow regime, no readily discernable difference in the hydrograph is apparent at a basin wide scale. The most significant changes in flow regime are likely to be directly downstream of the flow regulating structures. The optimal method of quantifying the cumulative effects of flow regulation on basin yield is to measure changes to yield at smaller scales closer to the diversion structures and add the change at each structure to arrive at the net change in yield for the entire watershed. Figure 4.34 presents the annual yield from Homestake Creek at Red Cliff over the period of record. There is a significant decrease in yield after the closure of Homestake Reservoir in 1967. The mean annual yield during the period from 1910 to 1966 was 62,800 acre-ft, whereas from 1967 to 2003 the mean annual yield was 30,700 acre-ft. Therefore mean annual yield on Homestake Creek near Red Cliff decreased 32,100 acre-ft, or 51%, after the closure of Homestake Reservoir, which correlates with the average volume of water diverted to the Front Range annually.

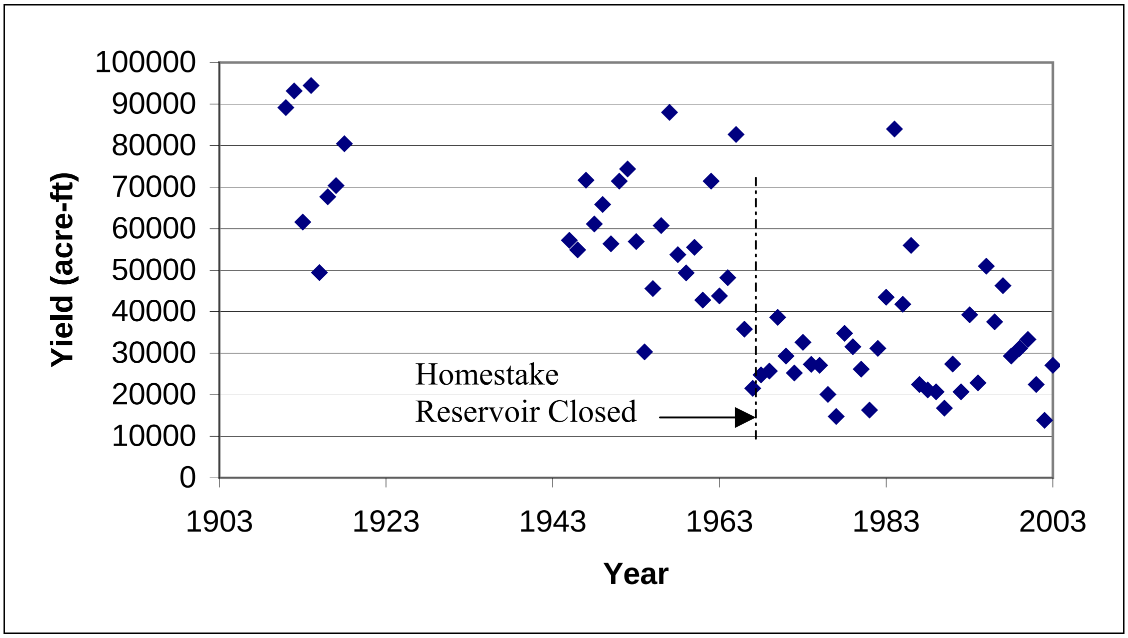


Figure 4.34: Annual yield from Homestake Creek near Red Cliff.

The following section of this report contains more information regarding specific changes to the flow regime on the main stem of the Eagle River at Gypsum and other locations throughout the watershed.

4.4.7 Streamflow Metrics

4.4.7.1 Overview of the Statistical Analysis

As part of the hydrologic regime analysis of the Eagle River and its tributaries, flow metrics were computed at each of the USGS gage stations. Each flow metric represents a measure of the hydrologic conditions occurring at that particular location. Mean daily flows over the period of record for 35 gaging stations were used to calculate 85 flow metrics describing the flow regime at these locations.

The program Flow SStats (Sanborn and Bledsoe, In Press; Sanborn, 2004), developed by Colorado State University, in conjunction with Indicators of Hydrologic Alteration (IHA)© (Richter *et al.*, 1996) was applied to determine flow metrics for all of the USGS gaging stations in the Eagle River watershed. The Indicators of Hydrologic Alteration© (IHA; Richter *et al.*, 1996) software was used to compute 33 streamflow metrics and their coefficients of variation. Olden and Poff (2003) identify additional metrics that may add significant information in characterizing flow regimes. A subset of these metrics was selected to more completely describe the magnitude, duration, frequency, timing, and rate of change of high, low, and average stream flows. Results and descriptions for all streamflow metrics computed for each USGS gage in the Eagle River watershed are provided in Appendix F.

4.4.7.2 Pre- and Post-streamflow Metrics

Analyses were performed at five USGS gages to evaluate the influence of reservoirs and transmountain diversions on the flow regime. The pre-impact dates represent the period of record prior to alteration of the flow regime, while post-impact indicates the time period following the alteration. The input into the Flow SStats streamflow metrics calculation program (Sanborn, 2004), described in the previous section, was defined as shown in Table 4.12. Although Homestake Reservoir was not completed until 1967, the Homestake Tunnel was completed in 1965, thus that year marks the beginning of potential modification of flow regime due to transmountain diversions on Homestake Creek.

Table 4.12: The name of the USGS gages and the water years considered prior to and following alteration of the flow regime.

Gage Name	Pre-alteration Years	Post-alteration Years
Eagle River at Red Cliff	1910-1924	1944-2001
Homestake Creek at Gold Park	1947-1953	1972-2001
Homestake Creek near Red Cliff	1910-1964	1965-2001
Black Gore Creek near Minturn	1947-1992	1993-2001
Eagle River below Gypsum	1946-1964	1965-2001

Hydrographs from the streams below the major reservoirs and transmountain diversions illustrate the changes in streamflow that have occurred since the completion of the diversion structures. Figure 4.35 is a three-dimensional plot of the annual hydrograph for Homestake Creek near Red Cliff for the entire period of record. Note how the magnitudes of flow peaks have been reduced after completion of Homestake Reservoir.

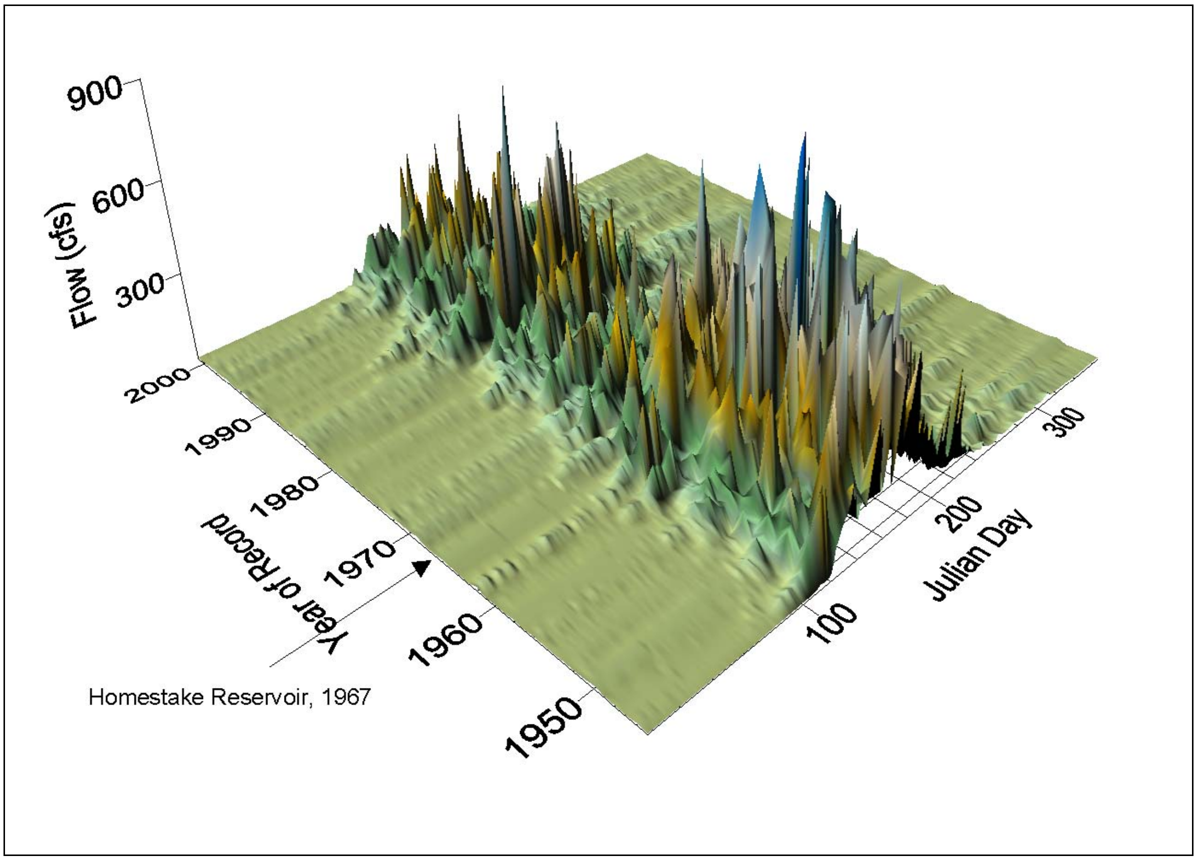


Figure 4.35: Period of record of streamflow in Homestake Creek near Red Cliff.

Figures 4.36 and 4.37 illustrate the changes in magnitude of peak flows on Homestake Creek at Gold Park and near Red Cliff, respectively, after the completion of Homestake Reservoir, which stores water for diversion to the Cities of Aurora and Colorado Springs. The yield analysis described at the beginning of this section on streamflow showed that the difference in volume of streamflow between the pre- and post-reservoir hydrographs is essentially equal to the volume of water that is diverted to those Front Range cities.

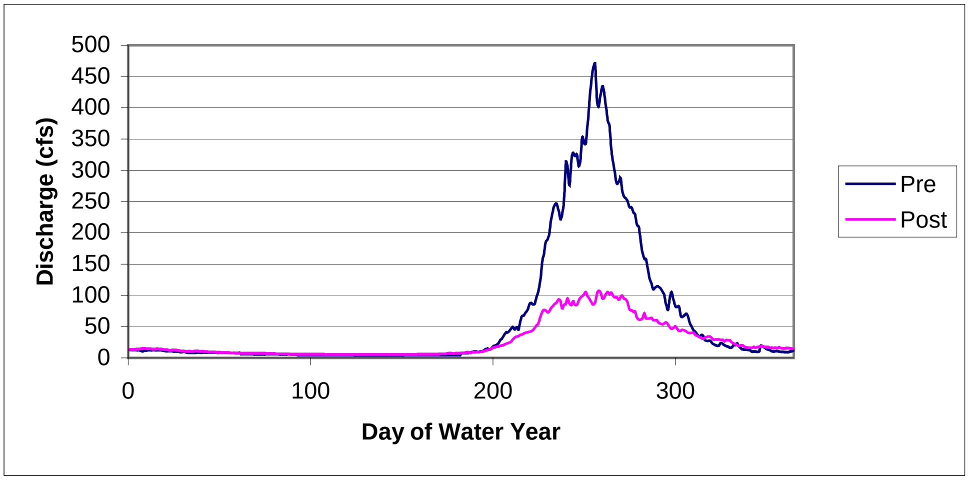


Figure 4.36: Pre- and post-Homestake Reservoir hydrographs for Homestake Creek at Gold Park.

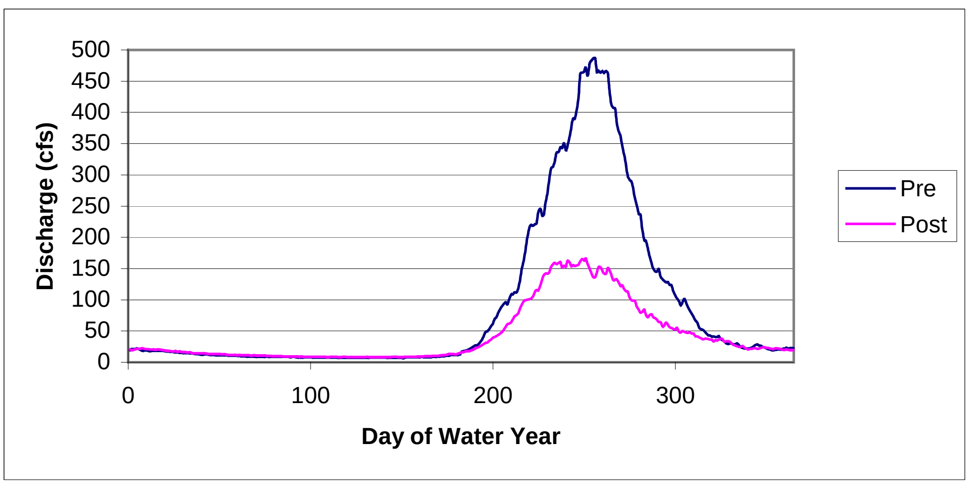


Figure 4.37: Pre- and post-Homestake Reservoir hydrographs for Homestake Creek near Red Cliff.

Average daily peak flows of Homestake Creek at Gold Park prior to Homestake Reservoir were generally above 400 cfs, but on average peak at 100 cfs today. The duration of snowmelt flow also appears to be truncated on Homestake Creek at both locations.

Transmountain diversions have occurred on the Eagle River above the USGS gage at Red Cliff since the late 1800s. Peaks have been significantly reduced at that location after the diversions, as can be seen from the three-dimensional daily flow hydrographs in Figure 4.38. Due to a break in the streamflow monitoring, there is a gap in the data between 1925 and 1944.

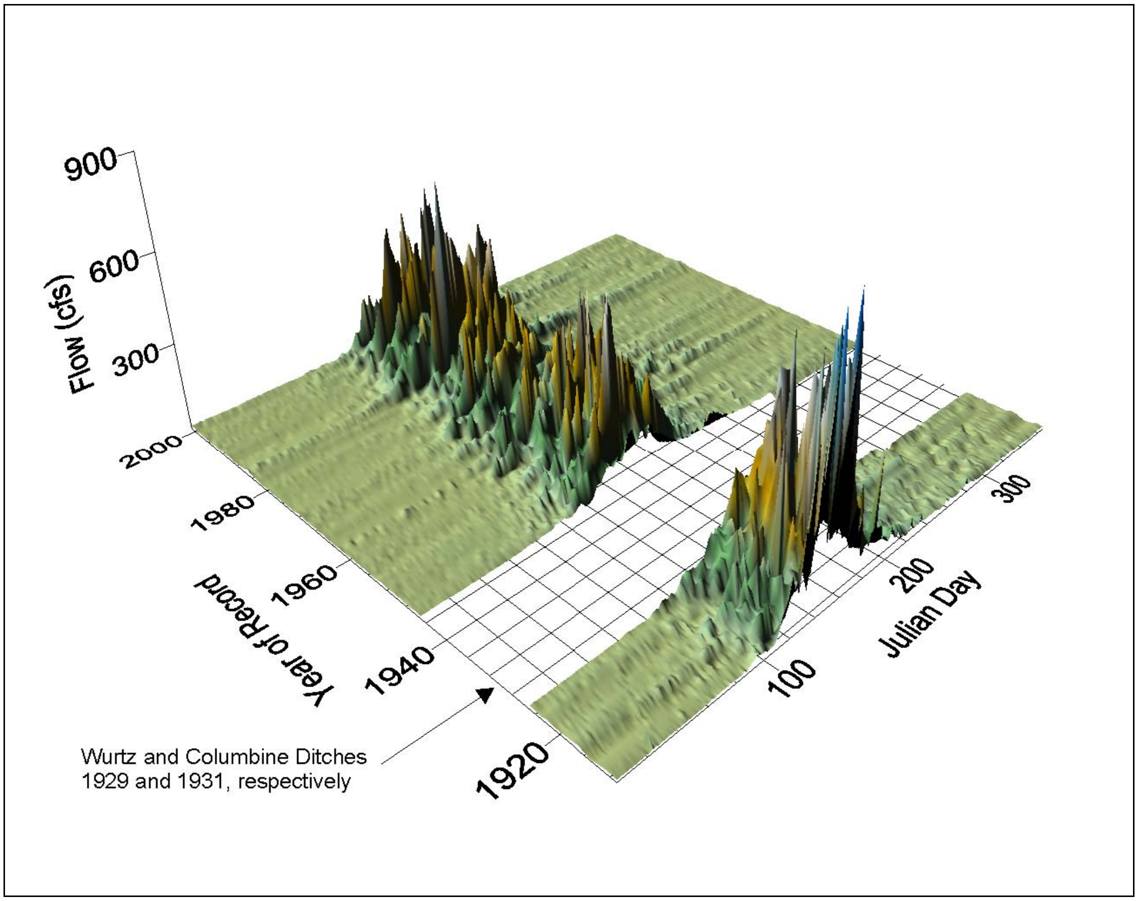


Figure 4.38: Period of record of streamflow in Eagle River near Red Cliff.

Figure 4.39 shows that the magnitude of the snowmelt peak flow has averaged approximately half of what it was prior to the diversions. The time period between 1905 and 1929 (pre-diversions) was the longest recorded wet period in Colorado history (McKee *et al.*, 2000). While part of the difference in the average hydrograph may be attributed to changes in the climate, analysis of direct measurement indicates that the combined withdrawal of the transmountain exports accounts for 19% of the total yield at the Red Cliff gage. Figure 4.40 illustrates the relationship between instream flows and the diversions at the USGS gage Eagle River at Red Cliff. The change in flow represented in the graph is completely attributable to the transmountain diversions. By expressing the streamflow through monthly values, flows are smoothed, and peaks are flattened.

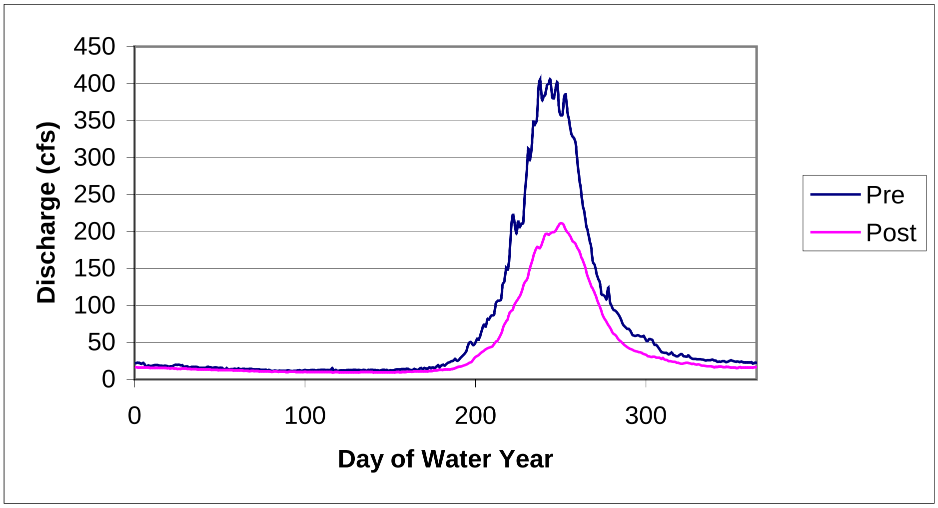


Figure 4.39: Pre- and post-transmountain diversion annual hydrograph for Eagle River at Red Cliff.

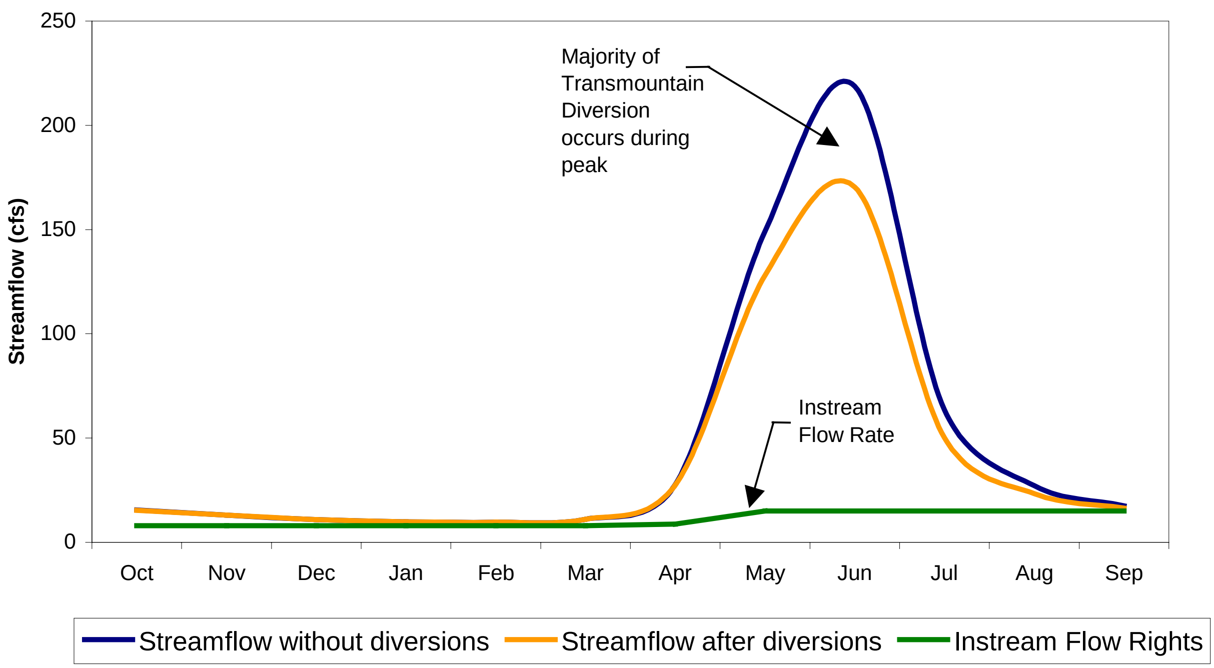


Figure 4.40: Timing of Columbine and Wurtz Ditch diversions in relation to the peak flow and the instream flow rights at the USGS gage Eagle River at Red Cliff (sources: CDSS, 2004; CWCB, 2003; USGS, 2004c).

The Colorado Division of Wildlife spearheaded construction of the Black Lakes Reservoirs to store water for flow augmentation. Figure 4.41 presents the streamflow in Black Gore Creek before and after completion of the Black Lakes Reservoirs. Note that the discharge values are plotted on a logarithmic scale to increase the resolution of changes in low flows. Although the mean baseflow has increased from 3 cfs to 3.4 cfs, the change is not statistically significant at the 90% confidence level. The Black Gore Creek hydrograph does not indicate a substantial change in high flow magnitudes after the completion the Black Lakes Reservoirs.

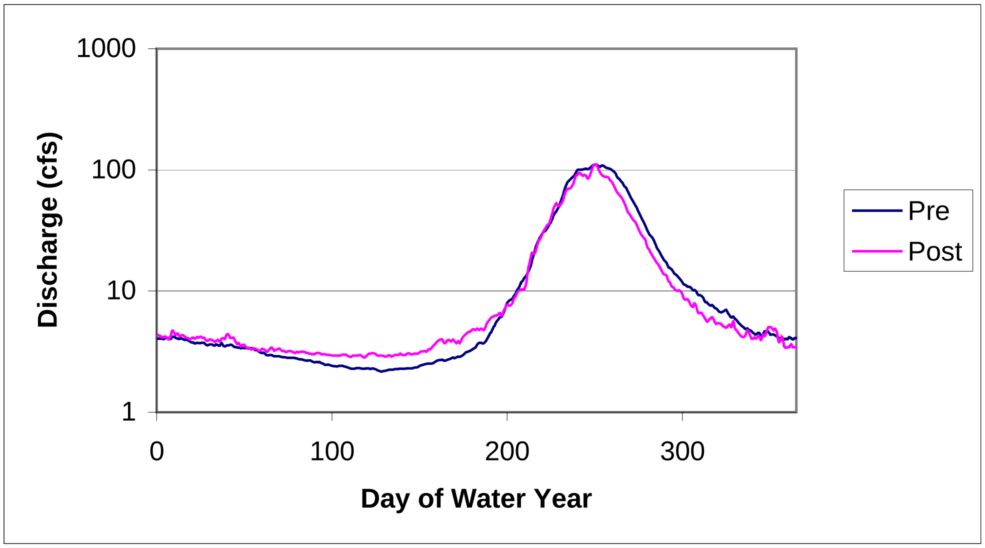


Figure 4.41: Pre- and post-Black Lakes Reservoirs hydrograph for Black Gore Creek.

Figure 4.42 presents the mean annual hydrograph near the basin outlet for the periods before and after the closure of Homestake Reservoir. Flow changes represent the accumulated changes in mean monthly flow from the entire watershed. Flow changes higher in the basin due to reservoir construction and transbasin diversions are less noticeable at the basin outlet due to the size of the contributing area that has been unaffected by the diversions. The hydrologic analyses have shown that changes in flow regime have been significant at locations higher in the basin on the Eagle River and Homestake Creek.

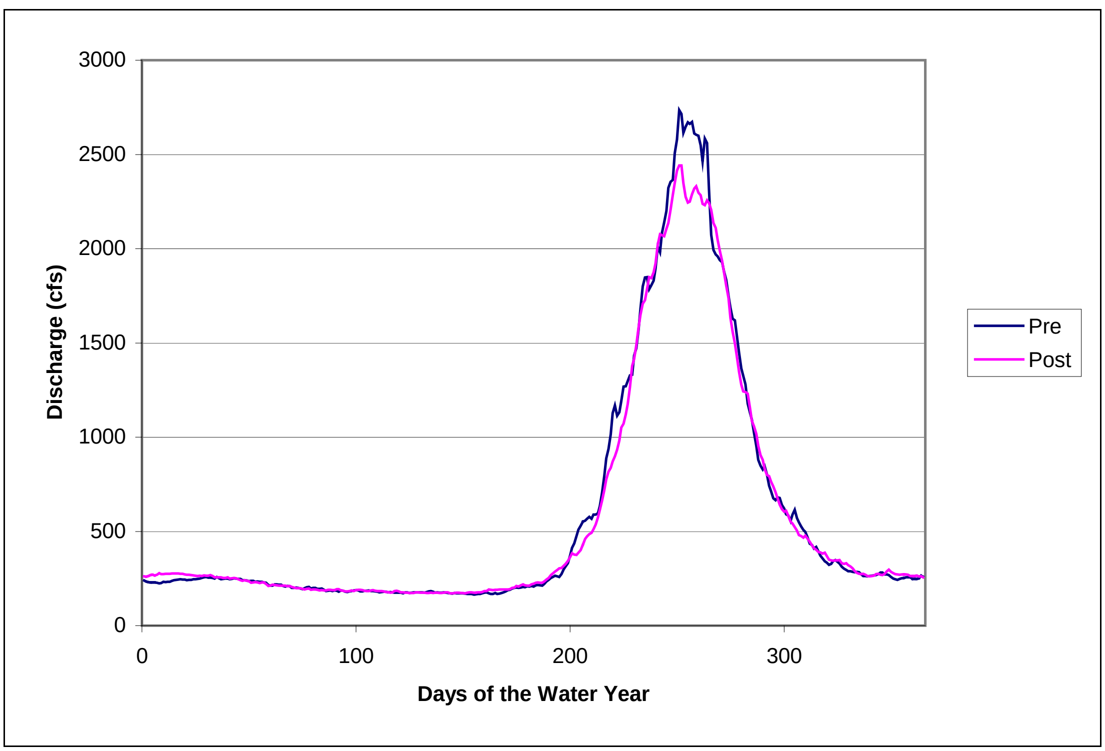


Figure 4.42: Pre- and post-reservoir hydrographs for the Eagle River below Gypsum.

4.4.8 Comparisons of Flow Metrics

Flow regime metrics were analyzed using the Flow SStats and IHA programs based on the dates of the completion of major reservoirs and diversion structures. The key issues, including changes in high flow, low flows, base flows, variability of flows, and timing of low flows are discussed in the following section. The results of comparing selected flow metrics are summarized in Tables 4.13 through 4.17. The entire collection of flow metrics is provided in Appendix F.

Table 4.13: Comparison of selected flow regime metrics at the USGS Eagle River at Red Cliff gage.

	Eagle River at Red Cliff			
	Mean Daily Stream Discharges (cfs)			
	Pre-impact	Post-impact	Deviation	%difference
Average 1-day Minimum	5.6	7.1	1.5	27%
Average 3-day Minimum	6.4	7.6	1.2	19%
Average 7-day Minimum	8.0	8.1	0.1	1.0%
Average 30-day Minimum	10	9.0	-1.0	-10%
Average 90-day Minimum	11	10	-1.0	-9.0%
Average 1-day Maximum	570	300	-270	-47%
Average 3-day Maximum	530	280	-250	-47%
Average 7-day Maximum	480	270	-210	-44%
Average 30-day Maximum	380	210	-170	-45%
Average 90-day Maximum	210	120	-90	-43%
Variability in Minimum Monthly Flows (MI13)	1.4	0.84	-0.56	-40%

Table 4.14: Comparison of selected flow regime metrics at the USGS Homestake Creek at Gold Park gage.

	Homestake Creek at Gold Park			
	Mean Daily Stream Discharges (cfs)			
	Pre-impact	Post-impact	Deviation	%difference
Average 1-day Minimum	3.3	4.4	1.1	33%
Average 3-day Minimum	3.3	4.6	1.3	39%
Average 7-day Minimum	3.4	4.8	1.4	41%
Average 30-day Minimum	3.8	5.2	1.4	37%
Average 90-day Minimum	4.1	5.6	1.5	37%
Average 1-day Maximum	640	230	-410	-64%
Average 3-day Maximum	590	200	-390	-66%
Average 7-day Maximum	540	170	-370	-69%
Average 30-day Maximum	400	120	-280	-70%
Average 90-day Maximum	220	77	-143	-65%
Variability in Minimum Monthly Flows (MI13)	1.7	1.1	-0.6	-35%

Table 4.15: Comparison of selected flow regime metrics at the USGS Homestake Creek near Red Cliff gage.

	Homestake Creek near Red Cliff			
	Mean Daily Stream Discharges (cfs)			
	Pre-impact	Post-impact	Deviation	%difference
Average 1-day Minimum	5.2	6.0	1.2	23%
Average 3-day Minimum	5.4	6.2	0.8	15%
Average 7-day Minimum	5.6	6.6	1.0	18%
Average 30-day Minimum	5.9	7.5	1.6	27%
Average 90-day Minimum	6.4	8.3	1.9	30%
Average 1-day Maximum	720	300	-420	-58%
Average 3-day Maximum	670	270	-400	-60%
Average 7-day Maximum	610	240	-370	-61%
Average 30-day Maximum	480	170	-310	-65%
Average 90-day Maximum	290	120	-170	-59%
Variability in Minimum Monthly Flows (MI13)	1.7	1.2	-0.5	-29%

Table 4.16: Comparison of selected flow regime metrics at the USGS Black Gore Creek near Minturn gage.

	Black Gore Creek near Minturn			
	Mean Daily Stream Discharges (cfs)			
	Pre-impact	Post-impact	Deviation	%Difference
Average 1-day Minimum	1.7	2.2	0.5	29%
Average 3-day Minimum	1.8	2.3	0.5	28%
Average 7-day Minimum	1.8	2.4	0.6	33%
Average 30-day Minimum	2.0	2.6	0.6	30%
Average 90-day Minimum	2.3	2.9	0.6	26%
Average 1-day Maximum	162	159	-3.0	-2.0%
Average 3-day Maximum	156	152	-4.0	-3.0%
Average 7-day Maximum	140	140	0.0	-0.0%
Average 30-day Maximum	110	100	-10	-9.0%
Average 90-day Maximum	57	54	-3.0	-5.3%
Variability in Minimum Monthly Flows (MI13)	3.5	1.1	-2.4	-69%

Table 4.17: Comparison of selected flow regime metrics for the USGS gage on the Eagle River below Gypsum before and after Homestake Reservoir.

	Eagle River at Gypsum			
	Mean Daily Stream Discharges (cfs)			
	Pre-Homestake	Post-Homestake	Deviation Pre-Post Homestake	%difference Pre-Post Homestake
Average 1-day Minimum	130	130	0.0	0.0%
Average 3-day Minimum	140	140	0.0	0.0%
Average 7-day Minimum	150	150	0.0	0.0%
Average 30-day Minimum	150	160	10	7.0%
Average 90-day Minimum	170	180	10	6.0%
Average 1-day Maximum	3800	3400	-400	-10%
Average 3-day Maximum	3600	3300	-300	-10%
Average 7-day Maximum	3400	3000	-400	-12%
Average 30-day Maximum	2700	2400	-300	-11%
Average 90-day Maximum	1600	1500	-100	-6.0%
Variability in Minimum Monthly Flows	0.91	0.74	-0.18	-19%

4.4.9 Changes in High Flows

Differences are apparent in comparing the maxima of the 1-day, 3-day, 7-day, 30-day, and 90-day means prior to and following impacts. At the Eagle River at Red Cliff gage, the cumulative effect of lower than average precipitation and diversion of flow via the Columbine and Wurtz Ditches has caused a consistent drop in all the maxima of approximately 45%. The Homestake Creek gages show decreases in the maxima ranging from about 58% to as great as 70%. The maxima at Black Gore Creek gage, however, exhibit a decline of less than 6%. The maximum 1-, 3-, 7-, and 30-day flow values near the basin outlet, on the Eagle River below Gypsum (Figure 4.43), decreased nearly 10 % after the closure of Homestake Reservoir. The change in 1-day peak flow values near the basin outlet, after the closure of Homestake Reservoir, was not significant at the 95% confidence level, presumably due to the large variability in those values over the period of record.

Figure 4.43: Summer low-flow conditions in a side channel of Gypsum Creek.

4.4.10 Changes in Low Flows

At the Eagle River at Red Cliff gage, minimum 1-, 3-, and 7-day flows slightly increased after the diversion ditches were introduced. This can most likely be attributed to either measurement error in the pre-1924 record, the influence of historical water storage near the Climax mine, or the fact that the period from 1905 to 1924 was the longest wet period in recorded Colorado history (McKee *et al.*, 2000). Differences of less than 2 cfs were reported in the 1-, 3- and 7-day values. The 30-day and 90-day minimum flows, however, have decreased in the period after the Wurtz and Columbine ditches began diverting flow to the Arkansas River basin.

Along Homestake Creek, minimum flows across all durations have increased anywhere from 15% to 40% more than the pre-impact minimum flows. Although not statistically significant at the 95% confidence interval, the low flow magnitudes in Black Gore Creek have increased since the closure of the Black Lakes reservoirs due to releases of stored water for flow augmentation. The 1-, 3-, and 7-day average low flows on the main stem of the Eagle River near the basin outlet remained the same between the periods from 1947 to 1965 and 1965 to 2002, but the 30- and 90-day average low flows increased after the closure of Homestake Reservoir by 6% and 7%, respectively.

Annual base flow, defined as average flow from September 15th to March 31st, was determined on Homestake Creek using the average daily flow values for the Homestake near Red Cliff gage. The base flow prior to the Homestake Reservoir (pre-1965) was compared with the base flow value determined after the installation of the Reservoir (post-1965). Statistical analysis determined that there was not a significant difference between the base flows at a 95% confidence level. The baseflow analysis was also performed at the Eagle River at Red Cliff gage before and after the transmountain diversions upstream of the gage came online. The analysis determined that the introduction of the Wurtz and Columbine Ditches caused a statistically significant decrease in the base flows at a 95% confidence interval.

Irrigation return flows account for a portion of baseflows in the Eagle River. It is hypothesized that the decline in return flows of irrigation water has contributed to the observed decrease in baseflows on the main stem of the Eagle River. Baseflows are supplied by water that moves slowly through shallow aquifers, which are relatively permeable regions of soil or bedrock. Irrigation water is applied to the land surface, whereupon it infiltrates into the soil. If more water is applied than can be transpired by plants or evaporated into the atmosphere from the soil surface, the excess water contributes to the local water table.

As discussed elsewhere, the available data show that the amount of water being used for irrigation has been declining since 1985. It was estimated by the USGS that discharge due to return flows from irrigation was 140 cfs in 1985 and 50 cfs in 1995. The mean daily flows on the Eagle River below Gypsum from the periods surrounding those dates are presented in Figure 4.44. Note that the discharge values are presented on a logarithmic scale to accentuate differences in low flows.

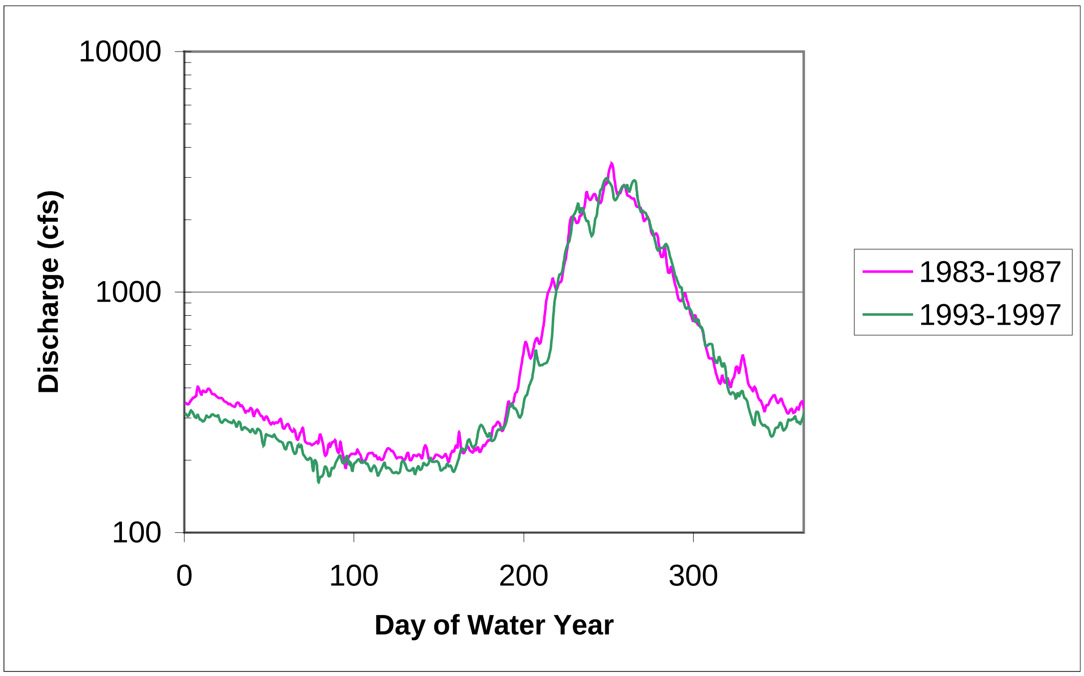


Figure 4.44: Comparison of base flows in the Eagle River below Gypsum for two periods of similar climate and differing irrigation return flows.

The mean maximum snowpack depth measured at the Vail SNOTEL site for the periods from 1983 to 1987 and 1993 to 1997 were 30 and 31 inches of snow-water equivalent, respectively. The snowpack depths during those two periods are almost identical; therefore there are other factors to which the decreased low flows are attributable. The available data support the hypothesis that the reduced application of irrigation water has contributed to a decrease in baseflows in the lower basin.

4.4.11 Timing of Low Flows

A continuous series analysis was used to transform streamflow data to determine the average timing of low flows at Homestake near Red Cliff, Homestake at Gold Park, and Eagle River at Red Cliff. Once the average of the continuous series was found, the data was transformed back to Julian Dates. The results of the analysis are shown in Table 4.18.

Table 4.18: Timing of average daily minimum flows.

Gage Name	Periods (Pre/Post)	Pre	Post
Homestake near Red Cliff	1910-1964 1965-2002	30 December	13 January
Homestake at Gold Park	1947-1953 1972-2001	10 December	7 Febuary
Eagle River at Red Cliff	1910-1924 1944-2001	21 November	18 January

From the analysis, it appears that low flows are consistently occurring later in the season as compared to pre-modification conditions. This is especially apparent at the Eagle River at Red Cliff and Homestake at Gold Park gages, where a difference in timing of about two months is notable. The changes are probably attributable to the timing of diversions and management of streamflows.

4.4.12 Variability

At the Eagle River at Red Cliff gage, the variability in mean minimum monthly flows declined by about 40% from pre to post impact, while both gages on Homestake Creek demonstrate reductions of greater than 30%. The Black Gore Creek near Minturn gage shows the greatest reduction in the variability of mean minimum monthly flows, with a decline of almost 70%. The variability of flows in the Eagle River below Gypsum decreased nearly 8% subsequent to the completion of Homestake Reservoir.

4.5 INSTREAM FLOWS

One of the most controversial issues in the region is the potential for ecological degradation due to reduced instream flows. Low flows are of particular concern in dry periods such as the current drought cycle. Instream flow rights established during the 1970s and 1980s sought to preserve the environment to a reasonable degree, but competing water demands for municipal and irrigation purposes sometimes leave sections of the Eagle River and its tributaries below recommended instream flow levels. The large quantities of senior conditional water rights held by Front Range municipalities have raised concern over the continued protection of instream flow rights. The following sections introduce the concept of minimum instream flows and assess the status of instream flows throughout the Eagle River watershed.

4.5.1 Introduction to Instream Flows

In 1973, Senate Bill 97 established Colorado's Instream Flow Program and vested the Colorado Water Conservation Board (CWCB) with the authority to appropriate and hold instream flow water rights on behalf of the people of Colorado to "preserve the natural environment to a reasonable degree" (§37-92-102(3), C.R.S. 1990). Many existing rights are senior to those designated for instream flow. Instream flows have priority at this time of adjudication. In Colorado, instream flow rights are mostly recommended through application of the R2CROSS methodology (Espegren, 1996). The R2CROSS method is used to provide rapid and repeatable estimates of minimum flow requirements for large numbers of stream segments and represents a balance between model complexity and practicality of implementation. R2CROSS uses Manning's equation to determine average depth, velocity, and percent wetted perimeter across one or multiple transect(s) in a stream or river segment. A transect represents one cross section, usually a riffle, chosen for a survey of channel shape, water depth, and streamflow velocity. A comparison of the R2CROSS with other instream flow quantification methods performed by Nehring (1979) is frequently cited as providing the ecological basis for the R2CROSS methodology. In this study, Nehring (1979) concluded that:

1. Instream flow recommendations for coldwater fish species based on the single-transect R2CROSS method should be set at the streamflow that meets two of the three criteria presented in Table 4.19 for the period May to September. "October to April flow recommendations will be at the same level, or at the natural undepleted flow, whichever is less."
2. The single-transect R2CROSS method "should be used only on those streams of little to perhaps moderate value as far as the fisheries resource is concerned. Examples might be head-water streams at high elevations that receive little or no use by the fishing public as well as streams on national resource lands where encroachment by diversion, pollution, and development is not anticipated as a serious problem."
3. A multiple transect methodology should be used on "major streams of moderate to good recreational potential or streams selected for some sort of stream improvement program. Streams in this classification support moderate to heavy public use for fishing, kayaking, and other types of outdoor recreation. They are usually more subject to the encroachments of water development, diversion, and pollution."

Current CDOW practice has evolved to recommending summer flows that meet all three hydraulic criteria in summer and winter flows that meet two of the criteria in Table 4.19 (Espregren, 1996). Instream flows that are quantified based on the hydraulic criteria of Nehring (1979) (Table 4.19), are also subjected to hydrologic analysis to determine if water is actually available to meet the recommendation given.

Table 4.19: Criteria used to determine minimum flow requirements using R2CROSS single transect method (Nehring, 1979).

Stream Top Width (ft)[1]	Average Depth[3] (ft) $(\bar{x}_d)$	Percent Wetted Perimeter (%)[2] (%WP)	Average Velocity (ft/sec) $(\bar{x}_v)$
1 - 20	0.2	50	1.0
21 - 40	0.2 - 0.4	50	1.0
41 - 60	0.4 - 0.6	50 - 60	1.0
61 - 100	0.6 - 1.0	≥70	1.0

[1] At bankfull discharge.
[2] Percent of bankfull wetted perimeter.
[3] One percent of top width.

4.5.2 Instream Flows in Eagle River Watershed

Within the Eagle River watershed, instream flow rights exist for 67 river reaches, many with different summer and winter rights. The USGS has maintained 36 streamflow gages within the watershed at varying time periods. However, only 17 of the gages were located within an instream flow right segment and had sufficient information to analyze the frequency of instream flow deficit for 20 of the instream flow rights. The instream flow rights and the gages used in the analysis are shown in Table 4.20.

Table 4.20: Instream flow rights and the gages used in the analysis.

ISF Right Case Number	Stream Name	USGS Gage Within Reach	Record Start Date	Record End Date	CDOW #	District	Segment Length	Upper Terminus	Lower Terminus	Appropria-tion Date	Instream Flow Recommendation	
5-80CW124	Eagle River	Eagle River Below Gypsum	10/1/1946	9/30/2002	20026	37	12.8 miles	confl Brush Creek	confl Colorado River	3/17/1980	130 cfs	(05/1 - 09/30)
											50 cfs	(10/1 - 04/30)
5-80CW134	Eagle River	Eagle River at Avon	10/1/1988	9/30/1999	20026	37	10.1 miles	confl Gore Creek	confl Lake Creek	3/17/1980	85 cfs	(05/1 - 09/30)
											35 cfs	(10/1 - 04/30)
5-78W3788	Eagle River	Eagle River Near Minturn	10/1/1989	9/30/2002	20040	37	6 miles	confl Homestake Creek	confl Cross Creek	5/12/1978	25 cfs	(05/1 - 09/30)
											11 cfs	(10/1 - 04/30)
5-78W3811	Eagle River	Eagle River at Red Cliff	10/1/1910	9/30/2002	20052	37	6 miles	confl Resolution Creek	confl Homestake Creek	5/12/1978	15 cfs	(05/1 - 09/30)
											8 cfs	(10/1 - 04/30)
5-78W3795	Cross Creek	Cross Creek Near Minturn	10/1/1956	9/30/2002	19845	37	8 miles	confl E Cross Creek	confl Eagle River	5/12/1978	20 cfs	(05/1 - 09/30)
											8 cfs	(10/1 - 04/30)
5-75W2719	Beaver Creek	Beaver Creek at Avon, CO	5/1/1974	9/30/2002	19073	37	7 miles	outlet Beaver Lake	confl Eagle River	5/1/1975	12 cfs	(05/1 - 09/30)
											4 cfs	(10/1 - 04/30)
5-77W3636	Gore Creek	Gore Creek At Mouth Near Minturn	10/1/1995	9/30/2002	20482	37	4 miles	confl Red Sandstone Creek	confl Eagle River	7/27/1977	22 cfs	(05/1 - 09/30)
											8 cfs	(10/1 - 04/30)
5-86CW216	Gore Creek	Gore Creek At Mouth Near Minturn	10/1/1995	9/30/2002	20482	37	4 miles	confl Red Sandstone Creek	confl Eagle River	5/9/1986	14 cfs	(10/1 - 10/31)
5-77W3637	Gore Creek	Gore Creek, Lower Station, at Vail, Colorado	8/18/1988	9/30/1999	20482	37	7 miles	confl Black Gore Creek	confl Red Sandstone Creek	7/27/1977	16 cfs	(05/1 - 09/30)
											6 cfs	(10/1 - 04/30)
5-86CW222	Gore Creek	Gore Creek, Lower Station, at Vail, Colorado	8/18/1988	9/30/1999	20482	37	7 miles	confl Black Gore Creek	confl Red Sandstone Creek	5/9/1986	10 cfs	(10/1 - 10/31)
5-80CW131	Middle Creek	Middle Creek Near Minturn	10/1/1964	9/30/2002	21230	37	4.8 miles	headwaters	Forest Service boundary	3/17/1980	1 cfs	(01/1 - 12/31)
5-77W3631	Red Sandstone Creek	Red Sanstone Creek, Near Minturn, CO	10/1/1963	9/30/2002	21624	37	4.5 miles	headwaters	confl Indian Creek	7/27/1977	2 cfs	(05/1 - 09/30)
											1 cfs	(10/1 - 04/30)
5-77W3632	Booth Creek	Booth Creek, Near Minturn, CO	10/1/1964	9/30/2002	23806	37	4 miles	headwaters	confl Gore Creek	7/27/1977	3 cfs	(01/1 - 12/31)
5-77W3633	Pitkin Creek	Pitkin Creek, Near Minturn, CO	10/1/1966	9/30/2002	24389	37	5 miles	headwaters	confl Gore Creek	7/27/1977	3 cfs	(01/1 - 12/31)
5-77W3634	Bighorn Creek	Bighorn Creek, Near Minturn, CO	10/1/1963	9/30/2002	23793	37	5 miles	headwaters	confl Gore Creek	7/27/1977	3 cfs	(01/1 - 12/31)
5-86CW221	Gore Creek	Gore Creek at Upper Station Near Minturn	10/1/1947	9/30/2002	23204	37	7 miles	headwaters	confl Black Gore Creek	5/9/1986	5 cfs	(10/1 - 10/31)
5-77W3635	Black Gore Creek	Black Gore Creek Near Minturn, CO	10/1/1947	9/30/2002	23212	37	10 miles	lower Black Lake	confl Gore Creek	7/27/1977	7 cfs	(05/1 - 09/30)
											3 cfs	(10/1 - 04/30)
5-86CW230	Black Gore Creek	Black Gore Creek Near Minturn, CO	10/1/1947	9/30/2002	23212	37	10 miles	lower Black Lake	confl Gore Creek	5/9/1986	4 cfs	(10/1 - 10/31)
5-78W3815	Turkey Creek	Turkey Creek Near Red Cliff, CO	10/1/1963	9/30/2002	22486	37	3 miles	confl Wearyman Creek	confl Eagle River	5/12/1978	7 cfs	(01/1 - 12/31)
5-78W3814	Wearyman Creek	Wearyman Creek Near Red Cliff, CO	10/1/1964	9/30/2002	26511	37	4.5 miles	headwaters	confl Turkey Creek	5/12/1978	2 cfs	(01/1 - 12/31)

Most of the instream flow rights in Colorado were adjudicated between 1976 and 1986. Therefore, the initial instream flow analysis only considered the years following the implementation of the instream flow rights. The number of days that instream flow rights were not met during the summer season, the winter season, and for the entire year was determined for each year of the record. In addition, the average percentage of the time that the instream flows were not met and the percentage of years that instream flows were not met was determined for each right. Some streamflow records cover the entire time since instream flow rights were adjudicated. Other gage records were established after the rights had been initiated. All gages in the analysis had at least 10 years of streamflow record, with the exception of the Gore Creek at the Mouth gage, which only had 5 years of streamflow data. The results of the analysis are shown in Table 4.21.

The results demonstrate that several instream flow rights are not met periodically, especially in tributaries and headwater streams. Previous analyses of the instream flow rights on the main stem of the Eagle River reported in the *1996 Eagle River Watershed Plan* and the ERA (1994) also estimated frequencies of instream flow right non-exceedance (Table 4.22).

In comparison, the results completed for this assessment are similar, as summarized in Table 4.23.

Two reaches previously identified in the Eagle River Watershed Plan (1996) did not have streamflow gages available for analysis. Only one USGS streamflow gage is located between Gore Creek and Lake Creek. Therefore, this reach was not split into two segments, upstream and downstream of Beaver Creek, as done in the previous analysis. In addition, no previous results were available for comparison upstream of Cross Creek. The current assessment determined that the reach between Resolution Creek and Homestake Creek drops below CWCB ISF levels more than any other measured segment on the Eagle River.

An additional instream flow analysis was recently performed by Eagle County and included in the Master Plan Update, which will be published in summer of 2004. The results of their analysis are illustrated in Figure 4.45.

The Eagle County analysis found results almost identical to the results in Table 4.23. The average number of days per year that instream flow rights are not met for various segments are illustrated in Figure 4.46.

Flow quantification methods used in other contexts rely on gage data to set recommendations by emulating the behavior of measured flows at different times of year. The Tennant Method (Tennant, 1976) relies on percentages of mean annual flow while the Range of Variability Approach (Richter *et al.*, 1997) quantifies the mean and variance of 32 flow variables in order to recommend targets for streamflow at different times of year. Management targets are set such that the value of each streamflow parameter falls within a range of natural variation determined through the interannual distribution (e.g., ±1 standard deviation).

We analyzed data from USGS flow gages in stream and river segments with decreed instream flow rights to compare the instream flow rights to the average and deviation of actual flows at different times of year. Figures 4.47 through 4.50 compare the instream flow rights with the mean monthly flows over the period of record for each recent gage on the main stem of the Eagle River. These results indicate that in the segments containing the Gypsum, Avon, and Minturn gages, instream flow rights were set more than one standard deviation below the average flow computed from post-transbasin diversion gage records for the low flow months of September to October and February to March. Instream flows rights at the Red Cliff gage are set closer to the mean behavior of the Eagle River, which explains the more frequent departure from decreed instream flows.

Table 4.21: Results of the analysis of USGS streamflow gages in stream and riser segments with an instream flow right.

Instream Flow Right	River or Tributary Name	USGS Gage Name	Period of Analysis (Water Years)	Period of Right	Average Number of Days Instream Flow Right *Not* Met Per Year	Average Percent of the Time Instream Flow Right *Not* Met	Percent of Years that Instream Flow Right is *Not* met
5-75W2719	Beaver Creek	Beaver Creek at Avon	1975-2001	Combined	203.8	55.83%	100.00%
	Winter	Beaver Creek at Avon	1975-2001	10/31 to 4/30	94.3	44.46%	92.59%
	Summer	Beaver Creek at Avon	1975-2001	5/1 to 9/30	109.5	71.58%	100.00%
5-77W3634	Bighorn Creek	Bighorn Creek Near Minturn	1977-2001	1/1 to 12/31	194.2	53.19%	100.00%
5-77W3635	Black Gore Creek	Black Gore Creek Near Minturn	1977-2001	Combined	137.8	37.75%	96.00%
	Winter	Black Gore Creek Near Minturn	1977-2001	10/31 to 4/30	91.0	42.92%	92.00%
	Summer	Black Gore Creek Near Minturn	1977-2001	5/1 to 9/30	46.8	30.59%	96.00%
5-86CW230	Black Gore Creek	Black Gore Creek Near Minturn	1986-2001	10/1 to 10/31	21.5	69.35%	93.75%
5-77W3632	Booth Creek	Booth Creek Near Minturn	1977-2001	1/1 to 12/31	196.5	53.83%	100.00%
5-78W3795	Cross Creek	Cross Creek Near Minturn	1978-2001	Combined	162.7	44.57%	100.00%
	Winter	Cross Creek Near Minturn	1978-2001	10/31 to 4/30	141.0	66.53%	100.00%
	Summer	Cross Creek Near Minturn	1978-2001	5/1 to 9/30	21.6	14.13%	87.50%
5-80CW134	Eagle River	Eagle River at Avon	1988-1998	Combined	4.6	1.27%	45.45%
	Winter	Eagle River at Avon	1988-1999	10/31 to 4/30	0.5	0.26%	18.18%
	Summer	Eagle River at Avon	1988-2000	5/1 to 9/30	4.1	2.67%	36.36%
5-80CW124	Eagle River	Eagle River Below Gypsum	1980-2001	Combined	2.8	0.77%	13.64%
	Winter	Eagle River Below Gypsum	1980-2001	10/31 to 4/30	0.0	0.00%	0.00%
	Summer	Eagle River Below Gypsum	1980-2001	5/1 to 9/30	2.8	1.84%	13.64%
5-78W3788	Eagle River	Eagle River Near Minturn	1989-2001	Combined	1.5	0.40%	7.69%
	Winter	Eagle River Near Minturn	1989-2001	10/31 to 4/30	0.0	0.00%	0.00%
	Summer	Eagle River Near Minturn	1989-2001	5/1 to 9/30	1.5	0.96%	7.69%
5-78W3811	Eagle River	Eagle River at Red Cliff	1978-2001	Combined	40.8	11.18%	91.67%
	Winter	Eagle River at Red Cliff	1978-2001	10/31 to 4/30	15.7	7.41%	66.67%
	Summer	Eagle River at Red Cliff	1978-2001	5/1 to 9/30	25.1	16.39%	75.00%
5-77W3636	Gore Creek	Gore Creek At Mouth	1995-2001	Combined	5	1.37%	14.29%
	Winter	Gore Creek At Mouth	1995-2001	10/31 to 4/30	0	0.00%	0.00%
	Summer	Gore Creek At Mouth	1995-2001	5/1 to 9/30	5	3.27%	14.29%
5-86CW216	Gore Creek	Gore Creek At Mouth	1995-2001	10/1 to 10/31	0.0	0.00%	0.00%
5-77W3637	Gore Creek	Gore Creek Lower Station at Vail	1988-1998	Combined	0.9	0.25%	27.27%
	Winter	Gore Creek Lower Station at Vail	1988-1998	10/31 to 4/30	0.3	0.13%	9.09%
	Summer	Gore Creek Lower Station at Vail	1988-1998	5/1 to 9/30	0.7	0.42%	20.00%
5-86CW222	Gore Creek	Gore Creek Lower Station at Vail	1988-1998	10/1 to 10/31	0.0	0.00%	0.00%
5-86CW221	Gore Creek	Gore Creek At Upper Station Near Minturn	1986-2001	10/1 to 10/31	7.9	25.60%	62.50%
5-80CW131	Middle Creek	Middle Creek Near Minturn	1980-2001	1/1 to 12/31	175.6	48.11%	100.00%
5-77W3633	Pitkin Creek	Pitkin Creek Near Minturn	1977-2001	1/1 to 12/32	162.1	44.42%	100.00%
5-77W3631	Red Sandstone Creek	Red Sandstone Creek Near Minturn	1977-2001	Combined	68.0	18.62%	100.00%
	Winter	Red Sandstone Creek Near Minturn	1977-2001	10/31 to 4/30	43.6	20.57%	76.00%
	Summer	Red Sandstone Creek Near Minturn	1977-2001	5/1 to 9/30	24.4	15.92%	92.00%
5-78W3815	Turkey Creek	Turkey Creek Near Red Cliff	1978-2001	1/1 to 12/31	206.4	56.54%	100.00%
5-78W3814	Wearyman Creek	Wearyman Creek Near Red Cliff	1978-2001	1/1 to 12/32	146.5	40.14%	100.00%

Table 4.22: Previous analyses of instream flow deficits (sources: *1996 Eagle River Watershed Plan*; Eagle River Assembly, 1994).

Section of the Eagle River	Instream Flow Deficits		
	Instream Flow Standard – Summer/Winter	Estimated Frequency of Flow Shortage – Summer	Estimated Frequency of Flow Shortage – Winter
Cross Creek to Gore Creek	50/20 cfs	1 in 5-10 years	1 in 10 years
Gore Creek to Beaver Creek	85/35 cfs	1 in 5-10 years	1 in 5-10 years
Beaver Creek to Lake Creek	85/35 cfs	1 in 2 years	1 in 5-10 years
Lake Creek to Brush Creek	110/45 cfs	1 in 5-10 years	1 in 5-10 years
Brush Creek to Colorado River	130/50 cfs	1 in 5-10 years	None observed

Table 4.23: Instream flow deficit results along main stem of the Eagle River, as per USGS streamflow data.

Section of the Eagle River	Instream Flow Deficits		
	Instream Flow Standard – Summer/Winter	Estimated Frequency of Flow Shortage – Summer	Estimated Frequency of Flow Shortage – Winter
Resolution Creek to Homestake Creek	15/8 cfs	3 in 4 years	2 in 3 years
Homestake Creek to Cross Creek	25/11 cfs	1 in 10 years	None observed
Cross Creek to Gore Creek	50/20 cfs	No gage	No gage
Gore Creek to Lake Creek	85/35 cfs	1 in 2-5 years	1 in 5-10 years
Lake Creek to Brush Creek	110/45 cfs	No gage	No gage
Brush Creek to Colorado River	130/50 cfs	1 in 5-10 years	None observed

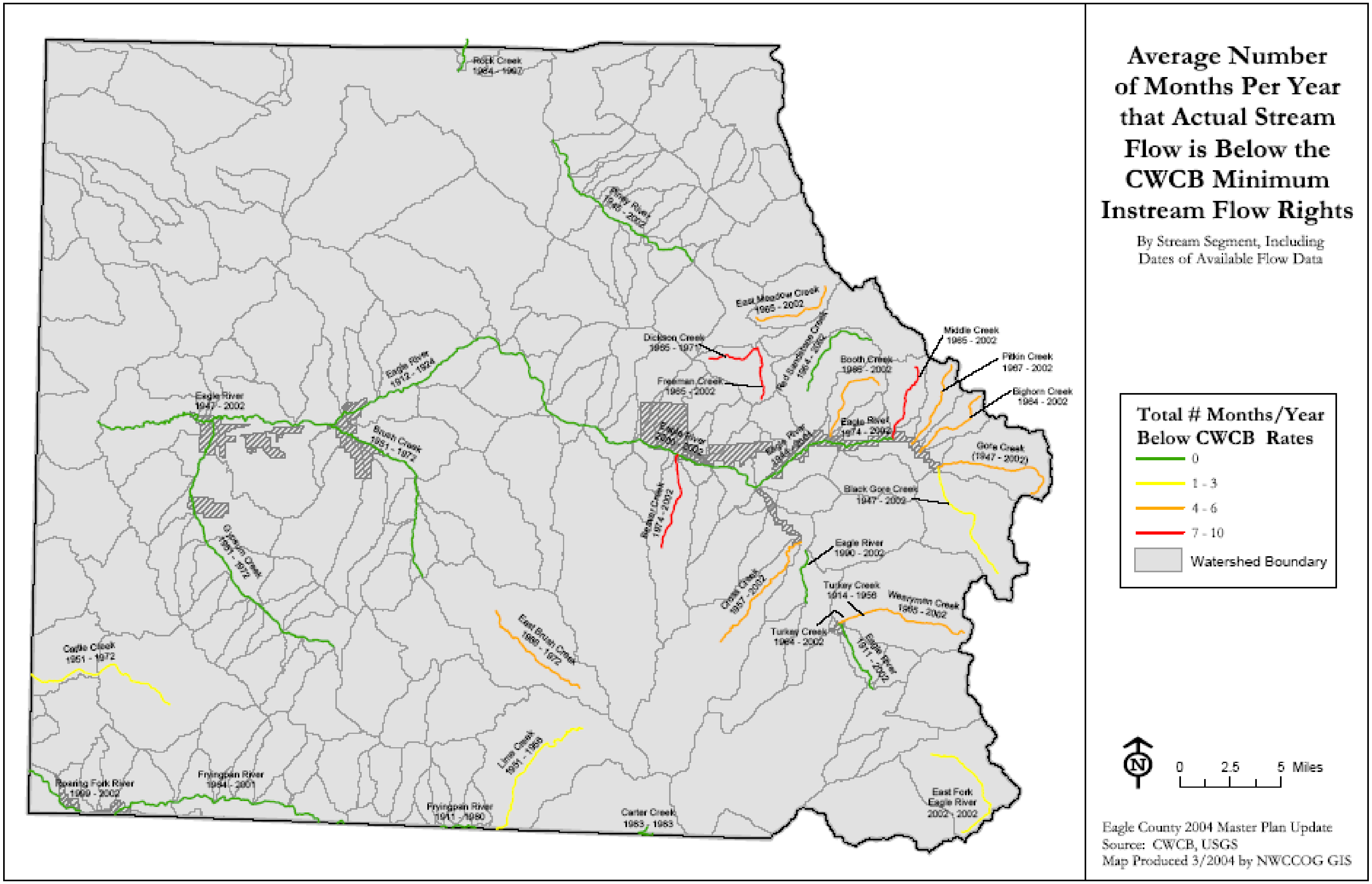


Figure 4.45: Instream flow analysis results from the Eagle County Master Plan Update. The graph demonstrates the number of months per year that flow is below the CWCB instream flow right. This analysis included all gages, current and historical.

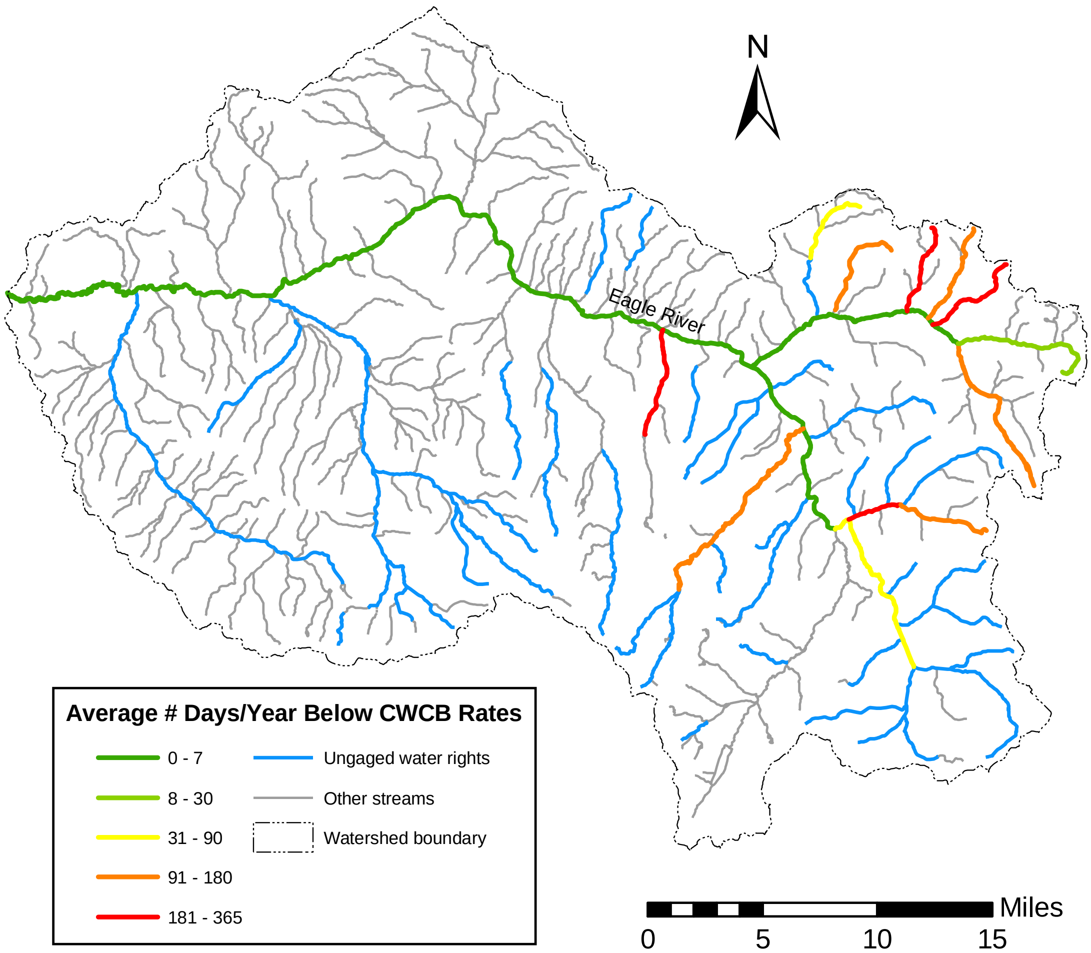


Figure 4.46: Average number of days per year instream flow right is not met. Stream segments highlighted in blue indicate that an instream flow right exists, but no current gage data are available for analysis.

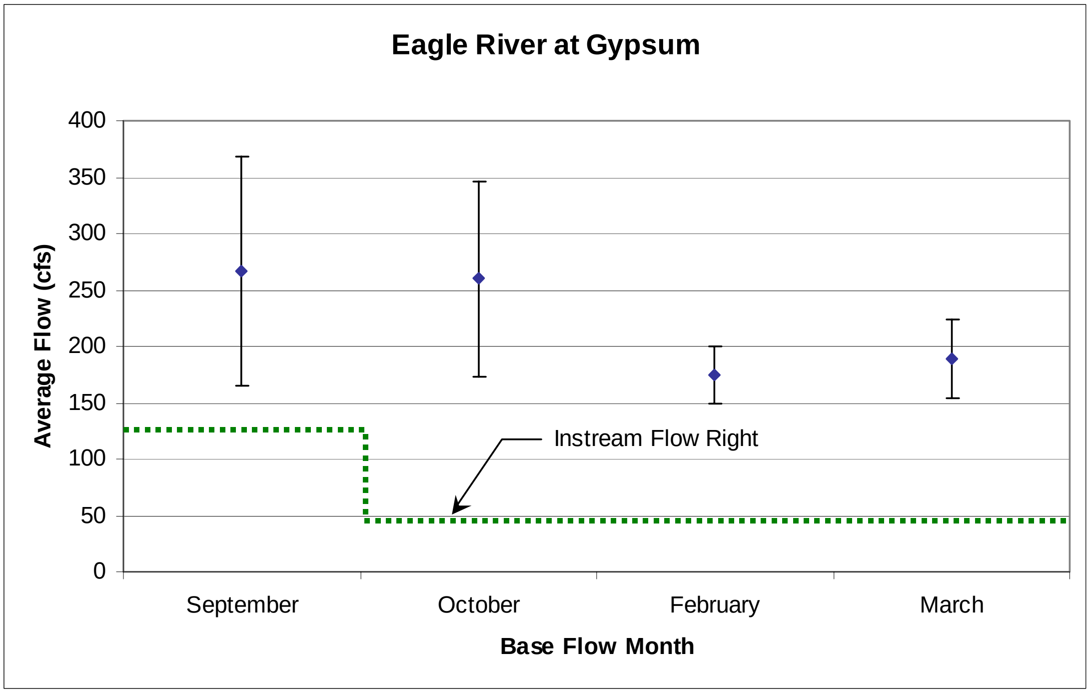


Figure 4.47: Monthly base flow averages over the period of record (1946 to 2001) at the Eagle River at Gypsum gage. The bars indicate the base flow average +/- one standard deviation. The green dotted line symbolizes the instream flow right at the segment of the Eagle River where the gage is located.

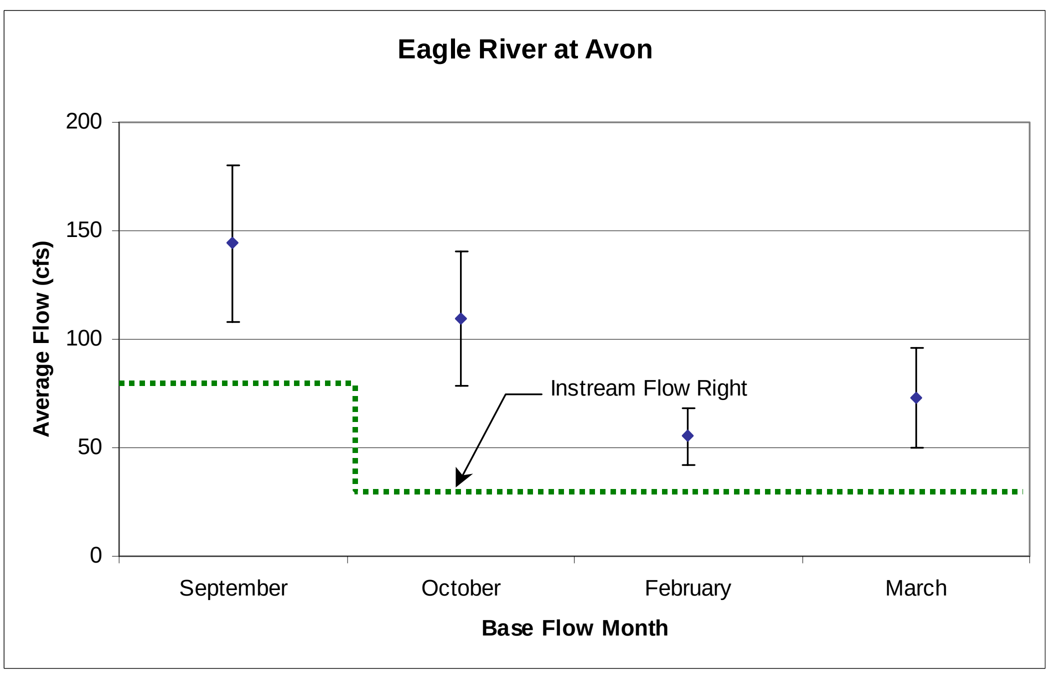


Figure 4.48: Monthly base flow averages over the period of record (1988 to 1998) at the Eagle River at Avon gage. The bars indicate the base flow average +/- one standard deviation. The green dotted line symbolizes the instream flow right at the segment of the Eagle River where the gage is located.

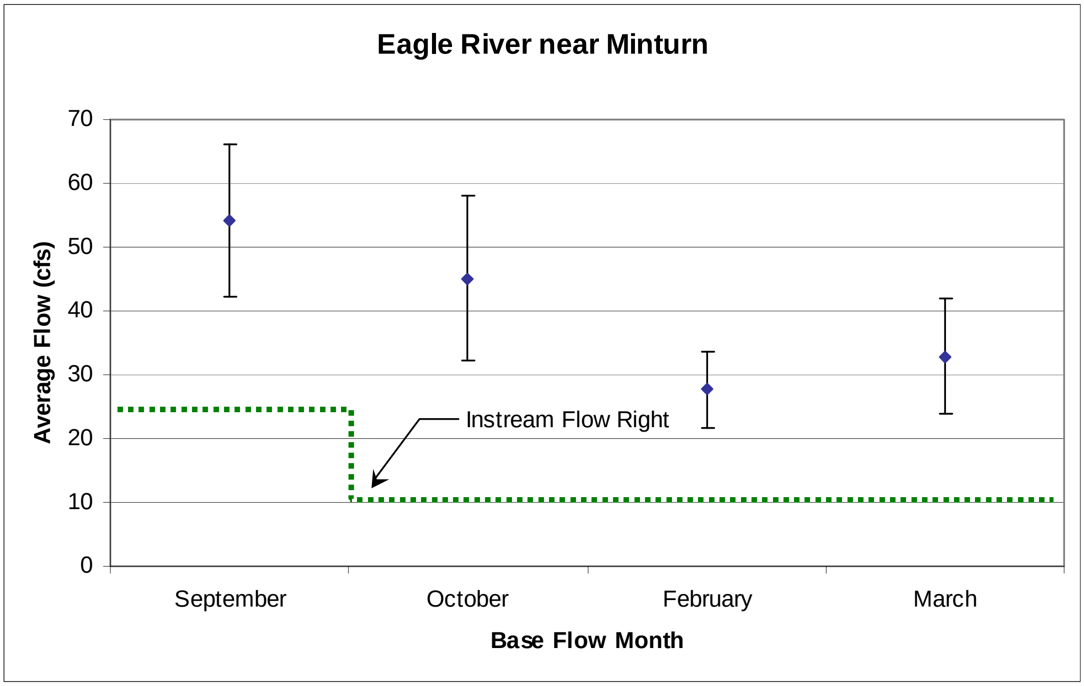


Figure 4.49: Monthly base flow averages over the period of record (1989 to 2001) at the Eagle River near Minturn gage. The bars indicate the base flow average +/- one standard deviation. The green dotted line symbolizes the instream flow right at the segment of the Eagle River where the gage is located.

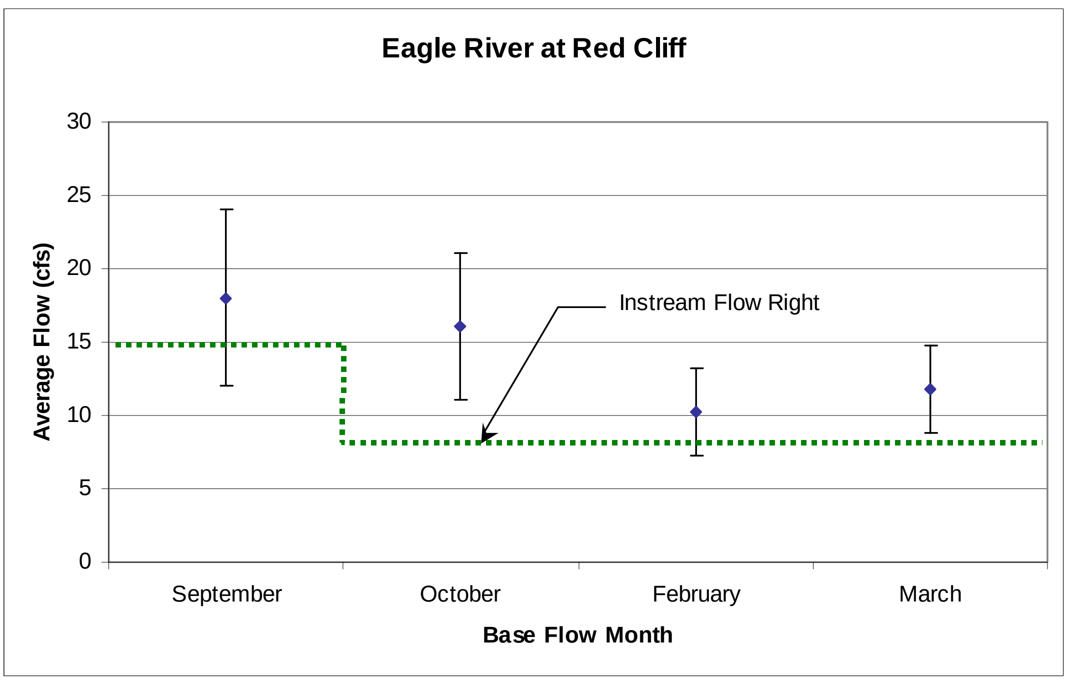


Figure 4.50: Monthly base flow averages over the period of record (1910 to 2001) at the Eagle River at Red Cliff gage. The bars indicate the base flow average +/- one standard deviation. The green dotted line symbolizes the instream flow right at the segment of the Eagle River where the gage is located.

At the Gypsum and Minturn gages, it appears that instream flows are set at levels that deviate significantly from period of record average flows. It is therefore not surprising that these levels are met the vast majority of the time, especially in the case of winter flows at these gages.

4.5.3 Relationship Between Drainage Area and Instream Flow Right

A fundamental concept of hydrology is that as the size of the drainage area increases as one moves downstream in a given river basin, the discharge generally increases. This relationship can be affected by factors including precipitation variability, withdrawals of water from the basin by diversion structures, lateral inflows, or outflows of groundwater. The relationship between streamflow at USGS stations in the Eagle River watershed as a function of drainage area is depicted in Figure 4.51. Yield represents the volume of water that passes through a particular gage on an annual basis, which corresponds to the average annual discharge.

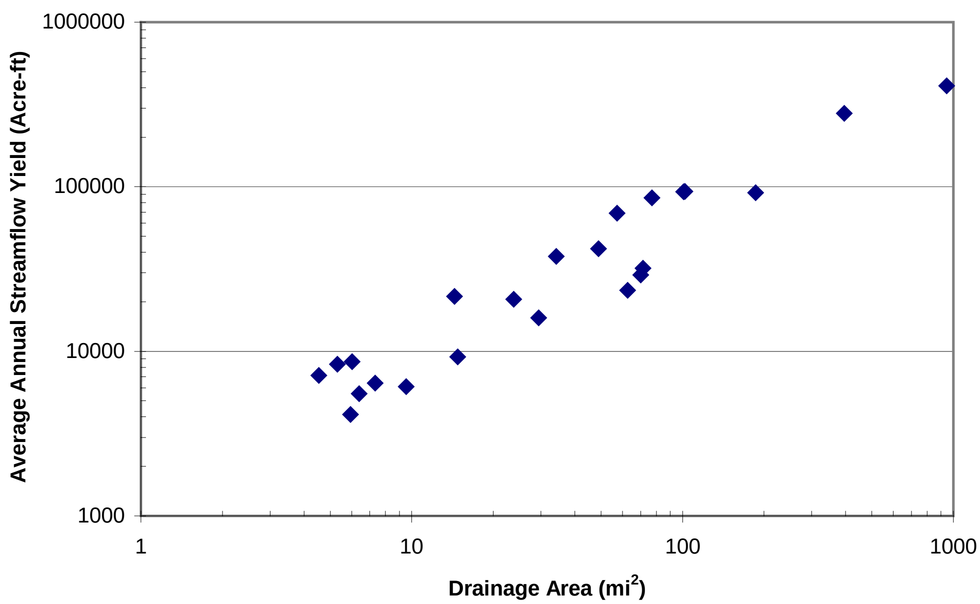


Figure 4.51: Streamflow yield as a function of drainage area for 23 USGS stations in the Eagle River watershed. USGS stations lacking a sufficient period of record were not included in the analysis.

From this relationship and trends in the hydraulic geometry of channels, it would be reasonable to expect some degree of positive correlation between drainage area of the watershed and instream flow rights. Because several stream segments in the Eagle River watershed have varying rights for summer and winter streamflows, separate analyses were necessary to examine instream flow rights as a function of drainage area. Drainage areas were established for each instream flow right using a geographical information system (GIS). The first analysis examined summer instream flow rights in the watershed (May 1st to September 30th) (Figure 4.52).

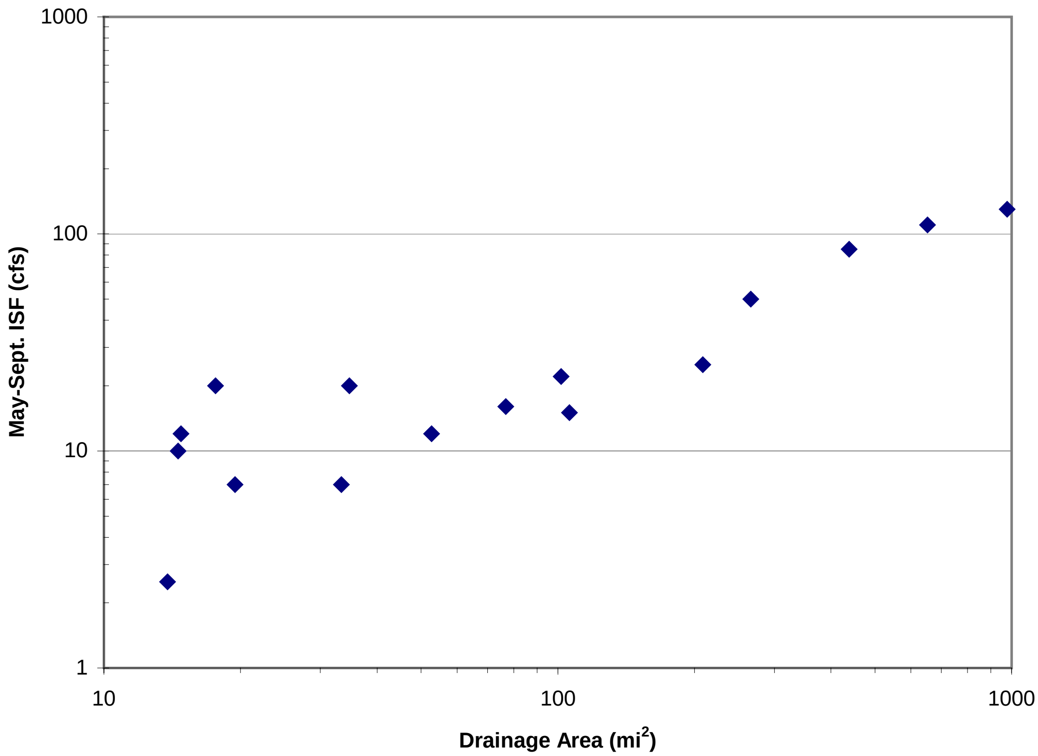


Figure 4.52: Summer instream flow rights as a function of drainage area for 19 USGS gage stations located in the Eagle River watershed.

A positive correlation exists between the summer instream flow rights and the drainage area on a logarithmic plot, as one would expect. A coefficient of determination (R^2) of 0.85 was computed for this relationship, indicating that the drainage area explains 85% of the variability in summer instream flow rights. However, when examining the instream flow rights that are appropriated as a year round value, the relationship is considerably more variable (Figure 4.53).

Figure 4.53 illustrates that although a positive correlation is present, the R^2 has a value of only 0.29, indicating that the watershed size explains 29% of variability in year round instream flow rights. The very large differences in instream flow rights for a given drainage area undoubtedly reflect variability in basin, geomorphic, and climatic characteristics, as well as common measurement errors related to estimates of channel roughness, bankfull stage, and other factors. The variability of these results, nonetheless, suggests that a re-examination of current instream flow quantities may be warranted for some sites.

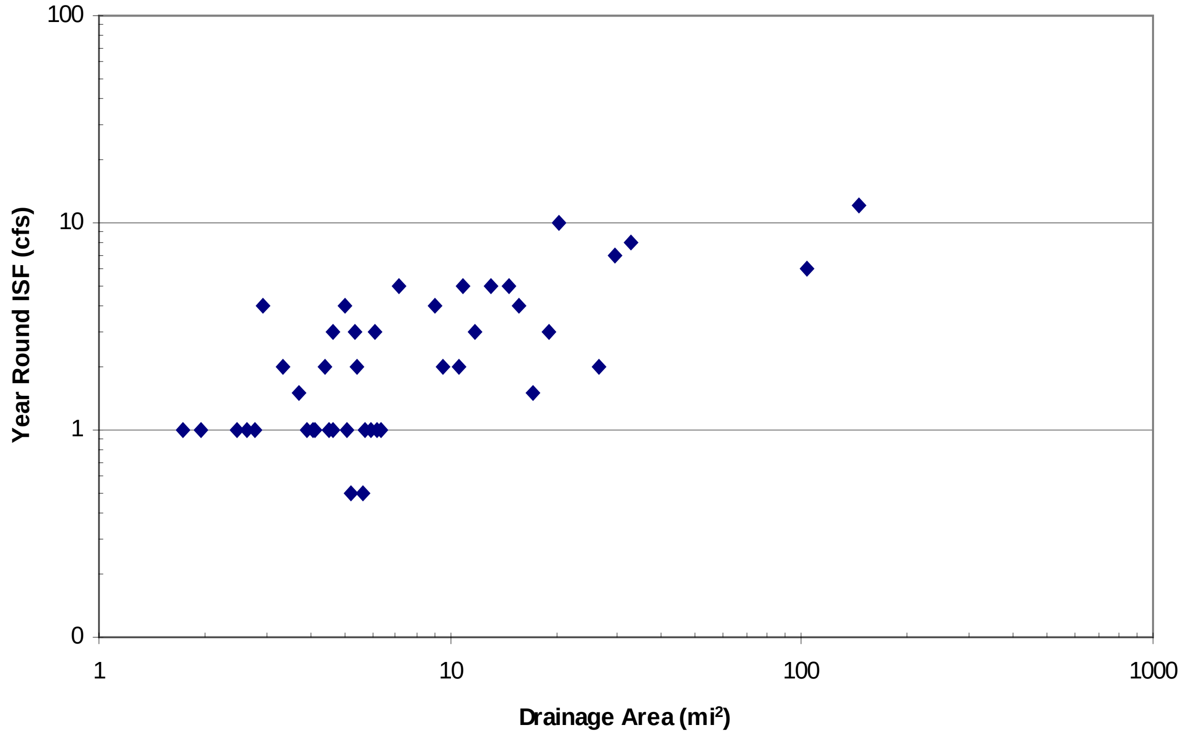


Figure 4.53: Year round instream flow rights as a function of drainage area for 44 instream flow rights in the Eagle River watershed.

4.5.4 Instream Flow Quantification Methods in the Eagle River Watershed

As part of the instream flow analysis, the original instream flow field forms describing cross-sectional data, inputs into R2CROSS, and recommended flows were compared with decreed instream flow rights. Table 4.24 lists decreed instream flow rights that differ from the original DOW recommendations.

Table 4.24: Instream flow rights differing from DOW recommendations (source: CWCB, DOW).

Case Number	Stream Name	Upper Terminus*	Lower Terminus*	ISF Right (cfs)	Original DOW Rec. (cfs)
5-80CW126	Eagle River	confl Lake Ck	confl Brush Ck	110/45	130/50
5-80CW134	Eagle River	confl Gore Ck	confl Lake Ck	85/35	85/45
5-77W3627	East Brush Creek	Lake Charles	confl W Brush Ck	7/4	7
5-77W3636	Gore Creek	confl Red Sandstone Ck	confl Eagle River	22/8	28/12
5-77W3637	Gore Creek	confl Black Gore Ck	confl Red Sandstone Ck	16/6	16/8
5-87CW270	Nolan Creek	confl Triangle Ck	confl E Brush Ck	2.5/1.5	2
5-77W3631	Red Sandstone Creek	headwaters	confl Indian Ck	2/1	4
5-78W3806	Rule Creek	headwaters	confl Eagle River	0.5	1

*The use of the abbreviation "confl" signifies a confluence between two streams.

The results of reviewing field forms for the Eagle River main stem are summarized in Table 4.25.

Table 4.25: Summary of results of reviewing field forms for the Eagle River main stem.

Segment of Eagle River Main Stem	Segment Length	No. of Transects Used to Set ISF	Discharge Meeting Three Habitat Criteria	Discharge Meeting Two Habitat Criteria	DOW Rec. ISF for May-Sept. / Oct.-April	Final ISF Right for May-Sept. / Oct.-April	Notes
Homestake Creek to Cross Creek	6 miles	1	82-85 cfs	20 cfs	25/11 cfs	25/11 cfs	ISF outside range of 0.4-2.5Q measured, Meets one of three criteria in winter and two of three criteria in summer
Cross Creek to Gore Creek	4 miles	1	290 cfs	87-107 cfs	50/20 cfs	50/20 cfs	ISF outside range of 0.4-2.5Q measured, Meets one of three criteria in winter and one of three criteria in summer
Gore Creek to Lake Creek	10.1 miles	no survey available	?	?	85/45 cfs	85/35 cfs	No survey located, winter flow reduced from recommended 45 cfs to 35 cfs
Lake Creek to Brush Creek	20 miles	1	226 cfs	130 cfs	130/50 cfs	110/45 cfs	Recommended summer / winter flow of 130/50 reduced to 110/45 cfs, Decreed right meets one of three criteria in winter and one of three criteria in summer, Assumed Manning n value
Brush Creek to Colorado River	12.8 miles	1	135 cfs	92-108 cfs	130/50 cfs	130/50 cfs	Top width = 100 ft yet average top width of 7 bankfull sections measured at Gypsum SWA = 252 ft, Meets one of three criteria in winter and two of three criteria in summer

Excluding the Gore to Lake Creek segment for which field records were not obtained, instream flow recommendations for the remaining 43 miles of the Eagle River main stem between Homestake Creek to Dotsero were made based on measurements at 4 locations using the single-transect R2CROSS method. Two of eight instream flow quantities decreed for reviewed segments meet two of the criteria recommended by Nehring (1979). Although the Eagle River exhibits substantial variability in morphology and hydraulic geometry, the length of river represented by a single transect (cross-section) ranges from 1.7 to 20 miles.

When flows are low, the first stream segments to go dry will be the riffles. Riffle sections are often areas of high productivity and biologically diverse segments due to the high current and heterogeneous substrate. Therefore, it makes sense to survey riffle sections of the river for instream flow right determinations. The single transect R2CROSS methodology specifies that the survey transect be located within a representative channel riffle, but does not specify the length of a river segment that one survey transect can represent. Instream flow rights in the basin were determined through the use of a single transect approach, with the exception of Beaver Creek, Black Gore Creek, Gore Creek, and Whitney Creek. The average length of channel represented by one R2CROSS transect in the Eagle River watershed is approximately 5 miles. Appendix E provides the number of transects used in the determination of each instream flow right for all reviewable rights surveyed.

As stated above, Nehring (1979) recommended that the R2CROSS single transect method be used with corrections for flow calibration on streams of little to perhaps moderate value as far as the fisheries resource is concerned. For major streams that are supporting moderate to heavy public recreation use and are more subject to encroachments of water development, diversion, and pollution, Nehring (1979) recommended that a multiple transect methodology be used in lieu of the single transect approach. Ultimately, it was recommended that streams of the greatest importance or in grave danger of pollution or diversion should utilize the IFG4 or the Wetted Surface Profile (WSP) interfaced with the IFG3 Habitat Program. The Instream Flow Group (IFG) of the U.S. Fish and Wildlife Service, Fort Collins, Colorado, first established the IFG2 and IFG3 programs of IFIM in the late 1970's (Bovee, 1982), and have subsequently updated and refined these procedures (Bovee *et al.*, 1998).

4.5.5 Linkages with Water Quality

Critical low flows, or low dilution conditions, are used to establish the Colorado Department of Public Health and Environment (CDPHE) wastewater treatment effluent limits for National Pollutant Discharge Elimination System (NPDES) permits. The critical flows are designed to ensure that chronic and acute water quality standards (and anti-degradation requirements in some instances) are met under all but extreme low-flow conditions (Parachini and Oppelt, 2003). Wastewater treatment plants (WWTP) in Colorado are provided acute (1E3) and chronic (30E3) low streamflows as part of the NPDES permit. The 1E3 flow generally corresponds to the lowest average daily flow that recurs once every three years, and 30E3 flow represents the lowest 30-day harmonic mean that recurs once in 3 years (E. Oppelt, CDPHE, pers. comm., 2004). When streamflows fall below these levels, WWTPs are no longer required to meet water quality standards. A comparison of the instream flow rights and the acute and chronic flows for selected point source dischargers in the Eagle River basin is presented in Table 4.26.

Table 4.26: Comparison of IE3 and 30E3 dilution flow values above which the 5 major Eagle River watershed WWTPs are required to meet effluent standards and the instream flow right of the Eagle River segment to which the WWTP is discharging. Dilution flows vary monthly for ammonia. Flows are in units of cfs.

Wastewater Treatment Plant	Acute 1E3	Chronic 30E3	Instream Flow Right Summer/Winter/October
Vail Wastewater Treatment Plant	6	7.7	16/6/10
Avon Wastewater Treatment Plant	32	40	85/35
Edwards Wastewater Treatment Plant	46	55	110/45
Gypsum Wastewater Treatment Plant	95	129	130/50
Eagle Wastewater Treatment Plant	86	118	130/50

Summer instream flow rights in the Eagle River main stem are greater than the chronic flows established for 5 major WWTPs in the basin. However, during winter months, streamflows could potentially meet instream flow rights, yet be below the levels at which dischargers are required to meet water quality standards and anti-degradation requirements. However, the relationship between instream flows and chronic flows designated in NPDES permits is complicated because effluent limits are based on design discharges at full WWTP capacity. The permit renewal process is initiated when a NPDES permitted facility reaches a monthly average discharge equal to 80% of design capacity. These results nonetheless illustrate the disparate quantification procedures used for identifying instream and dilution flows, as well as the interplay between instream flows, current and future low flow regimes, and implications for effluent limits in NPDES permits.

4.5.6 Instream Flows – Summary

Statistics indicating that instream flow rights are being met most of the time do not necessarily indicate that the environment is being protected to a reasonable degree if the flow rights were initially set too low. The lower an instream flow is set relative to the normal low flow condition of the river, the greater the likelihood it will be met over time. Most of the instream flow quantities for the Eagle River mainstem are set well below the mean low flow quantities recorded at gauging stations and, in some instances, below levels deemed necessary to protect the river from point source discharges of pollutants (1E3 and 30E3 flows). The more detailed methods recommended by Nehring (1979) for quantifying instream flows for rivers subject to encroachments of water development, diversion, and pollution were not used in the Eagle River watershed. Therefore, Chapter 6 includes recommendations for improving decision-making tools for managing flows in the watershed.

4.6 WATER QUALITY

Water quality can be defined in many different ways. A practical definition is that water quality "reflects the composition of water as affected by natural causes and human activities, expressed in terms of measurable quantities and related to intended water use" (Novotny and Olem, 1994). From a more ecological perspective, Karr (1991) defined water quality as "water of a quality necessary to support a balanced, integrated, adaptive community of riparian and aquatic organisms comparable to the natural systems of the region with the stability and capacity for self-repair." The approach adopted for this study is somewhat intermediate to these definitions, emphasizing both the composition of water and its ability to support native biota and non-native gamefish species such as brown, brook, and rainbow trout. In many instances, we primarily focus on biological monitoring data because (1) biota are valued *directly* by society, chemical concentrations are not; (2) biota are sensitive to a broad range of human impacts; (3) biota respond to physiochemical changes in complex, unpredictable ways; and (4) biota integrate effects of various impacts and do so through time (Angermeier, 1997).

It should be made clear from the outset that water *quality* is inextricably linked with water *quantity*. Low flow patterns in the Eagle River directly influence several aspects of water quality including:

- growth and persistence of algae in the river bed;
- deposition and flushing of fine sediment from land disturbance and erosion;
- concentrations of nutrients and oxygen below wastewater discharges;
- late summer temperatures for coldwater fishes; and
- dilution of pollutants from mine sites and stormwater runoff.

In general, increasing the load of pollutants to a given amount of flow will adversely affect water quality. Thus, any discussion of the current status of water quality in the Eagle River watershed must be presented with the caveat that these conditions may be reflective of future water quality patterns only to the extent that flow regime patterns in the streams and rivers of the Eagle River watershed are comparable in the future. A central challenge for stakeholders will be to maintain water quality despite population increases and greater demands placed on the valley's water quantity, coupled with growing volumes of treated wastewater and stormwater runoff entering the river.

With this as a general context, we can state that water quality is good in most parts of the watershed, due in no small part to maintenance of key physical and ecological processes in the headwaters. However, much room for improvement remains and changes will be necessary to maintain the current water quality in the face of rapid watershed change.

4.6.1 Overview of Water Quality in the Eagle River Watershed

Historically, the waters of the Eagle River watershed were cold and highly-oxygenated with very low nutrient levels (oligitrophic conditions) comparable to those still observed in minimally disturbed streams of the region. The streams of the upper watershed generally had little turbidity and low sediment loads except during occasional extreme events and episodes of mass wasting. Beaver (*Castor canadenis*) trapped large quantities of sediment in high mountain valleys, diversifying physical habitat and riparian plant communities. Fish communities were dominated by the Colorado cutthroat trout (*Oncorhynchus clarki pleuriticus*), with the mottled sculpin (*Cottus bairdi*) common in many streams. The lower watershed had naturally higher sediment loads and temperatures but also supported communities of dense woody riparian vegetation, often dominated by willows (*Salix* spp.), on smaller streams and expansive cottonwood forests in the broader Eagle River valley. All these characteristics have been influenced to some extent by our historical legacy and current land use practices.

Today, the predominant human influences on water quality arise from (1) nutrient enrichment via point discharges and polluted runoff, (2) metals loading from the Eagle Mine, other historic mining sites, and developed areas, (3) sediment loading from grazing in highly erodible subwatersheds of the lower basin, unpaved forest roads, traction sand, and stormwater, (4) habitat loss and temperature effects associated with riparian vegetation removal and channel modifications, and (5) stormwater runoff.

Numerous studies have been conducted on various aspects of water quality in the Eagle River watershed over the last three decades since passage of the Clean Water Act. For a brief review of selected recent publications addressing regional water quality, see Section 3.3. Particularly noteworthy studies include those of the USGS NAWQA program, the water quality synthesis contained in the most recent "208 plan" (NWCCOG, 2002), and extensive monitoring information related to metals impacts (e.g., Woodling and Rollings, 2004). Together, these documents provide a good compendium of information on issues affecting various segments of the river network. A map (Figure 4.54 from the *1996 Eagle River Watershed Plan*) identifying water quality impact areas in the Eagle River watershed remains germane to the discussion that follows.

Rather than duplicating these efforts, we have chosen to summarize the issues presented previously in Table 4.27 and Figure 4.54 and build upon the information contained in these documents in the following sections. This section of the ERIA is not intended to restate or supplant the findings of these previous studies, but instead necessarily focuses on pressing issues related to nutrients, metals, sedimentation, and elevated temperatures. In this context, we have analyzed existing datasets and new data from several sources and have endeavored to understand how these overarching stressors relate to the current status and potential future responses of aquatic life. The following sections provide further details on these key issues, results of data analyses, and background information pertinent to understanding the potential benefits of candidate restoration activities evaluated and described in Chapter 5.

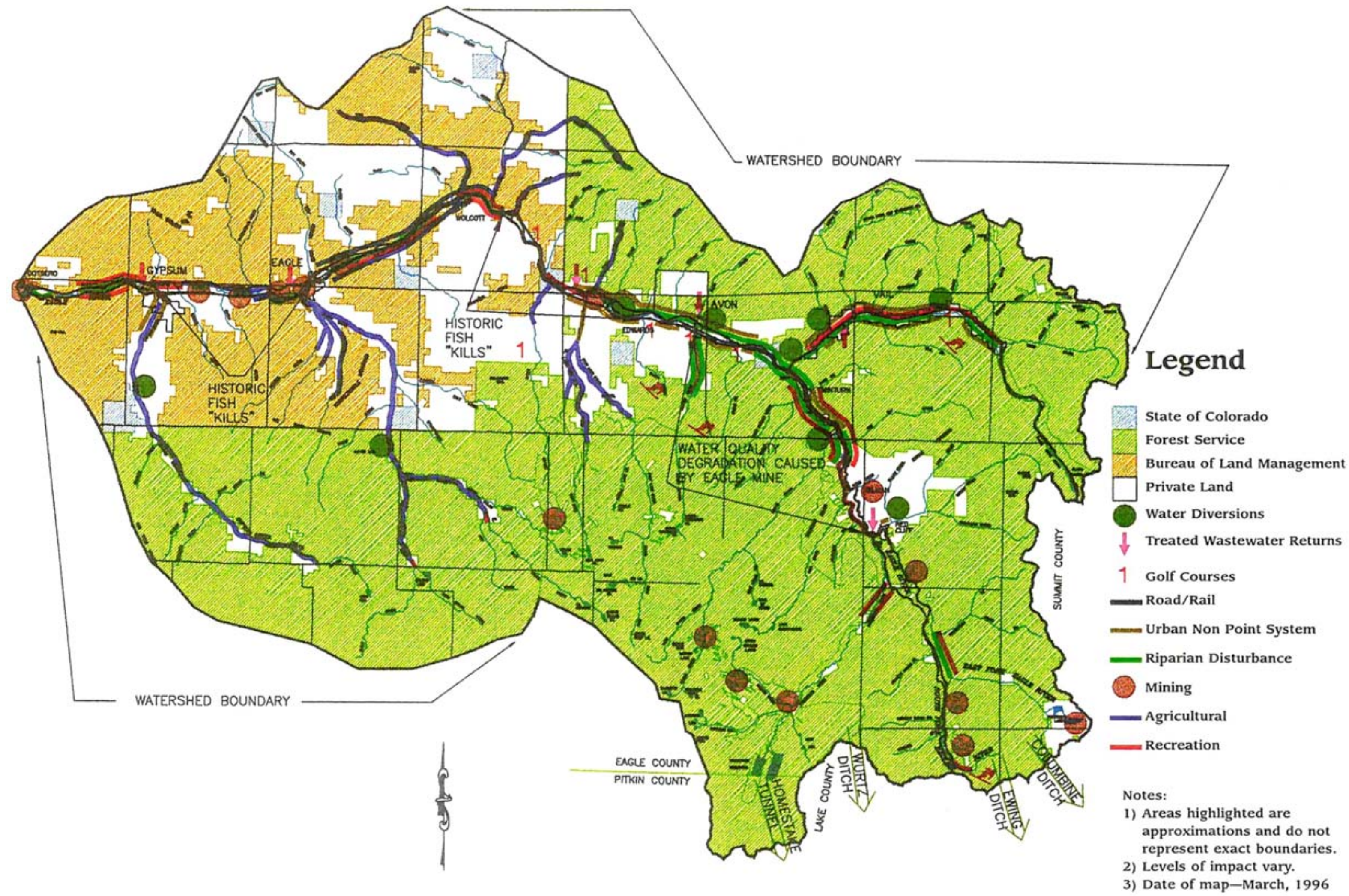


Figure 4.54: Water quality impact areas (*1996 Eagle River Watershed Plan*)

Table 4.27: Summary of key water-quality stressors in the Eagle River watershed (modified from NWCCOG (2002)).

River Segment*	1	2	3	4	5	6	7	8	9	10	11	12
Point Source Pollutants												
Metals					✓							
Wastewater Effluent	✓							✓	✓			
Nonpoint Source Pollutants												
Metals				✓	✓				✓			
Nutrients								✓	✓			
Sediments					✓		✓	✓	✓	✓	✓	✓
Urban Stormwater Runoff	✓				✓		✓	✓	✓	✓		
Irrigation Returns									✓	✓		✓
Salinity									✓		✓	

*The 208 Report describes the following stream and river segments:

Upper Eagle River Watershed
- Segment 1 – Eagle River above Belden
- Segment 2 – Homestake Creek
- Segment 3 – Fall Creek
- Segment 4 – Cross Creek
- Segment 5 – Eagle River from Belden to Gore Creek
- Segment 6 – Gore Creek above Black Gore Creek
- Segment 7 – Black Gore Creek
- Segment 8 – Gore Creek below Black Gore Creek

Lower Eagle River Watershed
- Segment 9 – Eagle River from Gore Creek to Dotsero
- Segment 10 – Gypsum Creek
- Segment 11 – Milk and Alkali Creeks
- Segment 12 – Brush Creek

4.6.2 Nutrients

4.6.2.1 Background

Nitrogen and phosphorus are the two primary nutrients affecting productivity in streams and rivers. Nitrogen (N) and phosphorus (P) occur naturally in streams at 'background' levels, even in pristine mountain watersheds. The Eagle River and its tributaries are naturally low in nutrients and productivity, or oligotrophic. In a study of the Upper Colorado River Basin, Spahr and Wynn (1997) estimated the median background levels of nitrate and total phosphorus (TP) at 0.09 mg/L and 0.03 mg/L, respectively. It is well established that a variety of watershed land uses alter the amounts of these nutrients reaching the stream. Eutrophication refers to the natural and artificial addition of nutrients to waterbodies and the accompanying effects on water quality—mainly increased organic matter production and the common side effects of periodically low oxygen levels and loss of sensitive species.

The nutrient most responsible for eutrophication can be N or P depending on the waterbody, and sometimes the time of year. Depending on the balance of N to P, primary producers such as diatoms and green algae may respond disproportionately to additions of the nutrient that is most limiting. Conventional wisdom has held that the vast majority of freshwater streams and lakes are phosphorus limited (Wetzel, 1983), but there is increasing evidence that many mountain streams and rivers in Colorado are limited by nitrogen for at least part of the year (Porter, Regional Biologist, USGS NAWQA Program, pers. comm.). Thus, in this instance it is important to consider both N and P loading.

Nitrogen and phosphorus additions directly stimulate production of autotrophs, which are organisms that acquire their energy from sunlight and materials from non-living sources. The term periphyton refers to autotrophs like diatoms and algae that live on substrates in stream and rivers. Virtually all surfaces receiving light in streams and rivers sustain a periphyton community. These communities make organic energy available to aquatic insects and fish and form the foundation of the aquatic food web. Periphyton communities are affected by factors other than nutrients including light, flow velocity, temperature, substrate stability, scouring, grazing by insects, and water chemistry (Table 4.28). Nonetheless, periphyton monitoring is an excellent assessment tool for understanding the consequences of nutrient enrichment because it is fundamentally linked to responses occurring at higher levels of the food web (aquatic insects and fish).

Table 4.28: Primary variables controlling periphyton community biomass accrual, general human activities that may influence these variables and the overall effects on periphyton biomass in shallow, stony streams (adapted from Biggs (2000a)).

Controlling Variable	Human Activity	Potential Effects on Biomass
Hydrological disturbance	flow regulation (reducing flow variability and increasing bed stability)	increase
	flow regulation (increasing flow variability)	decrease, but depends on pre-regulation conditions
	gravel abstraction (bed destabilization)	decrease, particularly if gravel removal is from within the wetted channel
	intensification of land use, forest/ scrub removal (increased runoff and bed destabilization)	decrease, particularly if catchment is steep
Nutrient supply	wastewater discharges (increased nutrient supply)	increase, particularly if from effluent ponds/treatment systems into shallow, stony bedded oligotrophic and mesotrophic streams
	intensification of land use, forest/ scrub removal (increased nutrient supply)	increase, providing it is not accompanied with excessive siltation
Light supply	riparian vegetation removal (increased light)	increase, in 1st- to 3rd-order streams
	intensification of land use, forest/ scrub removal (increased suspended sediment)	decrease, through increased siltation
Invertebrate grazing	intensification of land use, forest/ scrub removal (increased siltation)	increase, if siltation of invertebrate interstitial habitat decreases grazing activity
Baseflow velocity	abstraction/diversion (decreasing velocities)	increase, if filamentous green algae; increase or decrease, if stalked diatom/short filamentous communities; decrease, if mucilaginous communities
Baseflow temperature	abstraction/diversion (increased temperature)	increase, particularly if there is no riparian shade

4.6.2.2 Consequences of Nutrient Enrichment

The potential consequences of eutrophication in rivers and streams include significant changes in aquatic insect communities, proliferations of filamentous algae, and attendant consequences for fishes. Numerous instream values can be affected by excessive periphyton levels (Table 4.29). Shifts from a river substrate dominated by less visible diatoms to one dominated by highly visible filamentous algae can occur abruptly as nutrient enrichment increases (Coles *et al.*, 2004; Porter, USGS NAWQA Program, pers. comm.). Green or brown filamentous algae tend to cause more problems for contact recreation and are more conspicuous than diatom mats and slimes because of their coloration and the way filaments extend toward the water surface. Filamentous algae are most often concentrated in the low velocity edges of shallow streams where public activity is often focused.

Table 4.29: Instream values that can be compromised and associated problems that may arise as a result of periphyton proliferations (based on Ministry for the Environment (MFE, 1992) and Biggs (2000b); adapted from Biggs (2000a)).

Instream Value	Problem
Aesthetics	Degradation of scenery, odor problems
Biodiversity	Loss of sensitive invertebrate taxa through habitat alteration, possible reduction in benthic biodiversity
Contact recreation	Impairment of swimming, odor problems, dangerous for wading
Industrial use	Taste and odor problems, clogging intakes
Irrigation	Clogging intakes
Monitoring structures	Fouling of sensor surfaces, interferes with flow
Potable supply	Taste and odor problems, clogging intakes, disinfection byproducts
Fish conservation	Impairment of spawning and living habitat
Stock and domestic animal health	Toxic blooms of blue-green algae
Trout habitats/angling	Reduction in fish activity/populations, fouling lures, dangerous for wading
Waste assimilation	Reduces stream flow, reduces ability to absorb ammonia, reduces ability to process organics without excessive dissolved oxygen depletion
Water quality	Increased suspended detritus, interstitial anoxia in stream bed, increased dissolved oxygen and pH fluctuations, increased ammonia toxicity, very high pH

Changes in periphyton biomass have direct implications for aquatic insects and fish. Shifts from aquatic insect faunas typifying ‘clean waters’ to those found in organically degraded conditions have been widely observed as a result of nutrient enrichment (Biggs, 2000a). Nutrient additions to oligotrophic streams can also stimulate productivity up the food web to the level of fish. But there is growing scientific evidence that if enrichment becomes too high it can be detrimental to trout density and biomass (Biggs, 2000a; Quinn and Hickey, 1990; Hayes *et al.*, 2000). In extreme cases, levels of primary production can be stimulated by nutrients to a point that organic carbon will build up in the system and cause a subsequent low dissolved O_2 (DO) and high pH event. Fish and invertebrates will grow poorly and even die if the O_2 depletion and pH increases are severe (Welch, 1992; Dodds and Welch, 2000).

Prolonged periods of low summer flows are generally associated with increased risk and severity of proliferations as higher water velocities can prevent thick mats of algae from developing. Biggs *et al.* (1998)

suggested that filamentous algae can be maintained at less than 100 mg Chl *a* /m^2 if *near-bed* velocities are > 1 ft/s. It is interesting to note that the R2CROSS methodology for quantifying instream flow uses an *average* velocity criterion of 1 ft/s for *riffles* but can tend to overestimate the average velocity by an average of 45% from measured field values (Nehring, 1979). Therefore, recommended instream flows generally do not achieve near bed velocities that are known to reduce the risk of filamentous algae proliferations. It is very important to emphasize that stream organisms are also sensitive to the *duration* of periphyton proliferations. Thus the length of time that a river can accrue periphyton over the low flow season is an important factor to consider in assessing what level of periphyton biomass will likely have a detrimental effect on fish communities. Although few datasets are available on periphyton levels in renowned trout fisheries of North America, some data are available from New Zealand. Although some of these rivers exhibit elevated periphyton levels, accrual periods are inherently shorter than those in the Eagle River because of frequent scouring floods.

Research indicates that risk of periphyton proliferations can be reduced if riparian forest vegetation reduces summer light levels by 60 to 90 percent (Quinn *et al.*, 1997). It appears that changes in forest cover can also result in shifts between communities dominated by filamentous algae and diatoms (Biggs, 2000a), at least in smaller streams. This underscores the important linkage between light levels, temperature, riparian shading, and the aesthetic impacts of periphyton in the Eagle River watershed.

4.6.2.3 Sources of Nutrients in the Eagle River Watershed

Sources of nutrient additions in the Eagle River watershed include wastewater, fertilizers, septic systems, soil erosion, automobile exhaust, dishwashing detergent, animal waste, and atmospheric deposition. According to Eagle County records there are on the order of 2000 septic systems in the Eagle River watershed (Eagle County Environmental Health, pers. comm., 2004). No combined sewers have been documented in ERWSD sewer systems (Schorr, ERWSD, pers. comm., 2004) and no data were available for other jurisdictions. Although there are numerous sources of nutrients in the Eagle River watershed, the predominant source of nutrient additions above background levels is wastewater effluent. Municipal wastewater treatment facilities account for approximately 70% of the nitrogen load at Wolcott, 90% of the nitrogen load at Gypsum, and over 90% of the phosphorus load at both locations (NWCCOG, 2002). Although there are monitoring requirements for ammonia nitrogen, local wastewater treatment facilities and other point dischargers are not required to monitor the amount of total nitrogen and total phosphorus discharged. ERWSD conducts voluntary monitoring of nitrate, orthophosphate, and TP. USGS has also compiled an extensive database of watershed water quality data. The following sections draw primarily on these data sources.

4.6.2.4 Recommended Levels and Standards for Nutrients and Periphyton

Much research on stream and river systems has focused on the levels of nutrients and periphyton compatible with various ecological states and management objectives. Table 4.30 summarizes several studies that link TN and TP and/or periphyton levels with impairment risk. Dodds and Welch (2000) suggest that lower levels for nutrient criteria should be considered for regions with more pristine, oligotrophic systems (e.g., TN and TP levels of 0.3 and 0.02 mg/L, respectively, were chosen as TMDL targets for the Clark Fork River in Montana, Dodds *et al.* 1997).

Table 4.30: Nutrient (µg/L) and algal biomass criteria limits recommended to prevent nuisance conditions and water quality degradation in streams based either on nutrient-Chl *a* relationships or preventing risks to stream impairment as indicated (adapted and expanded from USEPA (2000a)). DIN and SRP are dissolved inorganic nitrogen and soluble reactive phosphorus, respectively. For comparisons with tables and figures presented below in units of mg/L, note that nutrient concentrations here are presented in µg/L. One mg/l is equal to 1000 µg/L.

PERIPHYTON Maximum in mg/m²						
TN (µg/L)	TP (µg/L)	DIN (µg/L)	SRP (µg/L)	Chl *a*	Impairment Risk	Source
				100-200	nuisance growth	Welch *et al.* (1987, 1989)
275-650	38-90			100-200	nuisance growth	Dodds *et al.* (1997)
				20 (mean) 60 (max)	Delimits oligitrophic and mesotrophic streams	Dodds *et al.* (1998)
1500	75			200	Eutrophy	Dodds *et al.* (1998)
300	20			150	nuisance growth	Clark Fork River Tri-State Council, MT
	20				*Cladophora* nuisance growth	Chetelat *et al.* (1999)
	10-20				*Cladophora* nuisance growth	Stevenson unpubl. data
		430	60		eutrophy	UK Environ. Agency (1998)
		100[1]	10[1]	200	nuisance growth	Biggs (2000a)
		<10	<1	15 (mean) 50 (max)	reduced invertebrate diversity	Biggs (2000a)
		25	3	100	reduced invertebrate diversity	Nordin (1985)
			15	100	nuisance growth	Quinn (1991)
		1000	10[2]	~100	eutrophy	Sosiak, pers. comm.

[1]30-day biomass accrual time
[2]Total Dissolved P

The Colorado Department of Public Health and Environment Water Quality Control Commission Basic Standards and Methodologies for Surface Water (Regulation No. 31; WQCC, 2003a) contains a narrative standard that is relevant to nuisance levels of periphyton:

"All surface waters of the state are subject to the following basic standards; however, discharge of substances regulated by permits which are within those permit limitations shall not be a basis for enforcement proceedings under these basic standards:

Except where authorized by permits, BMP's, 401 certifications, or plans of operation approved by the Division or other applicable agencies, state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which:

for all surface waters except wetlands;

- *can settle to form bottom deposits detrimental to the beneficial uses. Depositions are stream bottom buildup of materials which include but are not limited to anaerobic sludges, mine slurry or tailings, silt, or mud; or*
- *form floating debris, scum, or other surface materials sufficient to harm existing beneficial uses; or*
- *produce color, odor, or other conditions in such a degree as to create a nuisance or harm existing beneficial uses or impart any undesirable taste to significant edible aquatic species or to the water; or*
- *are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life; or*

- *produce a predominance of undesirable aquatic life; or*
- *cause a film on the surface or produce a deposit on shorelines".*

Biological criteria for specifically defining the relationship between periphyton proliferations and the narrative standard cited above have yet to be developed in Colorado. No general nutrient criteria that limit TN and TP loading are currently in place for streams and rivers in the Eagle River watershed.

4.6.2.5 Nutrient and Periphyton Levels in the Eagle River Watershed

Statistical distributions of nutrient concentrations at several monitoring stations on Gore Creek and the Eagle River were computed and are presented in Appendix G. In computing the distributions of nutrient concentrations, the 'optimized' TN and TP values from the entire period of record were obtained from the USGS online database for the following sites: Eagle River at Avon (USGS No.: 09067005), Eagle River at Edwards (USGS No.: 393845106353000), Eagle River at Gypsum (USGS No.: 09069000), Gore Creek at Mouth (09066510), Eagle River at Minturn (CDPHE No.:E-21), Eagle River at Red Cliff (USGS No.: 09063000), and Eagle River below Milk Creek near Wolcott (USGS No.: 394220106431500). The dataset for the Eagle River at Minturn contained only two values of TN and nine values for TP, and was thus discarded. There were many occurrences of constituent levels below detection limits. Those values were assumed to be equal to half of the detection limit (if data = "<1", replaced with "0.5", etc.) in accordance with USEPA (2000a). Detection limit changed over period of record for some sites.

The TN and TP data from each site were stratified by season. "Winter" included all dates from January 1st to March 31st. "Spring" included all dates from April 1st to June 30th. "Summer" dates began July 1st and ended September 30th, and "Fall" dates ranged from October 1st to December 31st. The data were ranked in descending order, by season and for the entire year. The percentile values were calculated using the Weibull plotting position: 100*(1-m/(n+1)), where m = rank, n = number of values in category.

Additional data collected by ERWSD above the Vail, Avon, and Edwards wastewater facilities are presented in Table 4.31 and Figures 4.55 through 4.60. Median nutrient concentrations computed for various stations along the Eagle River and Gore Creek were summarized and compared to watershed-specific and regional data on nutrient levels (Table 4.31). Nutrient parameters from the USGS database described above are presented for additional stations in Figures 4.61 through 4.77.

Table 4.31: Median annual nutrient values for selected sites in the Eagle River watershed and regional reference values.

Site Name	NO_3-N (mg/L)	TP (mg/L)
Gore Creek Background[1]	0.11	<0.01
Gore Creek just upstream of Vail WWTP[2]	0.40	0.06
Gore Creek at Mouth[3]	0.48	0.08
Eagle River at Red Cliff[3]	0.03	<0.01
Eagle River just upstream of Avon WWTP[2]	0.60	0.11
Eagle River just upstream of Edwards WWTP[2]	0.70	0.21
Eagle River near Wolcott[3]	0.60	0.09
Eagle River at Gypsum[3]	0.43	0.08
Upper Colorado River Basin Background[4]	0.09	0.03
Upper Colorado River Basin Developed[4]	0.30	0.04
Colorado Rockies (Ecoregion 21)[5]	<0.10	0.02

[1]Wynn *et al*. (2001)

[2]Eagle River Water and Sanitation District Data (1998 - 2004)

[3]USGS, Eagle River water quality database: http://co.water.usgs.gov/cf/eaglecf/default.cfm

[4] Spahr and Wynn (1997)

[5]USEPA (2000a); Reference nitrate value is total NO_3 - NO_2

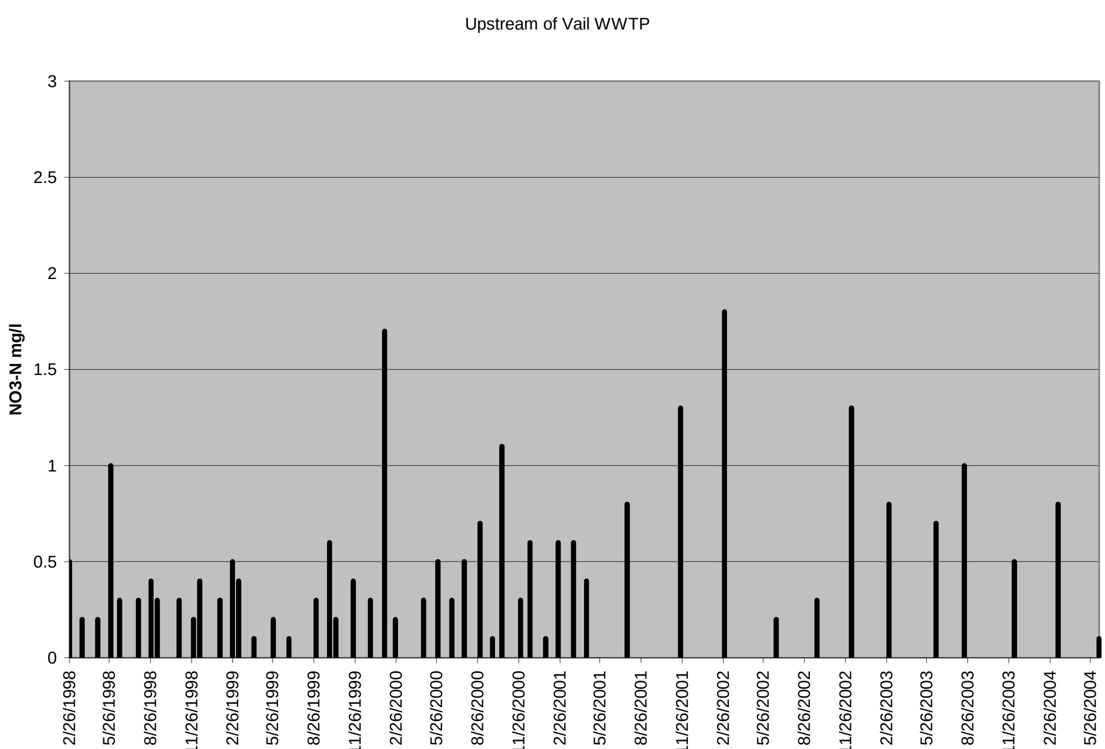


Figure 4.55: Nitrate concentrations just upstream of the Vail WWTP (source: ERWSD).

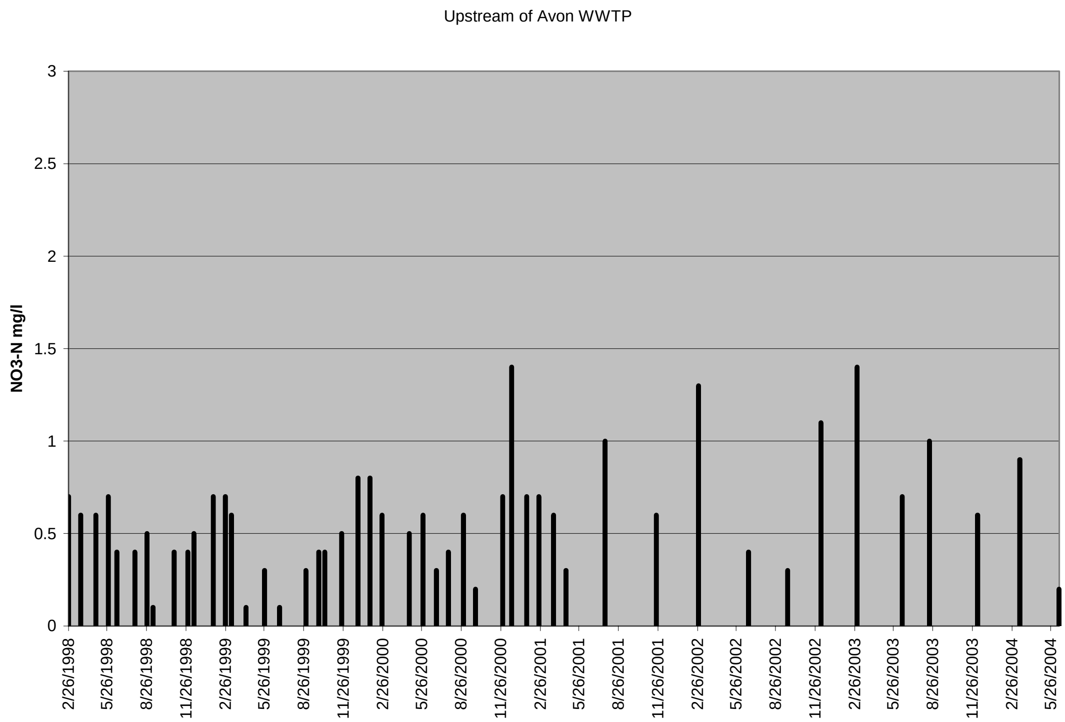


Figure 4.56: Nitrate concentrations just upstream of the Avon WWTP (source: ERWSD).

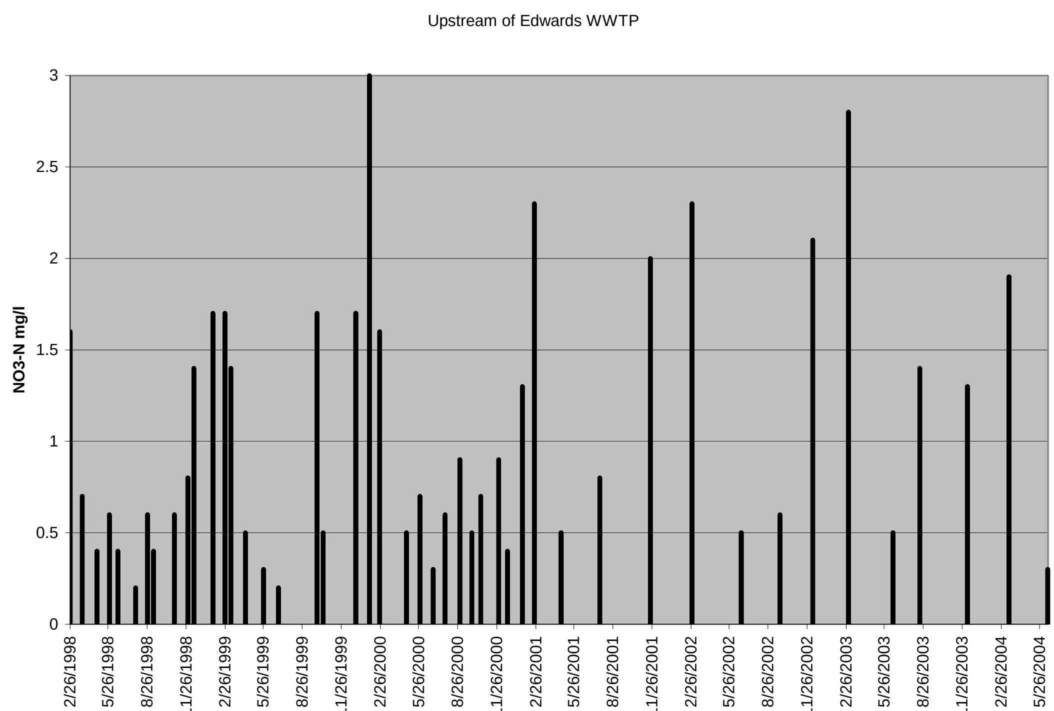


Figure 4.57: Nitrate concentrations just upstream of the Edwards WWTP (source: ERWSD).

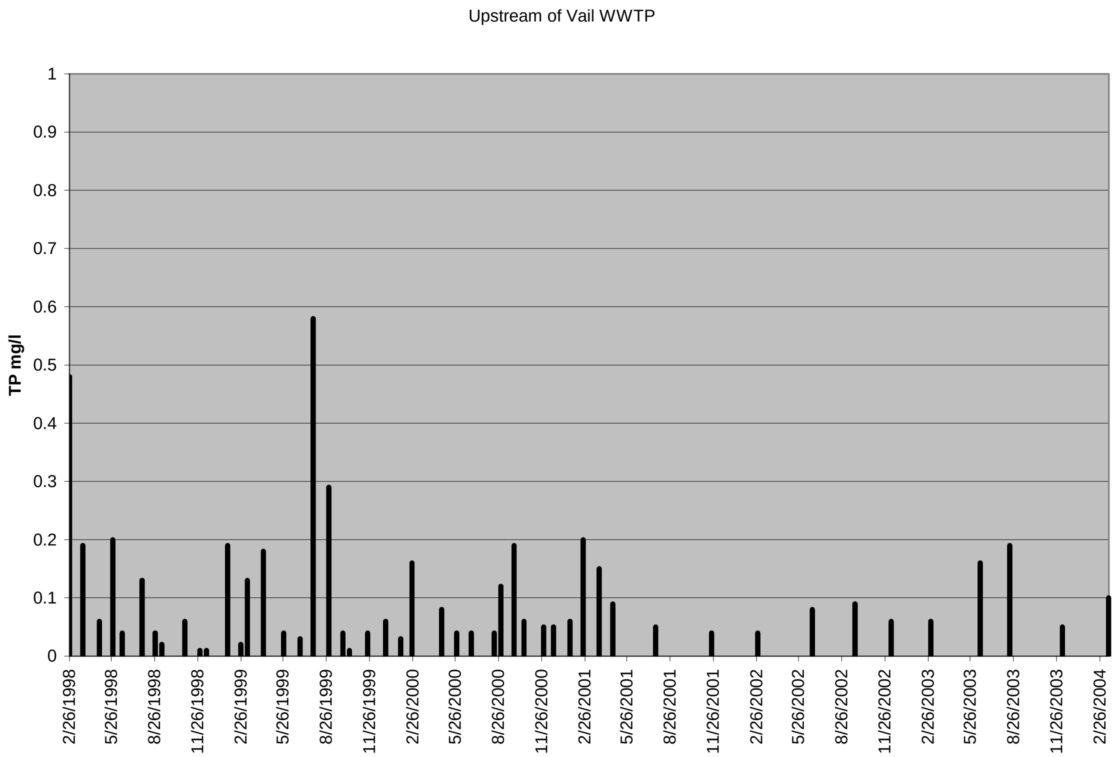


Figure 4.58: TP concentrations just upstream of the Vail WWTP (source: ERWSD).

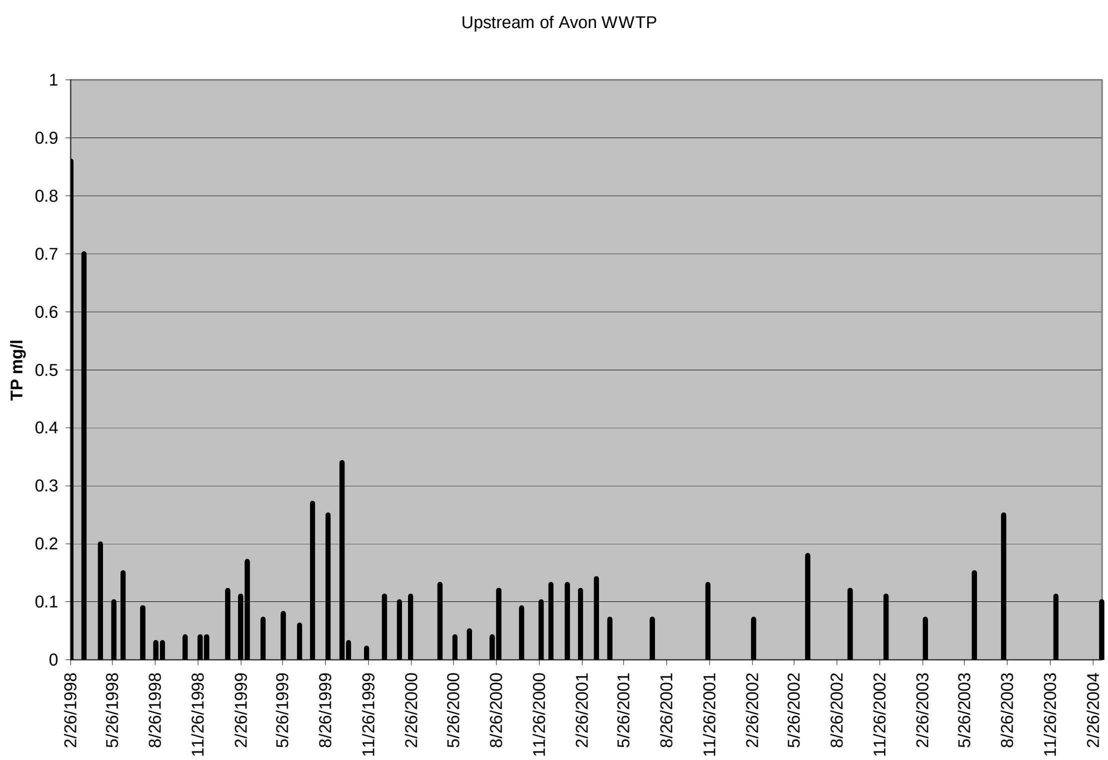


Figure 4.59: TP concentrations just upstream of the Avon WWTP (source: ERWSD).

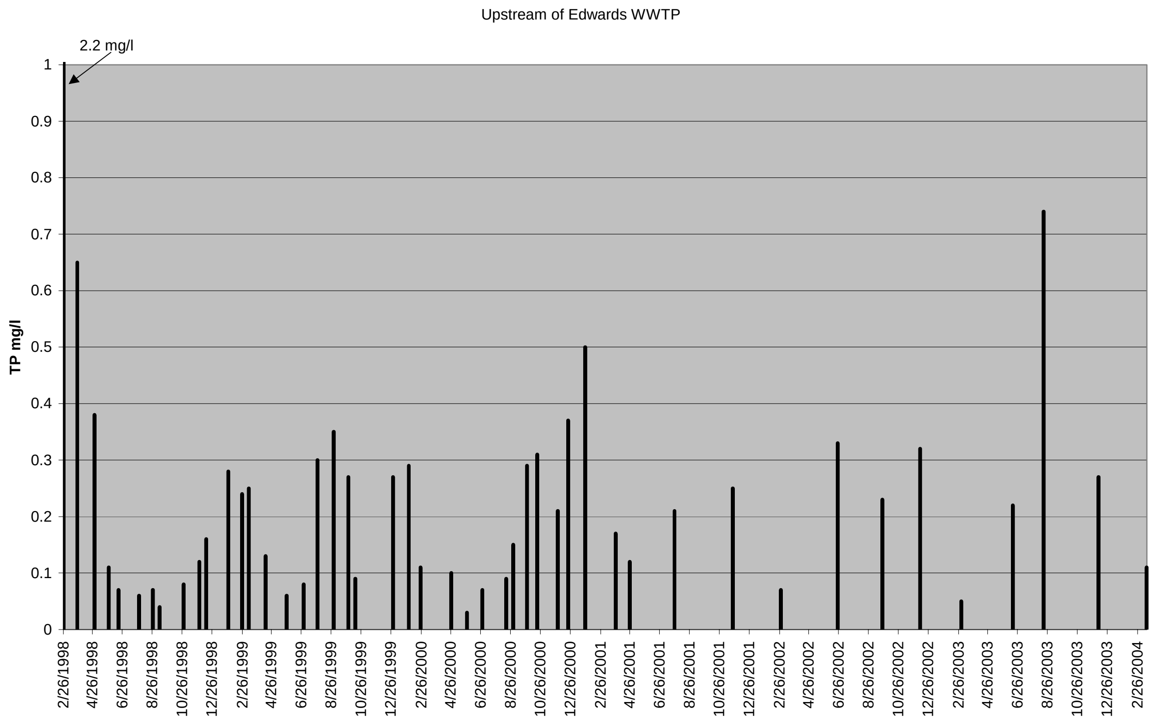


Figure 4.60: TP concentrations just upstream of the Edwards WWTP (source: ERWSD).

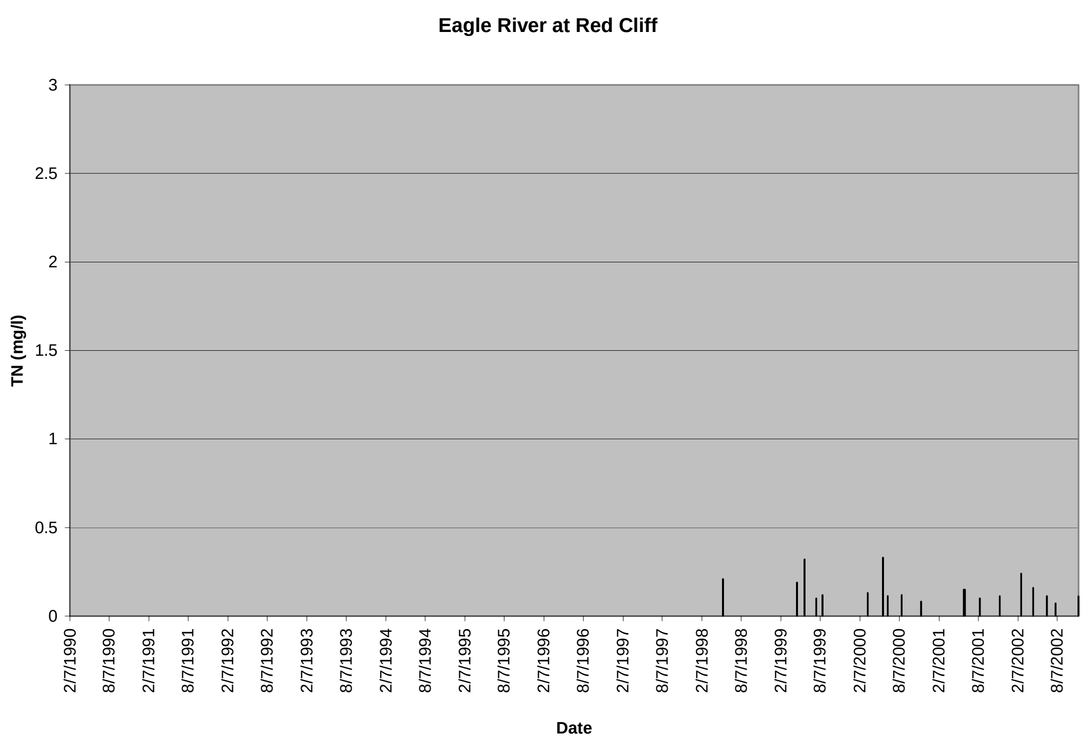


Figure 4.61: TN concentrations at monitoring location Eagle River at Red Cliff (source: USGS online database).

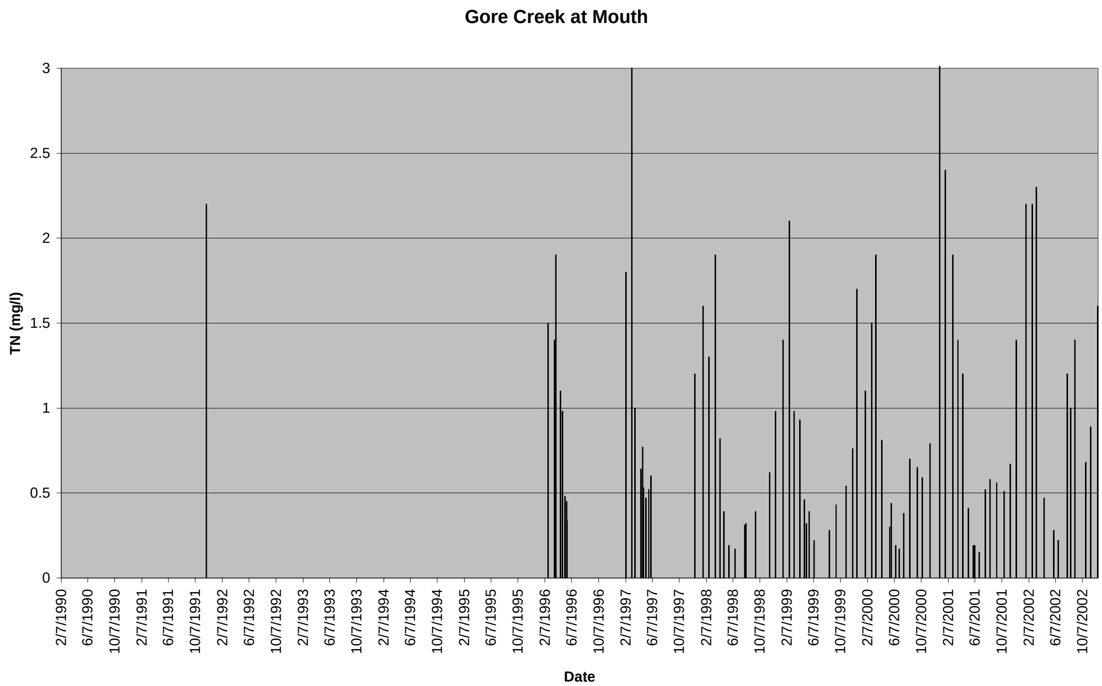


Figure 4.62: TN concentrations at monitoring location Gore Creek at Mouth (source: USGS online database).

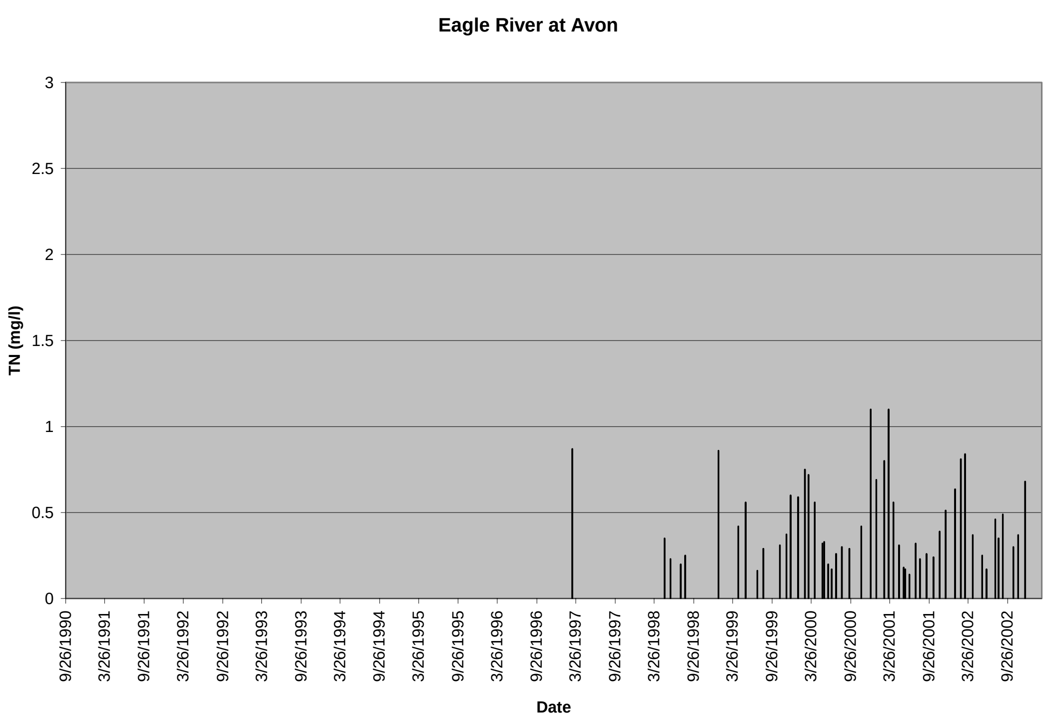


Figure 4.63: TN concentrations at monitoring location Eagle River at Avon (source: USGS online database).

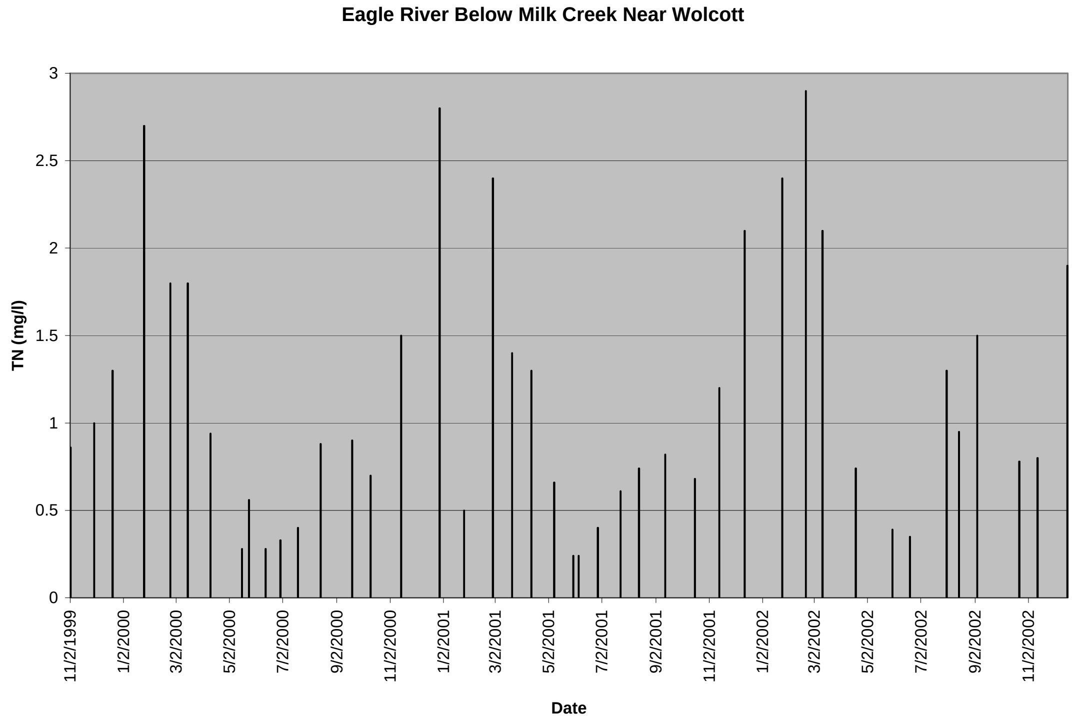


Figure 4.64: TN concentrations at monitoring location Eagle River below Milk Creek near Wolcott (source: USGS online database).

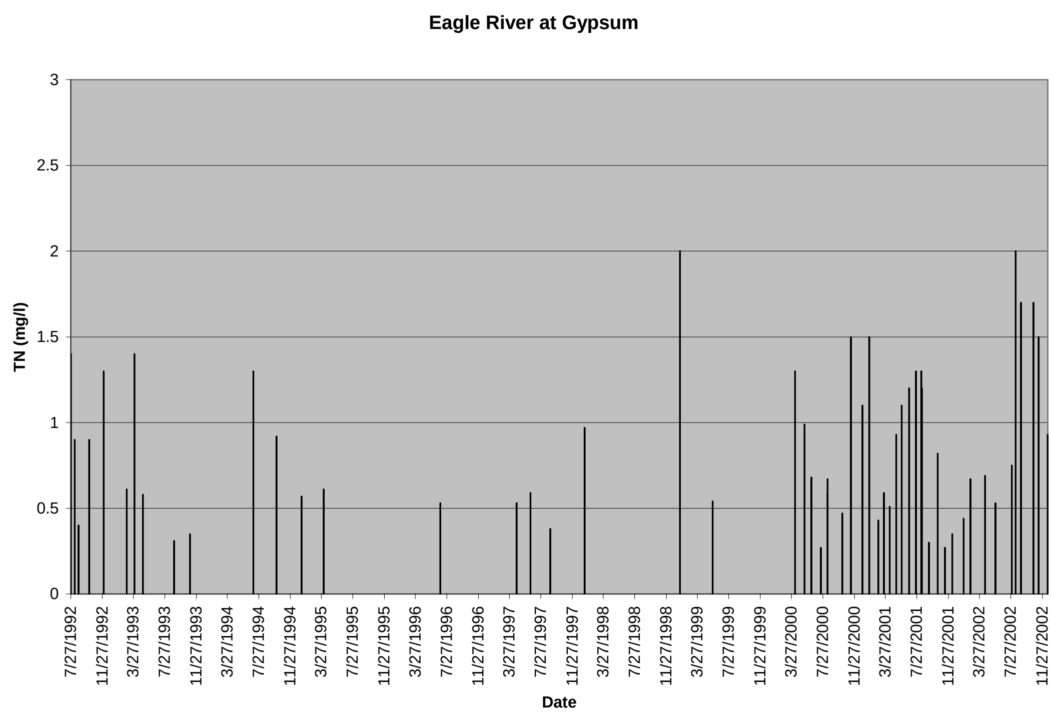


Figure 4.65: TN concentrations at monitoring location Eagle River at Gypsum (source: USGS online database).

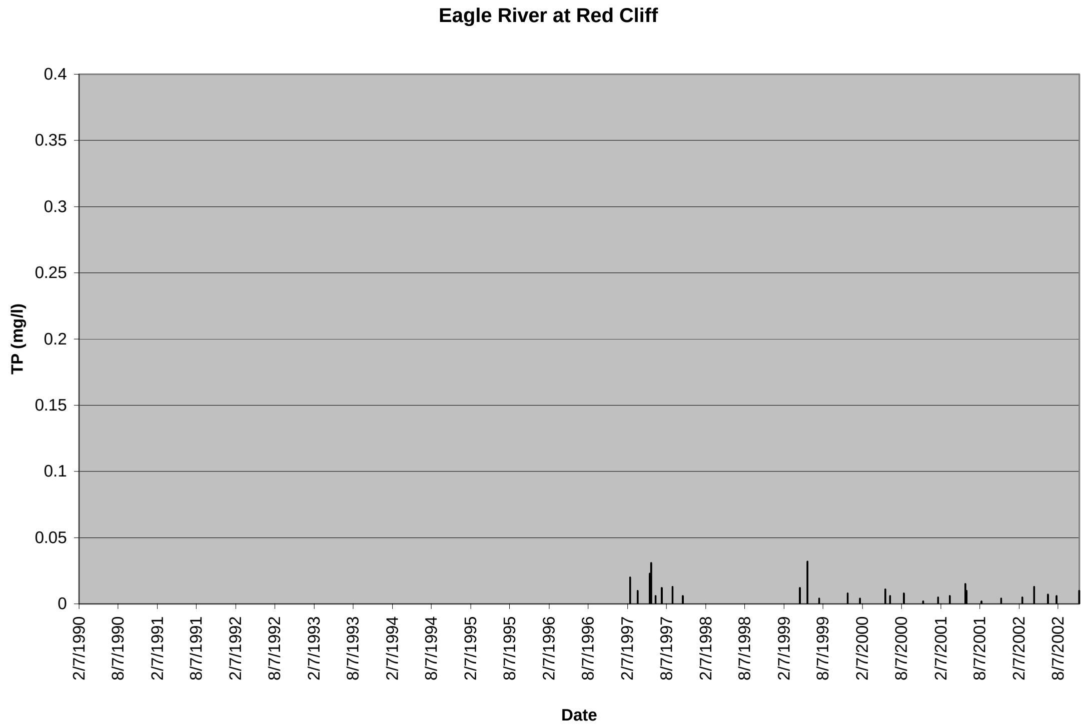


Figure 4.66: TP concentrations at monitoring location Eagle River at Red Cliff (source: USGS online database).

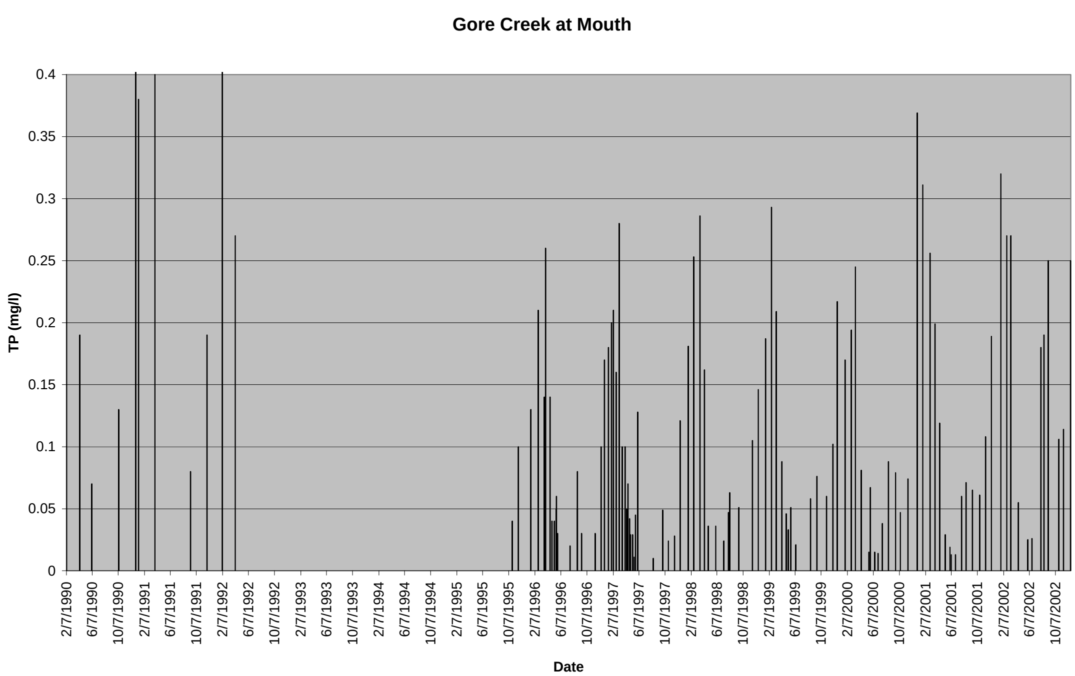


Figure 4.67: TP concentrations at monitoring locations on Gore Creek at Mouth (source: USGS online database).

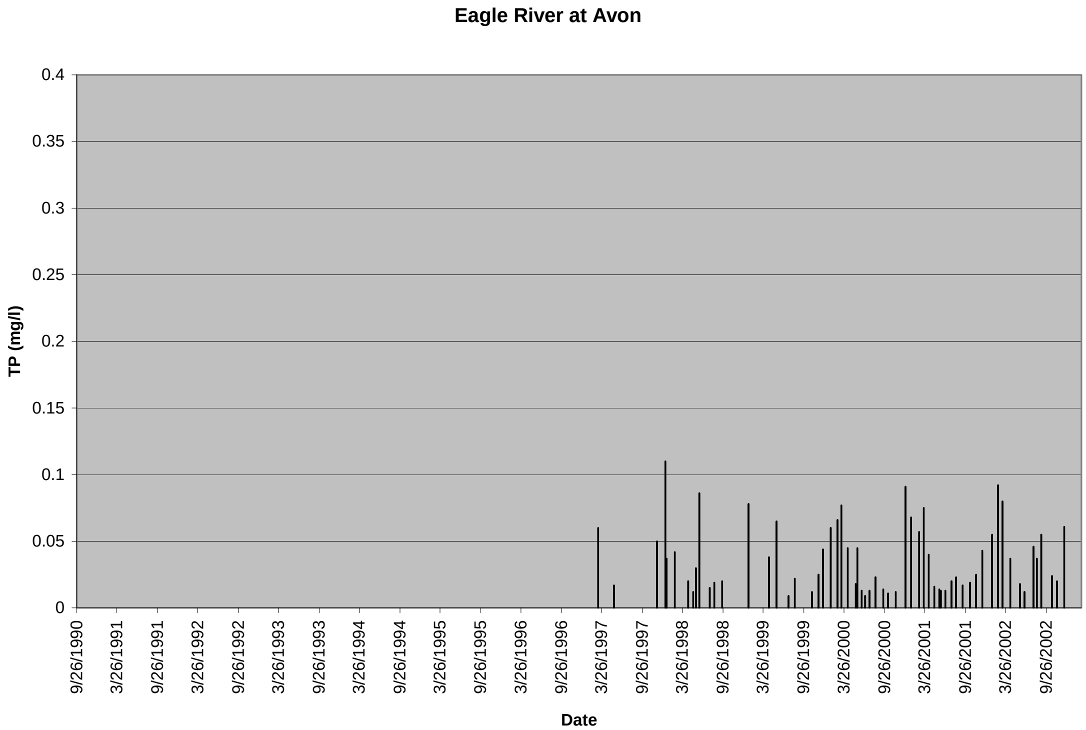


Figure 4.68: TP concentrations at monitoring location Eagle River at Avon (source: USGS online database).

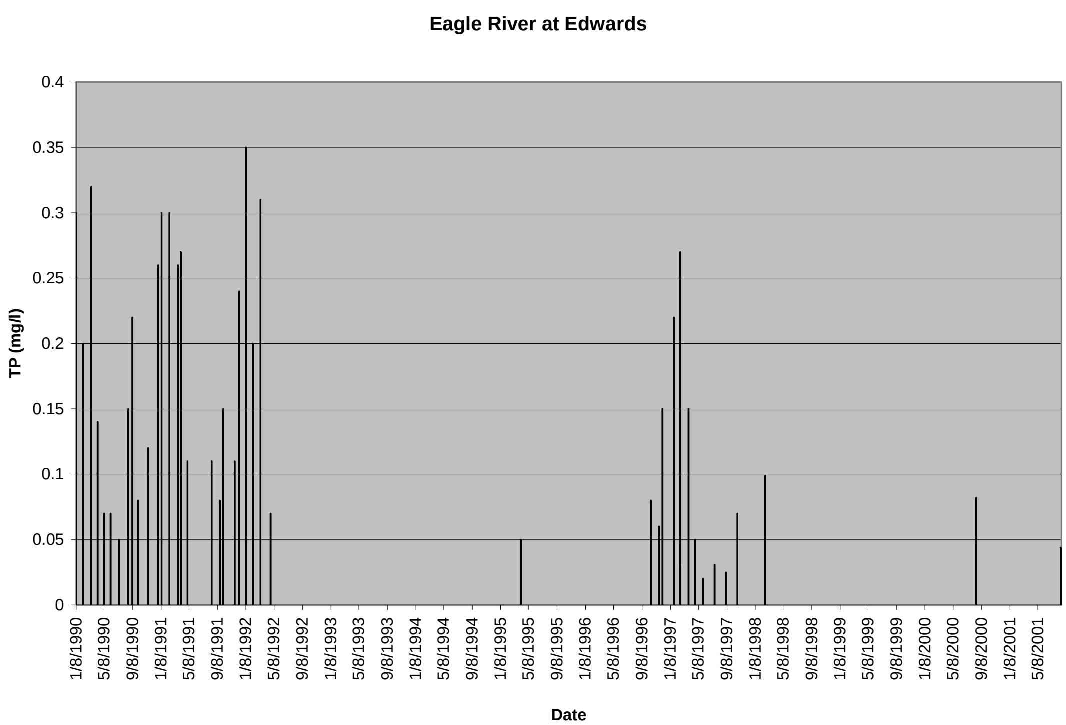


Figure 4.69: TP concentrations at monitoring location Eagle River at Edwards (source: USGS online database).

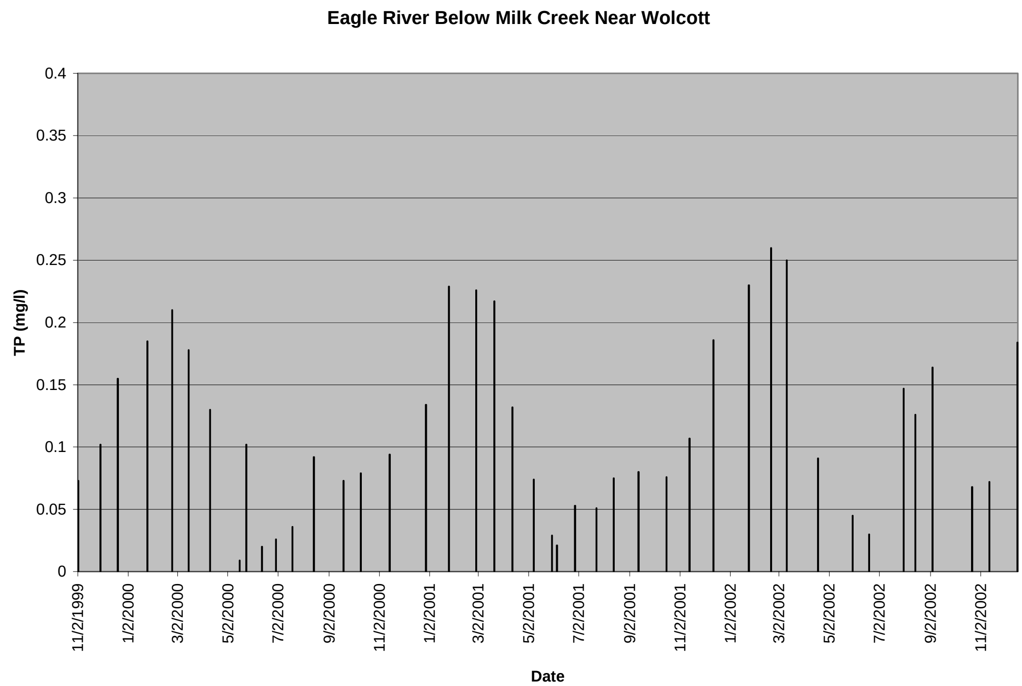


Figure 4.70: TP concentrations at monitoring location Eagle River below Milk Creek near Wolcott (source: USGS online database).

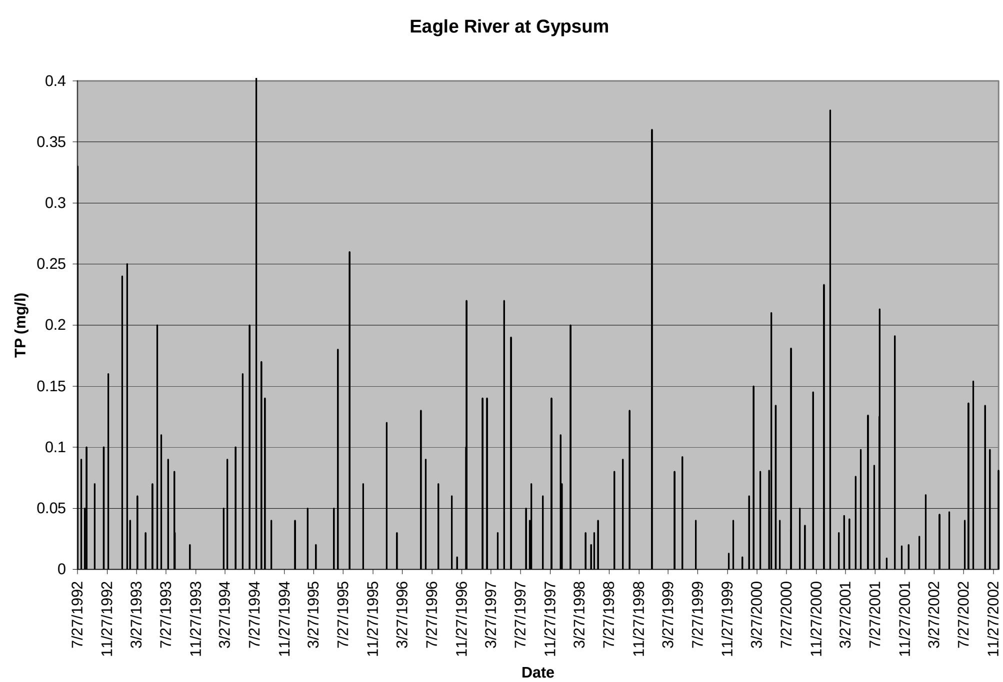


Figure 4.71: TP concentrations at monitoring locations on Eagle River at Gypsum (source: USGS online database).

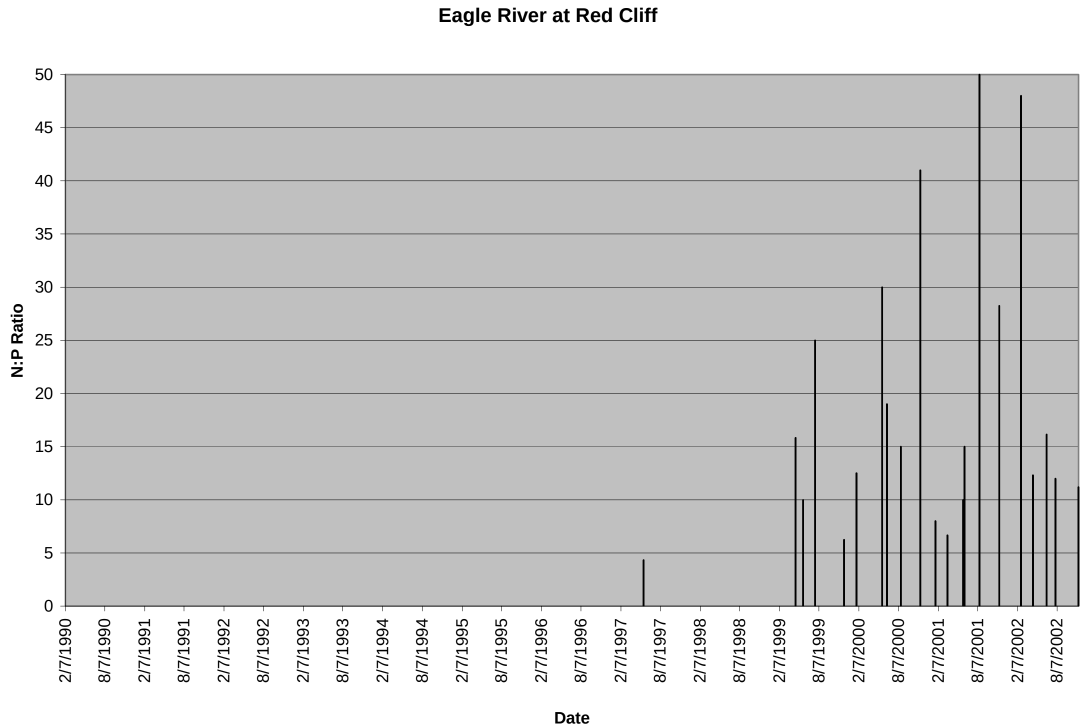


Figure 4.72: TN:TP ratio at monitoring location Eagle River at Red Cliff (source: USGS online database).

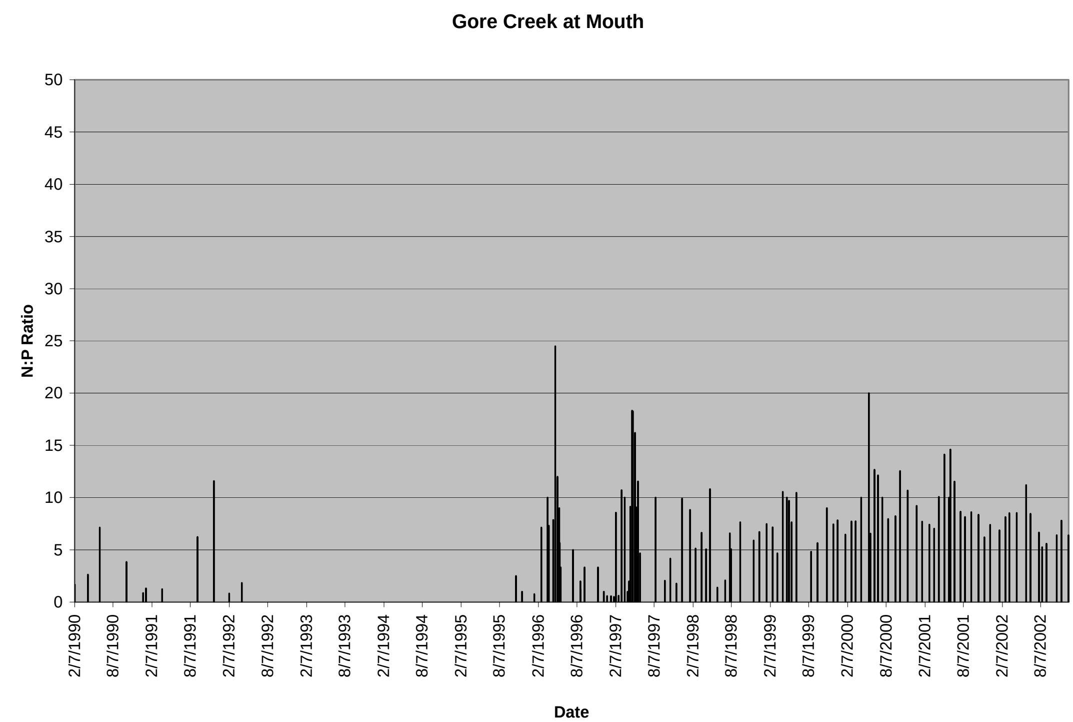


Figure 4.73: TN:TP ratio at monitoring location Gore Creek at Mouth (source: USGS online database).

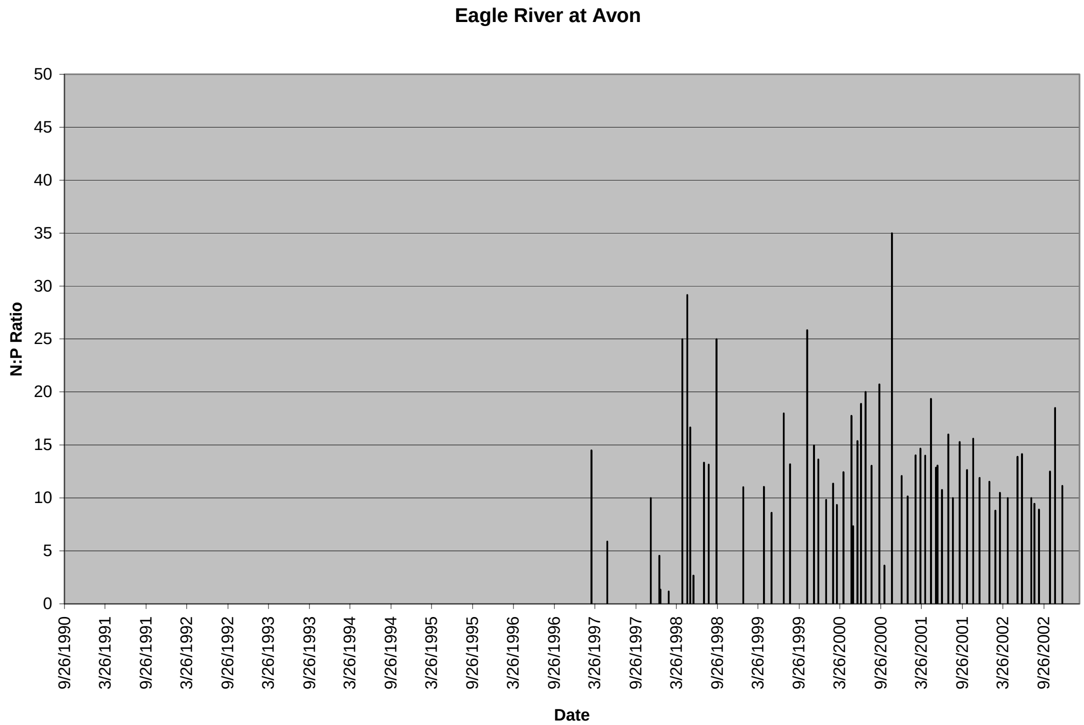


Figure 4.74: TN:TP ratio at monitoring location Eagle River at Avon (source: USGS online database).

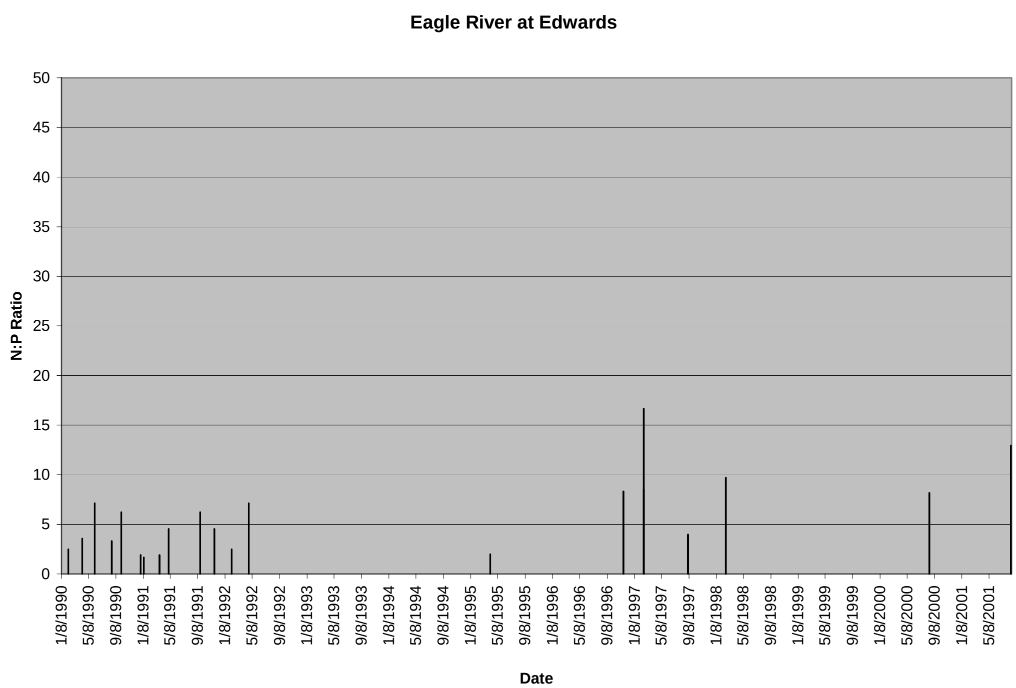


Figure 4.75: TN:TP ratio at monitoring location Eagle River at Edwards (source: USGS online database).

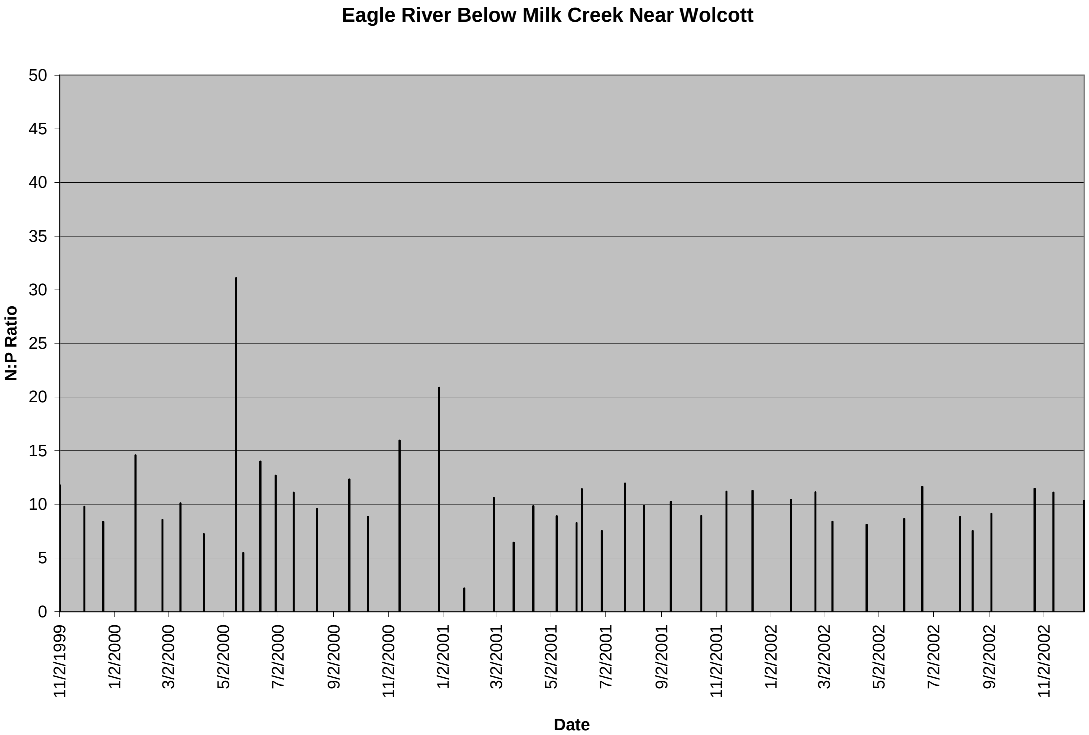


Figure 4.76: TN:TP ratio at monitoring location Eagle River below Milk Creek near Wolcott (source: USGS online database).

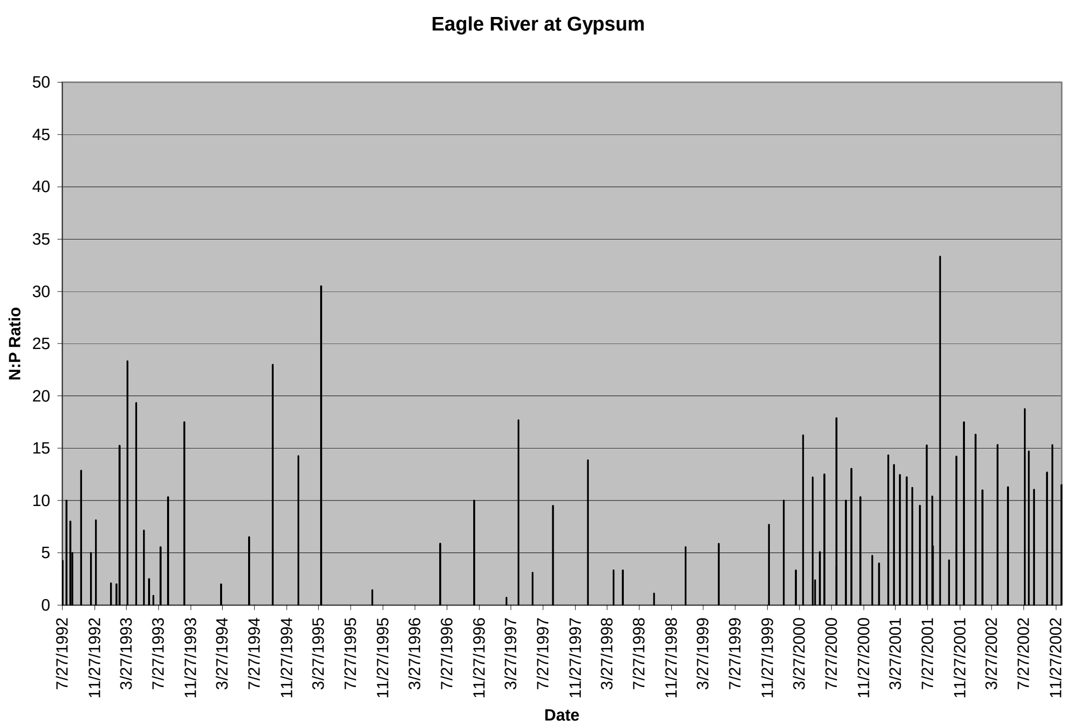


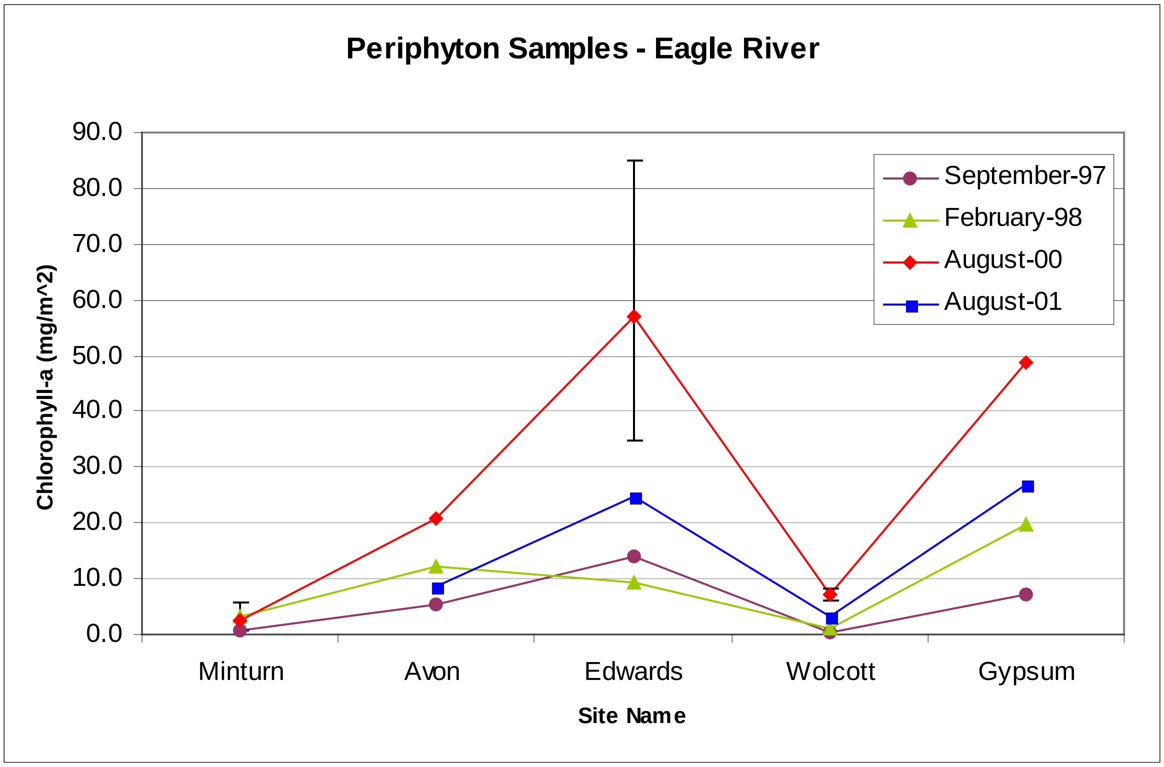
Figure 4.77: TN:TP ratio at monitoring location Eagle River at Gypsum (source: USGS online database).

Several relevant trends and patterns are apparent in these plots. First, nutrient concentrations in Gore Creek and the Eagle main stem are substantially higher than upstream background levels, regional levels, and levels recommended for preventing impacts to aquatic insect communities and nuisance levels of periphyton. Secondly, nutrient levels peak in winter as would be expected due to reduced biological uptake, seasonal human population increase, and reduced effectiveness of microbial treatment processes for wastewater. Lastly, TN:TP ratios in areas below wastewater discharges are significantly lower than upstream stations unimpacted by wastewater effluent. These results suggest (1) that a significant N-P interaction exists with nitrogen limitation likely, and (2) that it is necessary to consider both N and P as potentially limiting nutrients for periphyton biomass accrual. In general, a dilution effect occurs below the confluence of Gore Creek and Eagle River as indicated by data collected upstream of the Avon WWTP, with levels then progressively increasing again at Edwards and Wolcott.

4.6.2.6 Periphyton

USGS has sporadically monitored periphyton biomass at stations on Gore Creek and the Eagle River (Figure 4.78). These data indicate that periphyton biomass levels were elevated in some locations, but they remained below nuisance levels for aesthetic impacts at the monitoring stations. Periphyton biomass levels that exceed recommended criteria for maintenance of aquatic insect diversity were measured in the Eagle River at Edwards (57 and 86 mg Chl *a* /m^2) and in Gore Creek below the WWTP (56 Chl *a* /m^2). Periphyton biomass is low at the Wolcott station where nutrient levels are generally highest. This result underscores the importance of invertebrate-periphyton interactions as a disproportionate abundance of grazing *Brachycentrus* caddisflies (*Tricoptera*) apparently suppressed periphyton accrual in the Eagle River at this monitoring location (Deacon and Spahr, 1998). Periphyton communities in Gore Creek and the Eagle River are currently dominated by diatoms. An increase in relative biomass of blue-green algae in lower Gore Creek was observed by Wynn *et al.* (2001) as might be expected given the higher nutrient loading rates and reduced N:P ratios occurring below the Vail WWTP.

In making comparisons between the USGS data and datasets in the scientific literature, it should be noted that the USGS monitoring methodology has been observed to yield lower estimates of periphyton biomass than other protocols. In a meta-analysis of several studies on periphyton-nutrient relationships, Dodds *et al.* (1997) found that USGS periphyton data were more variable and contained no chlorophyll *a* values that were in excess of 100 mg Chl *a* /m^2. They stated that *"[b]ecause our experience suggests that at least some of the waters sampled should have mean chlorophyll values in excess of 100 mg·m^2, and the USGS data set was more variable, we are more confident in models constructed from the literature data set. However, the USGS data set correlations followed those obtained from the literature data set, so the overall trends resulting from the USGS data set (e.g., the ecoregion analysis) seem reliable.*"



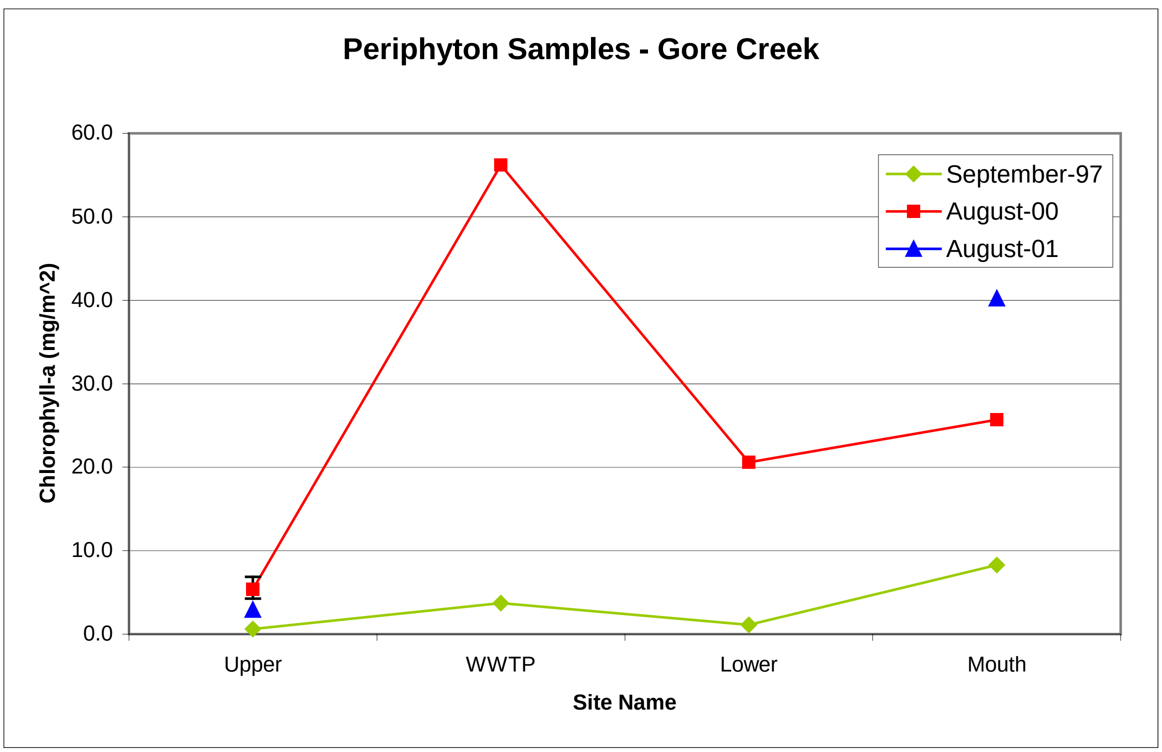


Figure 4.78: Periphyton biomass at stations on Gore Creek and the Eagle River. Bars at Edwards station depict range of three samples collected in August 2000 (source: USGS online water quality database).

4.6.2.7 Effects on Aquatic Insects and Fish

Nutrient levels in the main stem Eagle River and in Gore Creek exceed levels suggested by Biggs (2000a) for maintenance of benthic biodiversity. The following plots from studies by Deacon and Spahr (1998) and Wynn *et al*. (2001) indicate that a shift in the dominance of aquatic insect groups from "clean water" or sensitive species to more tolerant species has occurred in segments of the Eagle River and Gore Creek affected by elevated nutrient loading (Figures 4.79 and 4.80). Stoneflies (*Plecoptera*), generally considered the most sensitive order of stream insects, systematically decline in relative abundance as nutrient loading increases in a downstream direction along the Eagle River. Moreover, diversity in aquatic insect communities decreases systematically between Minturn and Wolcott (Deacon and Spahr, 1998), and the relative abundance of pollution tolerant midges (Diptera) and sludge worms increases substantially in lower Gore Creek (Wynn *et al*., 2001). The factors responsible for elevated nutrient levels and an unexpectedly high relative abundance of sludge worms in Gore Creek at station 16 above the Vail WWTP (Figure 4.80) are unknown. Upstream sources of nutrients include stormwater runoff from impervious surfaces, fertilizer use, and recycled wastewater applications. Clearly the elevated nutrient levels and associated increases in periphyton and invertebrate biomass in lower Gore Creek have stimulated productivity up the food web to the level of fish (Wynn, 1999; Biggs, 2000a). Adequate data for describing fish community response to recent patterns and downstream gradients in nutrient loading in the Eagle River are not currently available.

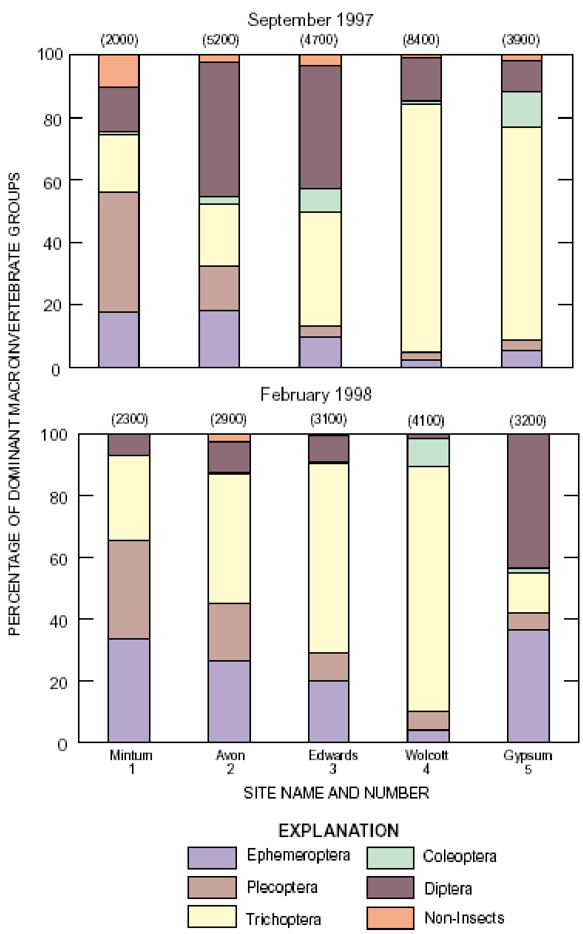


Figure 4.79: Relative percentages and densities of dominant macroinvertebrate groups in the Eagle River (numbers in parenthesis are densities of organisms per square meter and are rounded according to Britton and Greeson (1987)) (figure from Deacon and Spahr (1998)).

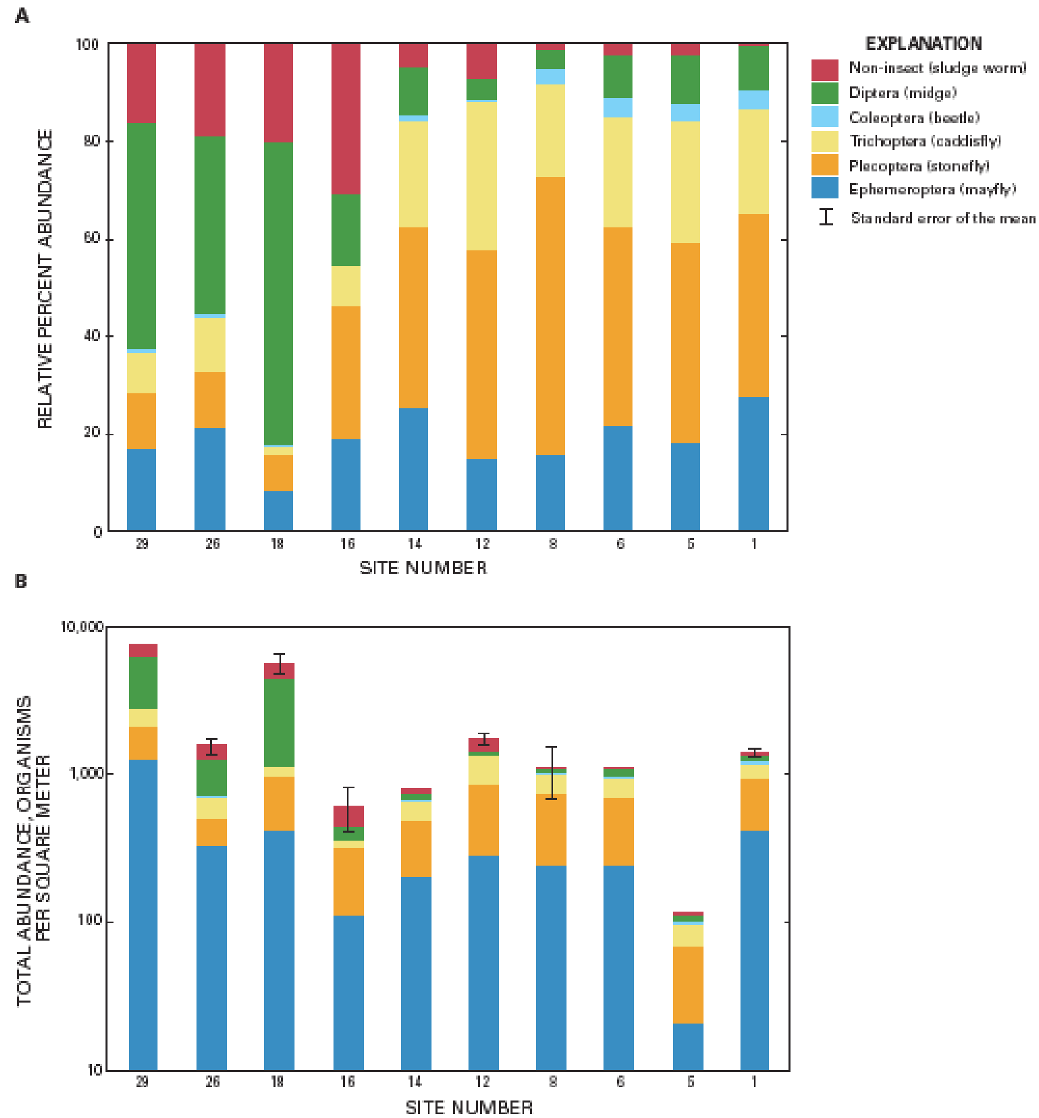


Figure 4.80: Relative (A) and total (B) abundance of the major macroinvertebrate groups at sampling sites on the main stem of Gore Creek (figure from Wynn *et al.* (2001)). Site numbers increase in a downstream direction. The Vail WWTP is located between sites 16 and 18.

4.6.3 Heavy Metals

4.6.3.1 Background

Sources of heavy metals loading to surface waters in the Eagle River watershed include mines and mine waste, automobiles, soil erosion, road salt, pesticides, wastewater, and the atmosphere. The predominant source of metals in the Eagle River watershed is the Eagle Mine site, which is the focus of much of following discussion. For more information on links between urban stormwater and heavy metals see Section 4.6.7. Before describing metals loading issues in Eagle River watershed, a brief discussion of the effects of metals on stream biota is warranted.

Abnormally high levels of heavy metals in streams can result in death of fish and invertebrates through the disruption of essential physiological functions. Lower concentrations of metals have sub-lethal effects such as reduced levels of reproduction, reduced feeding and growth rates, and reduced ability to resist diseases. Metals are generally most toxic to biota in dissolved form. Walsh and McRury (2003) provide an excellent overview of these effects with reference to the primary literature.

Though many metrics of water quality exist, the ones of interest in this section are those that relate to the effects of heavy metals on the aquatic community. These metrics are often compared to acute and chronic toxicity levels that are quantified by measuring the effect that a certain metal has on the health of a population of fish or macroinvertebrates in controlled lab experiments. The laboratory tests measure a concentration of the dissolved metal required to kill half of the population of, for example, rainbow trout over a period of 4 days (acute test) or a period of 30 days (chronic test). The lethal concentration killing 50% of the population, or "LC50" has been estimated for a number of fish and invertebrate species, and these values have been used in part to develop water quality standards (Tables 4.32 and 4.33).

Table 4.32: Reported literature values for dissolved zinc toxicity in brook trout, rainbow trout, cutthroat trout and mottled sculpin (table adapted from Walsh and McRury (2003) and expanded).

Species	Age	Hardness	Time	Type	LC50(μg/L)	Reference
Brook trout	juvenile	60	NR	acute	1458	Ref. in ERA, USEPA (2002)
Brook trout	life cycle	60	NR	chronic	2098	Ref. in ERA, USEPA (2002)
Brook trout	NR	47	96-hr	acute	1550	Holcombe and Andrew (1978)
Brook trout	NR	44	96-hr	acute	2420	Holcombe and Andrew (1978)
Brook trout	NR	179	96-hr	acute	6980	Holcombe and Andrew (1978)
Brook trout	juvenile	52.6	96-hr	acute	738	Davies *et al.* (2000)
Brook trout	juvenile	52.6	96-hr	acute	1178	Davies *et al.* (2000)
Brook trout	juvenile	52.6	5-9day	NOEC	221	Davies *et al.* (2000)
Brook trout	juvenile	52.6	5-9day	NOEC	608	Davies *et al.* (2000)
Brook trout	juvenile	52.6	5-9day	chronic	327	Davies *et al.* (2000)
Brook trout	juvenile	52.6	5-9day	chronic	819	Davies *et al.* (2000)
Cutthroat	NR	NR	24-hr	acute	620	Rabe and Sappington (1970)
Cutthroat	NR	NR	48-hr	acute	270	Rabe and Sappington (1970)
Cutthroat	NR	NR	96-hr	acute	90	Rabe and Sappington (1970)
Cutthroat	NR	34-47	14-day	chronic	670	Nehring and Goettl (1974)
Rainbow	adult	60	NR	acute	1004	Ref. in ERA, USEPA (2002)
Rainbow	larval	60	NR	acute	936	Ref. in ERA, USEPA (2002)
Rainbow	juvenile	60	NR	acute	534	Ref. in ERA, USEPA (2002)
Rainbow	larval	60	NR	chronic	1650	Ref. in ERA, USEPA (2002)
Rainbow	alevin	22	96-hr	acute	815	Chapman (1978)
Rainbow	swim-up fry	22	96-hr	acute	93	Chapman (1978)
Rainbow	juvenile	22	96-hr	acute	136	Chapman (1978)
Rainbow	NR	83	96-hr	acute	1760	Chapman and Stevens (1978)
Rainbow	NR	350	96-hr	acute	4520	Goettl *et al.* (1972)
Rainbow	NR	350	96-hr	acute	1190	Goettl *et al.* (1972)
Rainbow	NR	30	96-hr	acute	560	Goettl *et al.* (1972)
Rainbow	NR	30	96-hr	acute	240	Goettl *et al.* (1972)
Rainbow	NR	47	96-hr	acute	370	Holcombe and Andrew (1978)
Rainbow	NR	178	96-hr	acute	2510	Holcombe and Andrew (1978)
Mottled sculpin	juvenile	48.6	96-hr	acute	156	Woodling *et al.* (2002)
Mottled sculpin	juvenile	46.3	9-day	chronic	38	Woodling *et al.* (2002)
Mottled sculpin	juvenile	46.3	30-day	chronic	32	Woodling *et al.* (2002)

NR – no record

Table 4.33: Reported literature values for dissolved zinc toxicity in common macroinvertebrate taxa (table adapted from, and all references are found in, Walsh and McRury (2003)).

Taxa	Hardness	Time	Type	LC50 (μg/L)	Reference
Mayflies					
Baetis tricaudatus	30	11-day	Chronic	191 (est)	Harrahy (2000)
Baetis tricaudatus	30	7-day	Chronic	956 (est)	Harrahy (2000)
Baetis tricaudatus	35	96-hr	Acute	7357-10475	Harrahy (2000)
Drunella spp.	30-70	14-day	Chronic	>9200	Nehring (1976)
Ephemerella spp.	54	10-day	Chronic	16000	Warnick and Bell (1969)
Heptageniid spp.	36	10-day	Chronic	130 (est)	Kiffney (1995)
Mayfly spp.	60	NR	Acute	489	Ref. in ERA, USEPA (2002)
Caddisflies					
Caddisfly	60	NR	Chronic	18,092	Ref. in ERA, USEPA (2002)
Hydropsychid	52	11-day	Chronic	32,000	Warnick and Bell (1969)
Stoneflies					
Acroneuria stonefly	50	14-day	Chronic	32,000	Warnick and Bell (1969)
Pteronarcys	30-70	14-day	Chronic	>13,900	Nehring (1976)
Dipterans					
Chironomus midge	90	10-day	Chronic	159 (sediment)	Harrahy (2000)
Midge	60	NR	Acute	12,306	Ref. in ERA, USEPA (2002)
Tanytarsus midge	46.8	10-day	Chronic	36.8	Anderson *et al.* (1980)
Other Invertebrates					
Daphnia	60	NR	Acute	128	Ref. in ERA, USEPA (2002)
Daphnia	60	NR	Chronic	118	Ref. in ERA, USEPA (2002)
Gammarus amphipod	60	NR	Acute	860	Ref. in ERA, USEPA (2002)
Hyalella amphipod	60	NR	Acute	234	Ref. in ERA, USEPA (2002)
Snail	60	NR	Acute	1116	Ref. in ERA, USEPA (2002)
Tubificid worm	60	NR	Acute	2736	Ref. in ERA, USEPA (2002)

NR – no record

Nature is never as simple as the laboratory. Although an LC50 can be used as a starting point, Walsh and McRury (2003) point out that the value itself cannot be used for defining a "healthy" community, since 50% mortality of a species in a month is certainly not normal in nature. In the field, contaminants often come in suites, such as the heavy metals zinc, copper, manganese, cadmium and lead in the Eagle River. While it might be desirable to determine the effect of each metal on each species, this is not practical. Further, it has been shown that some suites of metals have a multiplicative negative effect on biota, while others have less negative effect than would be expected (Walsh and McRury, 2003; and references therein). For example, invertebrate sampling in Cross Creek and other metal impacted streams of the southern Rockies suggests that there are synergistic negative effects on certain mayfly taxa at dissolved zinc and copper concentrations of approximately 100 μg/L and 10 μg/L, respectively (Clements, CSU Dept. of Fish and Wildlife Biology, pers. comm.). In an experimental study, Kiffney and Clements (1994) exposed stream insects from the Arkansas River, Colorado to a mixture containing 1.1, 12, and 110 μg/L of cadmium, copper, and zinc, respectively, for 10 days. The results of this study indicated that several invertebrate taxa were negatively affected (Table 4.34), with mayflies (Ephemeroptera) exhibiting the greatest sensitivity.

Table 4.34: Relative change in abundance of dominant taxa, major insect groups, and community-level indices in stream insects from the Arkansas River, Colorado. Aquatic insects in treatment streams were exposed to a mixture containing 1.1, 12, and 110 μg/L of cadmium, copper, and zinc, respectively, for 10 days and compared with control streams (adapted from Kiffney and Clements (1994)).

Taxa	% Change
Ephemeroptera	(-)68
Heptageniidae	(-)90
Baetis tricaudatus	(-)76
Drunella grandis	(-)65
D. doddsi	(-)66
Plecoptera	(-)44
Pteronarcella badia	(-)60
Suwallia pallidula	(-)36
Sweltsa coloradensis	0
Trichoptera	(-)12
Lepidostoma ormeum	(-)17
Chironomidae	(+)56
Tanypodinae	(+)94
Orthocladiinae	(+)5
Chironomini	(+)8
Tanytarsini	(+)84
Number of individuals	(-)20
Number of taxa	(-)22

4.6.3.2 Mining Impacts

Water contamination from historic mining practices has occurred in many areas of the West. In Colorado, it has been estimated that one quarter of 3rd and 4th order streams are affected by mining operations, resulting in increased levels of heavy metals such as cadmium, lead and zinc (Clements *et al.,* 2000). These metals occur naturally in rock formations, and it is typical for surface and groundwaters to acquire low concentrations of zinc and other metals when in contact with several of the formations found in the southern Rockies mineral belt. Some metals are slightly soluble in water, and surface runoff can transport metals as sediments erode from soils and exposed rock parent material. Melting snow can dissolve significant quantities of metals as it infiltrates and becomes groundwater. This groundwater also dissolves metals as it moves through cracks, fissures and permeable subsurface formations.

Precipitation that passes through mined areas takes up metals in a similar fashion. Rain and snow fall on mounds of waste rock and tailings, dissolving metals as water runs off or seeps to the water table. Sulphurous rocks exposed during the mining process become oxidized and generate acid that leaches metals, and mineshafts containing rock high in metal content may act as conduits for groundwater. In both cases, the concentration of metals increases greatly over normal conditions because (1) water is in direct contact with a greater volume of metal-rich rock, and (2) the increased surface-to-volume ratio of crushed rock allows more metals to be dissolved. The result can be a dramatic increase in dissolved metal concentration, which in turn can have a significant effect on the stream biota.

4.6.3.3 Regulations Regarding Heavy Metal Contamination

Because poor water quality can negatively affect human health and the environment, the USEPA established water quality standards under the Clean Water Act. Standards are also established for water quality affected by Superfund sites under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). In Colorado, the USEPA has delegated the authority of setting site-specific standards to the Colorado Department of Public Health and Environment (CDPHE), Water Quality Control Commission (WQCC). The WQCC defines the chronic toxicity standard or "Table Value Standard" (TVS) as the concentration not to be exceeded by a single representative sample, or calculated as an average of all samples collected in a 30-day period. It represents the level that is thought to protect 95% of genera from the toxic effects of individual metals. The WQCC also has the authority to establish site-specific water quality standards as described in Regulation 31 (WQCC, 2003a).

The toxicity of heavy metals generally decreases as water hardness increases. Zinc and other metals bind with carbonates, thus making them unavailable to be absorbed directly by aquatic biota. The USEPA has developed an equation that establishes the TVS for zinc, based on this relationship with water hardness. The equation, expressed below, yields the chronic dissolved zinc standard deemed protective of 95% of aquatic life genera.

$$\text{Chronic Toxicity Concentration of Zinc } (\mu g/L) = \exp(0.8473[\ln(\text{hardness mg/L})]+0.8699)$$

A TVS standard of 106 μg/L is listed by the WQCC for the affected stretch of the Eagle River between Belden and Gore Creek.

4.6.3.4 The Eagle Mine and Vicinity

The Eagle Mine was one of the largest zinc mines in the United States, producing nearly 13 million tons of ore prior to being abandoned in 1984. The State of Colorado sued the owners of the mine in 1984 under CERCLA, and the USEPA listed the area as a Superfund site in 1986. The USEPA and the CDPHE oversaw subsequent cleanup activities, which began in 1988. Remediation has included consolidating and capping tailings piles, diverting surface water around tailings piles, and treating metal-laden waters collected from mine shafts and Waste Rock Pile #8 to remove zinc and other selected constituents (Naugle *et al.,* 2003). Although cleanup activities have resulted in a significant decrease of heavy metals in the river, water quality monitoring sites still exceed the TVS for zinc (Figure 4.81).

Due to the success of the remediation actions, the USEPA signed a Record of Decision (ROD) in 2001 and has declared the construction of the remedy complete. The remediation has now shifted to an "operation, maintenance and monitoring" mode, which requires continued monitoring of metals, fishes, and macroinvertebrates. Temporary criteria different from the TVS for zinc have been established, and are discussed below. Lower Cross Creek and the segment of the Eagle River from Belden to Gore Creek are not supporting designated uses according to CDPHE and are listed on the State's 303(d) list as required by the Clean Water Act.

As noted above, significant reductions in zinc have been achieved at the Eagle Mine site through a variety of remediation activities. Notable among these are the actions to capture and treat polluted runoff and groundwater in the Rock Creek drainage, and the cleanup of the roaster drainage in Belden. The following sections present the results of an analysis intended to define and bracket *remaining* sources of zinc loading in this segment, and possible sources of future loading in order to evaluate the potential for further improving water quality. The following discussion frequently refers to Figure 4.82 in describing the monitoring locations and various aspects of the Eagle Mine site.

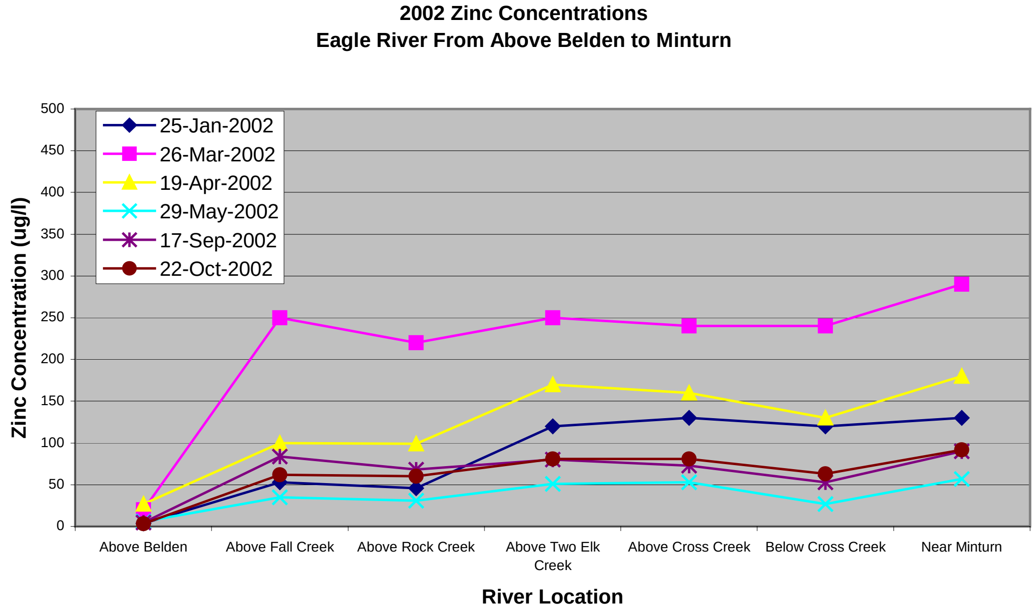


Figure 4.81: Zinc concentration plotted throughout the year of 2002. Zinc increases downriver, and all sites except E-3 above Belden regularly exceed the TVS of 106 μg/L during March and April. On any given date, the largest increases in zinc concentrations usually come from the areas between (1) Belden and Fall Creek; and (2) Rock Creek and Two Elk Creek.

Figure 4.82: Monitoring locations and various aspects of the Eagle Mine site.

4.6.3.5 Belden Area Sources of Metals Loading

Currently the largest overall and "unaccounted" source of zinc loading in the Eagle River watershed is from the Belden area, which is bracketed by Eagle Mine monitoring stations E-3 and E-5 (Figure 4.82). Unaccounted sources in Belden, on average, equaled 60% of the zinc load delivered to Minturn in October over the last two years (Figures 4.83 and 4.84). On average over the last five years, the Belden area has contributed the highest incremental zinc loads measured in the Eagle Mine site during March and April, as well as during late summer (Figures 4.85, 4.86, and 4.87). The second largest source of zinc loading is the Rock Creek area (T-10).

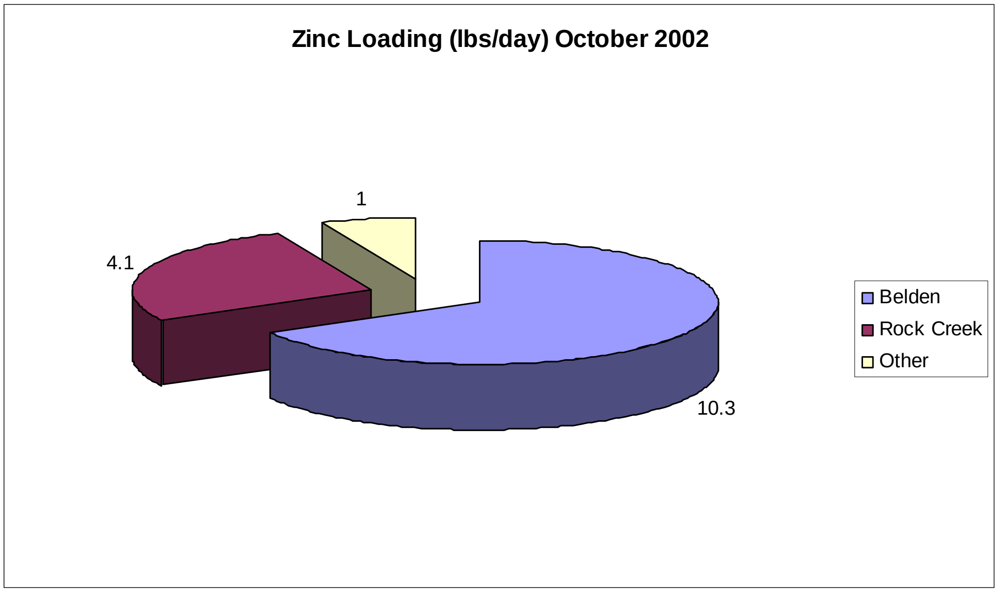


Figure 4.83: Zinc loading at Minturn. 'Other' denotes difference between loading inputs at Belden plus Rock Creek segments and load measured at Minturn, October 2002 (NewFields, 2003).

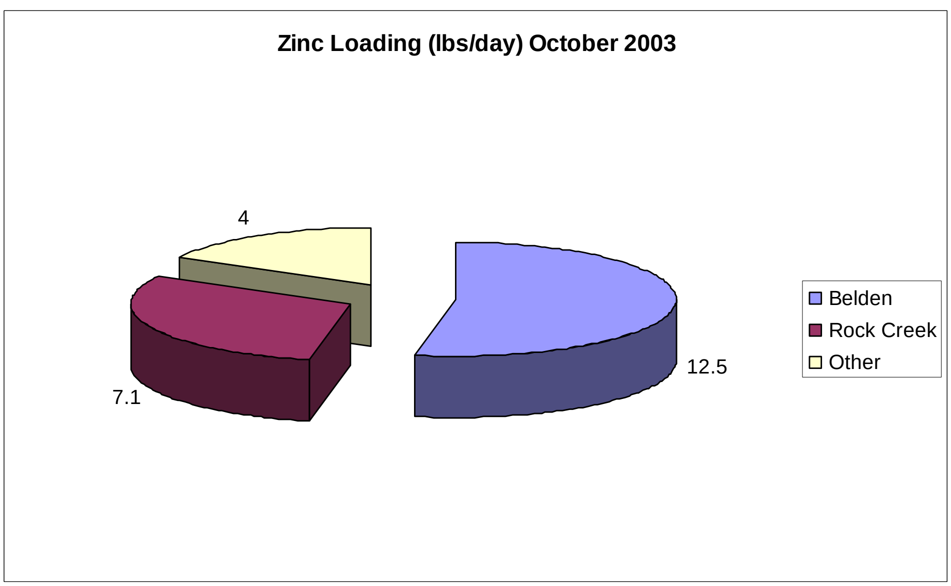


Figure 4.84: Zinc loading at Minturn. 'Other' denotes difference between loading inputs at Belden plus Rock Creek segments and load measured at Minturn, October 2003 (NewFields, 2004).

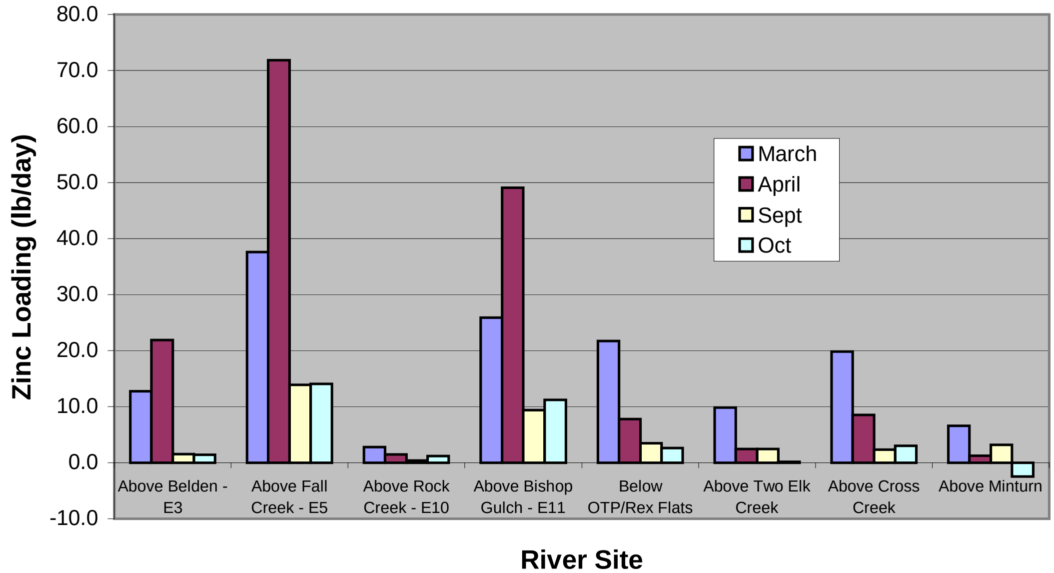


Figure 4.85: Location and time of zinc loading within specific river segments from above Belden to Minturn, 1998 to 2002. Average zinc added at each section of the Eagle River is estimated in pounds per day (NewFields 2003). Regardless of the season, the locations with the greatest relative gain in zinc loading are (1) between E3 and E5 (Belden area); and (2) between E10 and E11 (Rock Creek area).

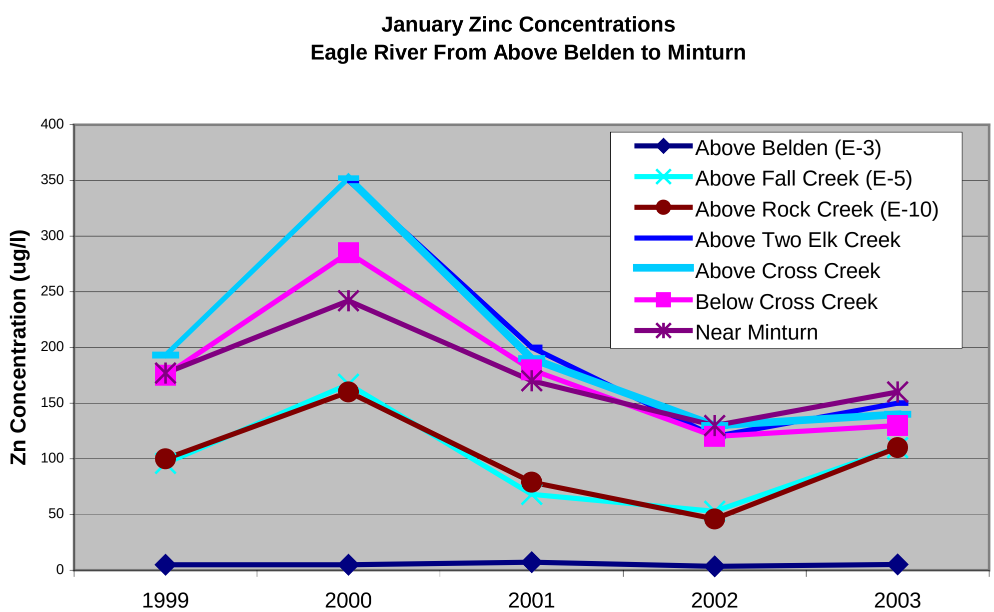


Figure 4.86: Zinc concentrations measured in January (1999 to 2003). Zinc concentrations above the Belden Mine are regularly less than 50 µg/L for most months.

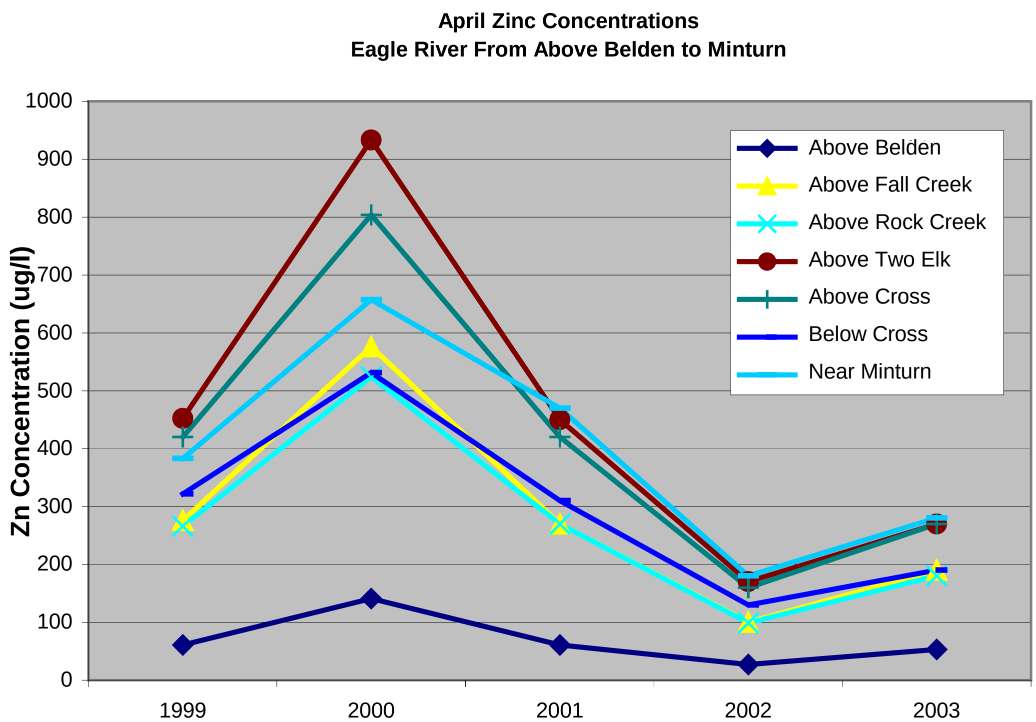


Figure 4.87: Zinc concentrations measured in April (1999 to 2003). Concentrations increased in 2003 in association with greater precipitation and runoff.

We combined data previously presented by Dames & Moore (1997) and NewFields (2003, 2004) with additional data from the CDPHE database to examine patterns in zinc concentrations and loading in the Belden and Rock Creek vicinity. These data provided multiple lines of evidence pointing to the Tramway tributary area as a principal source of zinc loading in the Belden area. Although the data indicate additional diffuse sources of metals in the Belden segment, particularly during snowmelt runoff, the Tramway area appears to be a relatively concentrated source of zinc loading within the Eagle Mine site.

Previous reports describing the results of the Eagle Mine monitoring program have clearly documented the abrupt increase in zinc loading that occurs between stations E3 and E5 in the Eagle River (Figures 4.85, 4.86, and 4.87). These monitoring locations, however, preclude further 'bracketing' of sources and determining whether unaccounted sources are relatively diffuse or concentrated in the Belden segment. Data sporadically collected at station E-4A, a monitoring location intermediate between E-3 and E-5 (Figure 8.82), indicate that during non-snowmelt periods stations E-4A and E-5 bracket the abrupt increase in zinc loading documented in the Belden reach (Figure 4.88). This finding indicates that although diffuse sources of loading exist throughout the Belden segment between E-3 and E-5, observed increases in zinc concentrations appear to occur primarily downstream of E-4A beyond the apex of the river bend. The following sections provide additional information regarding this portion of the Belden reach.

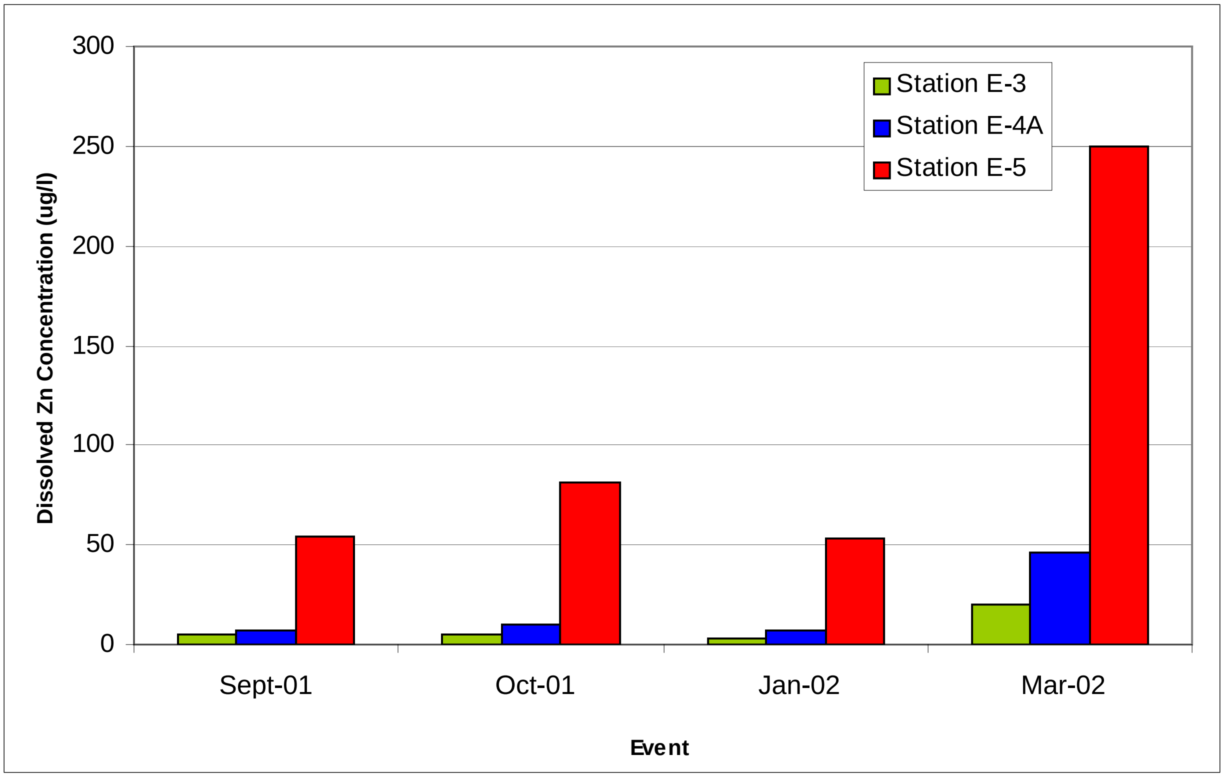


Figure 4.88: Dissolved zinc concentration at Stations E-3, E-4A, and E-5 indicating that increases in concentration occur primarily below E-4A in the Belden area.

4.6.3.6 Tramway Tributary Surface Runoff

In a study of the Belden area from 1995-1997, Dames & Moore (1997) monitored surface runoff quality during numerous rainfall-runoff and snowmelt events. Data from this study indicate that the Tramway tributary exhibits relatively high zinc loading during both thunderstorms and snowmelt periods as compared to other Belden locations.

The Tramway tributary (Station T-TR) exhibited dissolved zinc concentrations ranging from 32,000 to 170,000 μg/L (Figure 4.89) and zinc loads from surface runoff in excess of one lb/hr during multiple rainfall-runoff events (Figure 4.90). A highly elevated load resulted from an intense rainstorm that was monitored on July 29, 1996. The total event zinc load from the Tramway Tributary during this storm was 6.3 lbs/hr. By comparison, the total event zinc loads from Rock Creek and T-4 were 6.9 lbs/hr and 0.004 lbs/hr, respectively. However, direct comparisons between Rock Creek and the Belden tributaries may not be entirely appropriate in that the respective monitoring locations occupied landscape positions that could differ substantially in terms of shallow subsurface stormflow, saturation overland flow, and groundwater contributions during these events. During rainfall-runoff events on July 27 and August 17, 1997, field data indicated that flow from the Tramway did not directly reach the river as surface runoff. During other rainfall-runoff events, dissolved zinc load contributions from the Tramway tributary ranged from an estimated 31 to 94 percent of the load increase observed between E-3 and E-5 (Dames & Moore, 1997).

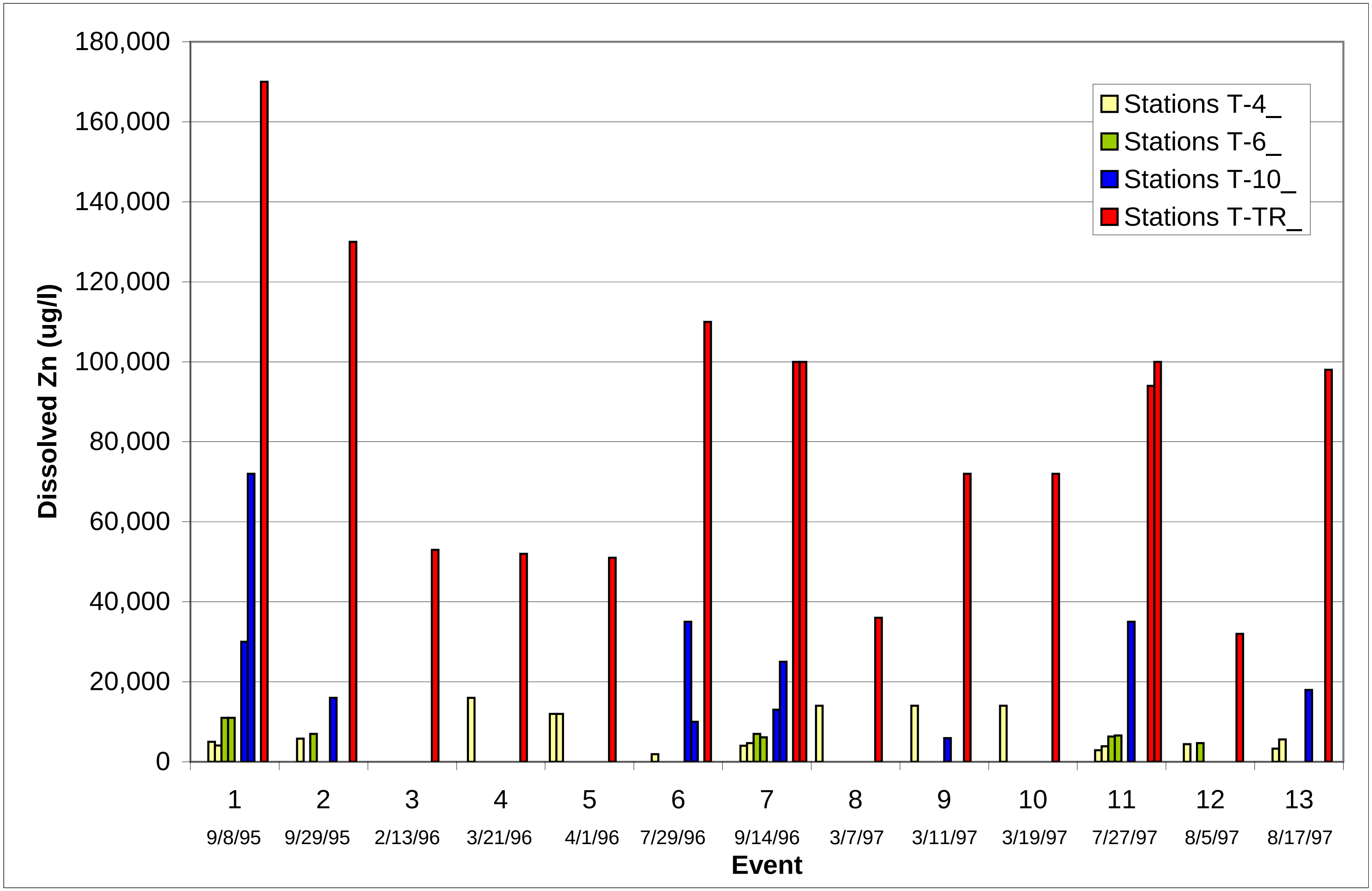


Figure 4.89: Dissolved zinc concentrations from the Belden tributaries for 13 measured runoff events. Total recoverable zinc concentrations were considerably higher. The tramway tributary is labeled T-TR.

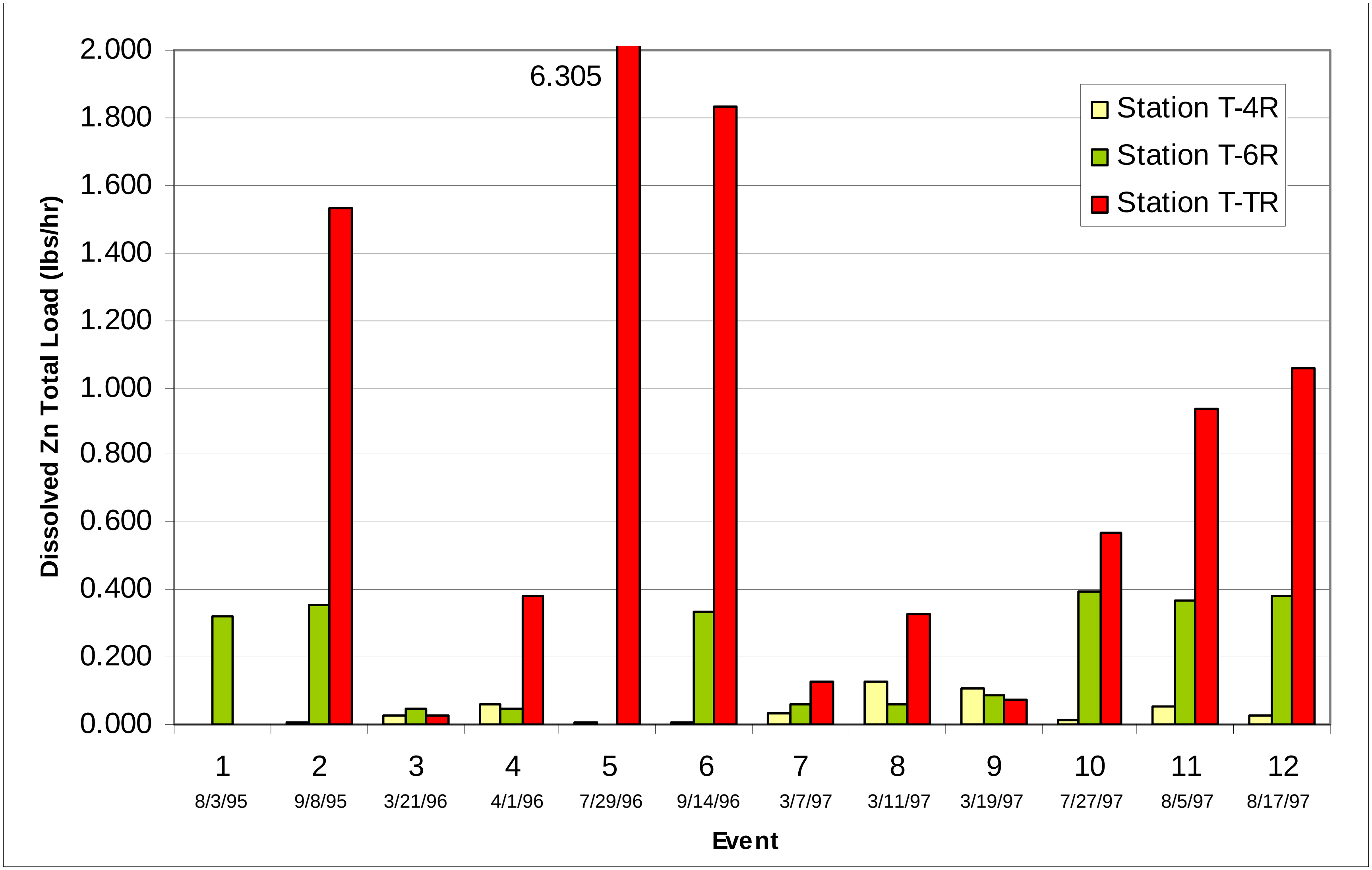


Figure 4.90: Total event zinc loads from the Belden tributaries for 11 measured runoff events. The tramway tributary is labeled T-TR.

4.6.3.7 Groundwater in the Belden Area

Typical surface elevations of water stored in the Eagle Mine (the 'mine pool') are approximately 200 ft above the Eagle River. Zinc concentrations measured in the mine pool water are on the order of 12,000-16,000 µg/L (NewFields, 2004). The hydrostatic pressure of the mine pool results in the subsurface movement of mine water. Groundwater quality was monitored in the Belden area from 1995-1997 (Dames & Moore, 1997) and intermittently at least through 2001 (data obtained from CDPHE). Figures 4.82 and 4.92 depict the locations of the Belden groundwater monitoring locations. Groundwater wells BW-3 and BW-9 are located down gradient of the Tramway drainage. The available water quality data from BW-3 and BW-9 indicate zinc concentrations substantially higher than other Belden wells (Figure 4.91) but the lack of samples from these locations precludes a clear interpretation. The current monitoring program in Belden does not require collection of groundwater quality samples.

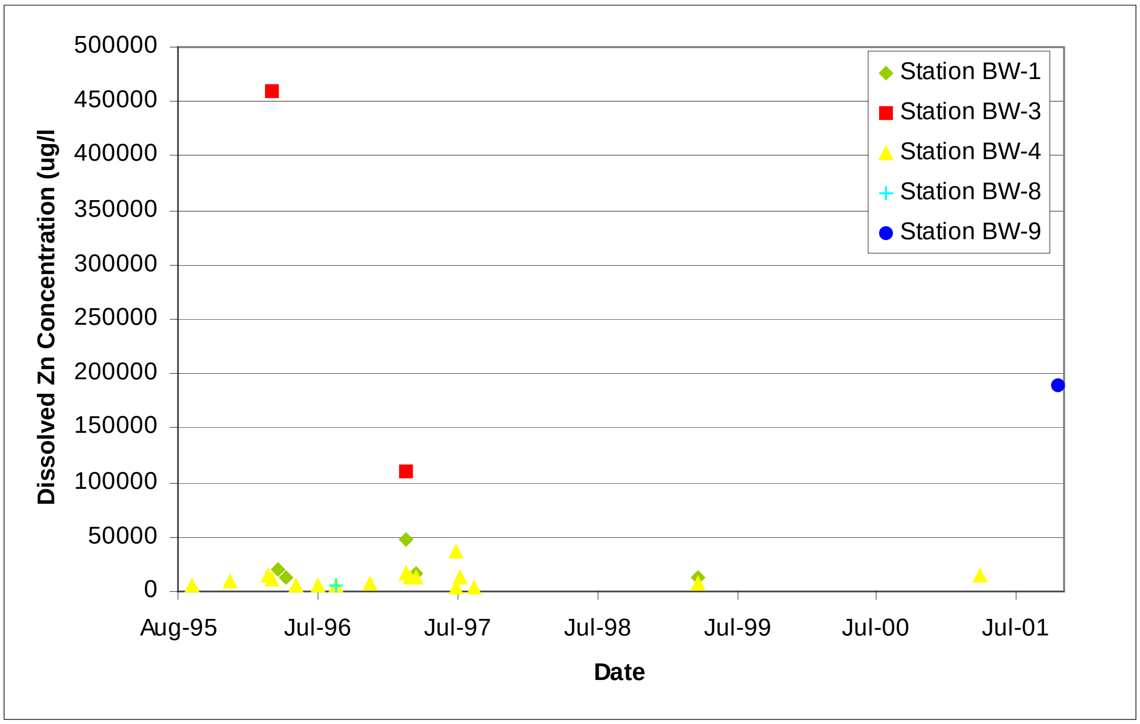


Figure 4.91: Dissolved zinc concentration for the Belden ground water monitoring locations.

During the course of the 1995 to 1997 study, water was present in well BW-3 from December 1995 through April 1996 and from November 1996 through August 1997. An increase in BW-3 ground water levels during the usually dry months of November and December was "not readily explainable" (Dames & Moore, 1997). Comparisons of well BW-3 chemistry to Newhouse Tunnel mine seep chemistry indicated similar concentrations of sulfate, cadmium, copper, lead, and zinc suggesting mine seepage as a potential source of ground water at well BW-3. Values of pH, specific conductivity, and alkalinity were also similar. However, the Newhouse Tunnel is now thought to be dry due to lowering of the mine pool (D. Hinrichs, NewFields, pers. comm.).

Preliminary groundwater loading estimates were computed by Dames & Moore (1997), based on well hydraulics and well water quality sampling results. These estimates suggested that well BW-3 (Belden loading area) had the highest potential to affect Eagle River water quality in the Belden reach. The estimated potential instantaneous zinc loads from BW-1, BW-3, and BW-4 during snowmelt were 0.7, 59, and 0.3

lbs/day, respectively. Although these calculations were based on several simplifying assumptions and limited data, the resulting preliminary loading estimate for BW-3 during snowmelt is equal to 82% of the average Belden load increase of 72 lbs/day measured in April between 1998-2002. Although the Dames & Moore (1997) report ultimately concluded that "during snowmelt periods, Belden reach tributary areas contributed an average of 9 percent of the dissolved zinc load measured at Station ER-5," this statistic did not include the preliminary estimates of groundwater loading.

4.6.3.8 Waste Rock Piles

Several waste rock piles exist on the Eagle Mine site. Waste rock piles WP-8, WP-10, WP-12, WP-13, WP-14 have been classified as likely to generate acid based on laboratory analyses (Figure 4.92; Dames & Moore, 1997). WP-8 and WP-12 are located in the Rock Creek drainage and WP-10, WP-13, and WP-14 are located at Belden. Figure 4.93 depicts the pH value and neutralization/acid potential ratio of 15 waste rock piles on the Eagle Mine site. Lower values of pH and neutralization/acid potential ratio are associated with higher risk of acid generation and release of metals. Two waste rock piles with disproportionately high potential to contribute metals (WP-13 and WP-14) are located in the Tramway tributary drainage. Of special note is WP-14, the only waste rock pile described as containing roaster material. Potential ground water pathways to the Eagle River may exist for WP-10, WP-13, and WP-14 (Dames & Moore, 1997). A brief description of the waste rock piles classified as having the highest acid production potential is provided below.

WP-8 is a large waste rock pile in the Rock Creek drainage that is readily visible from US24 at Gilman. The pile is benched with relatively coarse dolomitic materials with little or acid production potential in the upper bench. The lower bench is much finer and generates acid.

WP-10 results indicated that two downhill samples have little or no net potential to generate acid, but two uphill samples have net acid generation potential. A grain-size analysis indicated that half of the material is coarse sand to gravel sized and thus is less likely to release metals than finer grained piles.

Material from WP-12, in lower Rock Creek Canyon, was used as backfill during the construction of the Rock Creek culvert. Results of two samples indicated a net potential to generate acid. WP-13 is located below Rocky Point adit. Three samples were collected from WP-13 and all results indicated the net potential to generate acid. Two of the three samples had no neutralization potential. A grain-size distribution test indicated that more than half of the material is gravel sized and, therefore, is less likely to release metals than finer material.

WP-14 is process waste and includes roaster material. All seven samples collected from this pile indicated a net potential to generate acid. Three of the samples collected showed no neutralization potential. Grain-size distribution tests indicated that 65 to 85 percent of the material is medium sand size and smaller and is therefore more likely to release metals than coarser material. A sample collected from WP-14 contained the finest material of all monitored waste rock piles with 55% of the material passing a #200 sieve (Dames & Moore, 1997). Field reconnaissance indicated that runoff from WP-14 could also potentially enter the lower Tramway drainage just upstream of the mouth.

Tributary T-4 (Figure 4.82) is an additional source of metals loading in the Belden reach as indicated above, but monitoring data indicate lower rainfall runoff and snowmelt loading as compared to the Tramway tributary. Groundwater wells in this area also indicate lower concentrations compared to BW-3 and BW-9, and the preliminary study by Dames & Moore (1997) suggested lower groundwater loading potential.

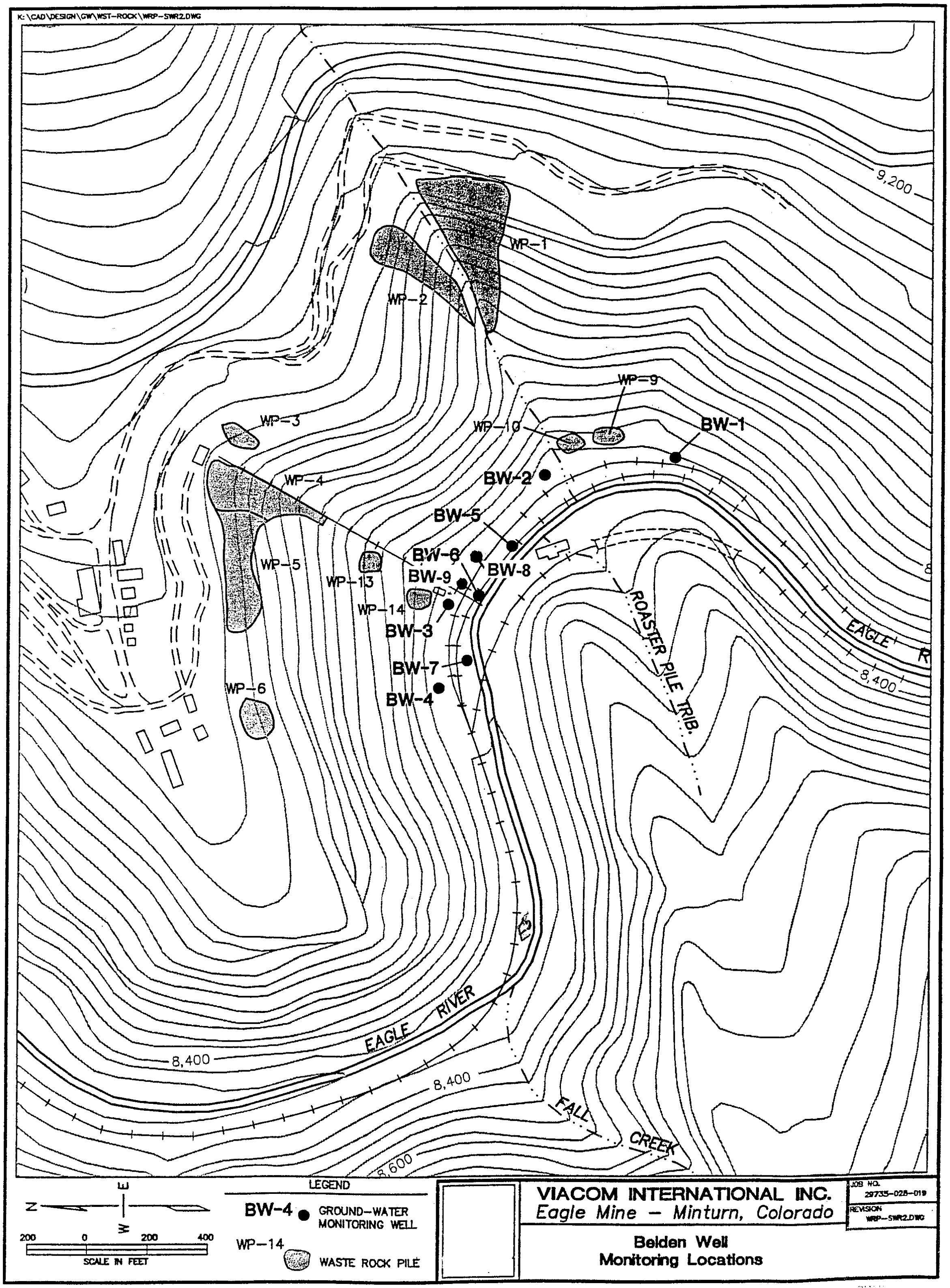


Figure 4.92: Belden well monitoring locations (from NewFields (2004b)).

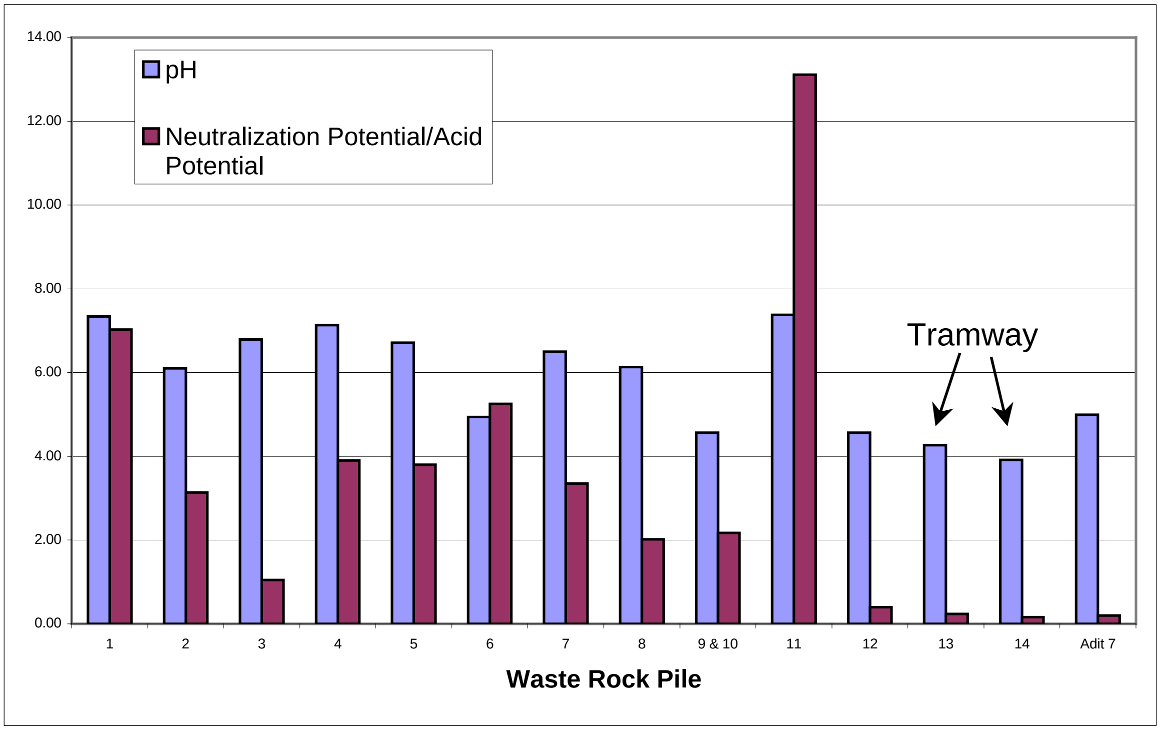


Figure 4.93: pH value and neutralization/acid potential ratio of 15 waste rock piles on the Eagle Mine site. Lower values of pH and neutralization/acid potential ratio are generally associated with higher risk of acid generation and release of metals (data from Dames & Moore (1997)).

4.6.3.9 Belden Cribbings

Field reconnaissance upstream of the Superfund site boundary revealed additional sources of current and potential metals loading. Several historical wooden structures or 'cribbings' that were used to stabilize waste rock piles are located in the segment between E-3 and E-4A. These structures are decaying and collapsing. A series of cribbings that is readily observable from U.S. Highway 24 is of particular concern given hillslope angles, proximity to the river, and the relatively large amounts of fine waste rock material that would probably be delivered directly into the Eagle River in the event of a catastrophic failure (Figure 4.94).

Monitoring and analysis of the metals loading potential of these waste piles is currently in progress in an effort to better assess the likely consequences of waste rock inputs resulting from cribbings failure. As part of this effort, 25 samples of waste rock were collected from the west facing slopes of the Belden site, upstream of the Eagle Mine site boundary by MFG, Inc., Fort Collins, Colorado, office. The collected samples were assessed in the geochemistry laboratory of MFG for paste pH and leachable zinc. All paste pH determinations were acidic and all samples produced leachable zinc on simple rinsing with distilled water. The observed acid pH values and zinc release indicate that the waste material has the potential to negatively impact water quality in the Eagle River. Paste pH measurements (Sobek *et al.*, 1978) ranged from 1.74 to 2.95. Leachable zinc concentrations ranged from 0.27 to 5.38 mg zinc/lb rock. The average value was determined to be 1.48 mg zinc/lb of waste rock. The potential impacts of these waste rock piles range from acute to chronic. Acute impact estimates based on a catastrophic failure of the cribbings structures suggest a short-term zinc load that produces a stream pulse with elevated zinc as high as 350 mg/L over current conditions (Williamson *et al.*, 2004).

Figure 4.94: Waste rock piles supported by decaying cribbings in the Belden area, upstream of the Superfund site.

In general, the potential impact of the Belden waste rock on water quality in the Eagle River can occur by several mechanisms:

- The waste rock may continue to weather in place, with zinc delivered to the Eagle River as a result of overland water flow during snow melt events and summer rains.
- The waste rock may be directly loaded into the river and completely submerged as a result of structural failure of the waste rock cribs with the concomitant release of acidity and zinc.
- The waste rock may, on structural failure of cribs, fill the margin of the river bank, exposing the material to alternating unsaturated weathering and seasonal rinsing during high water.

The potential for current and future water quality impacts due to the first scenario is probably best understood by in-stream zinc measurements. Currently, no significant iron staining is observed connecting the waste rock to the river. As the acidic past pH of the waste determined in the present evaluation attest, iron is produced during chemical weathering of the waste material. In the absence of significant iron staining, overland flow of contaminated water to the river is not implied. The potential for such flow to occur in the subsurface is real and the best way to assess possible zinc loading along this pathway is best determined by in-stream zinc monitoring (Williamson *et al.*, 2004).

Upon slope failure, releasing waste rock to the river, there would be an immediate impact to water quality as the waste rock is rinsed of its weathering products. The pH of the river water would be lowered. The extent to which it is lowered is dependent upon the buffering capacity of the river at the time that the slope failure occurred. Zinc loading would occur, consistent with the average zinc release determined in the present study, about 1.48 mg zinc per pound of rock. Table 4.35 summarizes calculations to estimate acute zinc loading to the Eagle River based upon two combinations of potential slope failure size and flow rate in the river. Calculations were made using the average 1.48 mg zinc per pound of waste rock and a thirty second time allowance to calculate water volume from river flow (same as contact time in leach tests). The magnitudes of the hypothetical slope failures that load directly into the river are calculated as (1) a moderate impact scenario where the crib itself collapses and the material immediately behind it is released, and (2) a worst case scenario in which all material above the angle of repose is released to the river, over the entire uphill extent of the waste rock. The worst-case scenario calculation results in 5,000 tons of the estimated total 22,000 tons being deposited in the river. The moderate impact scenario estimates 1,500 tons deposited in the river. The result of the calculation is that for the moderate case scenario, acute zinc concentrations in the river may reach 13 mg/L above baseline conditions. The worst-case scenario results in short term pulse concentration of approximately 350 mg/L above baseline conditions.

Table 4.35: Estimated acute water quality impacts.

Condition	Waste Rock Load (tons)	Waste Rock Load (lbs)	Flow Rate (cfs)	Flow Volume (cu ft)	Volume (L)	Zinc (mg/L)
Worst Case	5,000	10,000,000	50	1,500	42,480	349
Best Case	1,500	3,000,000	400	12,000	339,840	13

For the third condition, where waste rock reports to the margin of the river, but is not completely submerged, as assumed for the second condition, chronic water quality impacts to the river may be anticipated. The magnitude of that impact is difficult to estimate, as there are currently no data available concerning the rate of chemical weathering of the waste rock. These data are typically gathered by using humidity cells that simulate field weathering in a controlled laboratory setting. The lack of such data, however, does not detract from the basic reality that the waste rock produces acidic, zinc-bearing drainage water. Thus, the waste rock can only have a negative impact on water quality and its placement on the margin of the river through structural failure, or any other mechanism, should be avoided (Williamson *et al.*, 2004). The ongoing degradation and potential failure of these structures represent a significant risk to the biological improvements that have been achieved in the Eagle Mine site.

4.6.3.10 Belden - Leaking Adit

An unaddressed leaking adit is also located off the Superfund site just upstream of the Belden cribbings area. The concrete pipe shown in Figure 4.95 delivers runoff from the leaking adit through the railroad bed to the Eagle River. This adit and the several waste rock piles located upstream of the Superfund site contribute to zinc loading during snowmelt runoff. There were anecdotal reports of iron-stained discharge from this culvert during snowmelt in 2003, but no monitoring data were obtained for this location and the magnitude of metals loading during snowmelt runoff at this location is currently unknown.

Figure 4.95: Culvert that delivers metal contaminated water from a leaking mine adit located upstream of the Superfund site. Notice cribbings in background.

4.6.3.11 Summary of Belden Loading Analysis

Given the abrupt increases in zinc concentration recorded between Belden Stations E-4A and E-5, and the lack of other obvious loading sources between the Tramway tributary and E-5, it appears that the Tramway tributary area may be a relatively concentrated source of zinc loading in the Belden area. Zinc concentrations in groundwater samples collected in the Tramway area are also very high as compared to other Belden groundwater wells, but the three available 'snapshots' of water quality from the current well locations do not provide an adequate basis for interpretation. Potential groundwater loading estimates based on these limited water quality data from well BW-3 suggest that the Tramway area could account for a substantial portion of the snowmelt load measured at E-5. In addition, the Tramway tributary apparently has the highest rainfall runoff loading of any tributary in the Belden area. Finally, two waste rock piles (13 and 14) with relatively high potential to leach metals are located in the Tramway drainage; waste rock pile 14 is known to contain fine roaster material. Although these multiple lines of evidence point to the Tramway tributary area as a key source of zinc loading, the mechanisms controlling delivery of metals at different times of year remain uncertain. The relationship between mine pool elevations and groundwater loading, to our knowledge, has not been systematically analyzed, and changes in the management of the mine pool further complicate interpretation of existing data. Other potential sources of loading beyond those described above could include a buried adit, and roaster material that has undoubtedly leached into the railroad fill in the Tramway loading area. It is also plausible that waste rock was used for railroad fill in the Tramway vicinity when the Belden siding was constructed and contributes to metals loading. However, a review of well drilling logs did not directly specify the existence of waste rock material in the railroad bed.

The latest five-year review of the Eagle Mine site (USEPA, 2000c) stated that "*…the whole Belden area, including the associated waste rock, remains as one of the most difficult set of problems on the site. While the various efforts to address these problems have no-doubt lessened the zinc load reaching the Eagle River, this area remains as the single largest contributor of zinc. EPA and the State have not proposed any further work in this area at this time but will review the situation following the finalization of biological-based in-stream standards for the river. Any further effort to deal with these large quantities of waste rock will be subject to a complete cost-benefit, engineering, and environmental analysis as required by the National Contingency Plan. However, groundwater in the Belden area is a probable source of metals loading and, as such, is still being investigated.*" The current monitoring program in the Belden area is not designed for a rigorous evaluation of potential groundwater loading and bracketing of any potential 'hotspots.' Thus, the data and information needed to conduct a cost-benefit analysis are not available. A monitoring effort to collect spatially dense water quality samples in the vicinity of the Tramway has the potential to define more clearly how concentrated or diffuse the sources of zinc loading are in this reach.

4.6.3.12 Rock Creek

The segment of the Eagle main stem currently receiving the second largest incremental load of zinc is the vicinity of Rock Creek located just north of Gilman (Figures 4.83 through 4.85; NewFields (2004)). This drainage is bracketed by monitoring stations E-10 and E-11 and contains waste rock pile 8, the lower tier of which has been identified as an important source of metals loading. Although it remains uncapped in place, remediation efforts have resulted in the capture of a significant portion of the metals load coming from the Rock Creek drainage. The captured leachate and runoff are transported along with mine pool water through a gravity-fed pipeline to a treatment facility located downstream at the consolidated tailings pile.

4.6.4 Standards and Biological Criteria for the Eagle Mine Segment

USEPA has declared construction of the cleanup remedy for the Eagle Mine to be complete. The Table Value Standard for zinc for the Eagle River between Belden and Gore Creek is 106 µg/L based on hardness levels measured below the treatment facility. This concentration is thought to be protective of a wide range of aquatic species, and is consistent with values presented for salmonids and most macroinvertebrates in the scientific literature. Brown and brook trout are more resistant to dissolved zinc than cutthroat and rainbow trout (Table 4.36). However, the mottled sculpin, a native fish, is much more sensitive. The chronic LC50 value for this species is very low (32 µg/L), suggesting that sculpin would be unable to recolonize the Belden to Gore segment of the river in its current state and even if the TVS were achieved (Figure 4.96). Figure 4.97 shows that the TVS is not met with regularity in this segment except for the reference site above Belden. Table Value Standards established by the USEPA are thought to be values that will protect 95% of the aquatic genera that would normally inhabit the waterbody. None of the affected sites regularly support 95% of the aquatic genera found at the reference site below Red Cliff, though there was a steady improvement during the period 1997 to 2001 (Figure 4.98).

Table 4.36: Comparison of fishes recorded during shocking of mine-affected and reference sites.

	Reference	Affected
Total fish recorded	2360	2237
Native fish as percentage of total	19	<1
Brown trout as percentage of total	78	93
Sculpin as percentage of total	18	<1
Rainbow as percentage of total	3	<1
No. of species	7	5
No. of native species	4	2

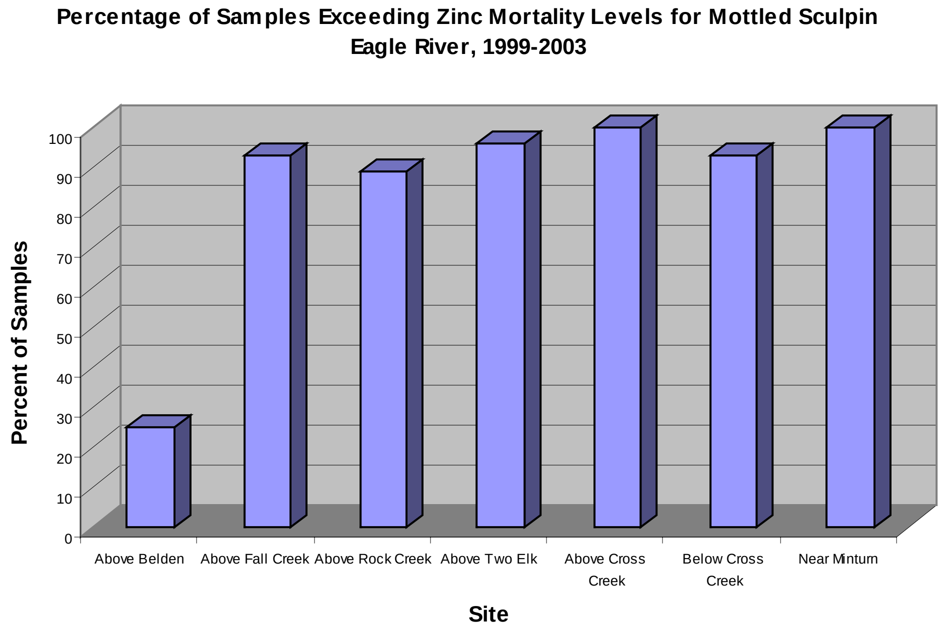


Figure 4.96: Based on 28 water samples taken from each site between 1999 and 2003 (NewFields, 2004), only the site upstream of the Belden mine does not regularly exceed the 30-day chronic limit of zinc for mottled sculpin. The species is found upstream of Belden, in Two Elk Creek, Cross Creek, and in the Eagle River downstream from Avon but will not recolonize sites between Belden and Minturn unless water quality improved significantly.

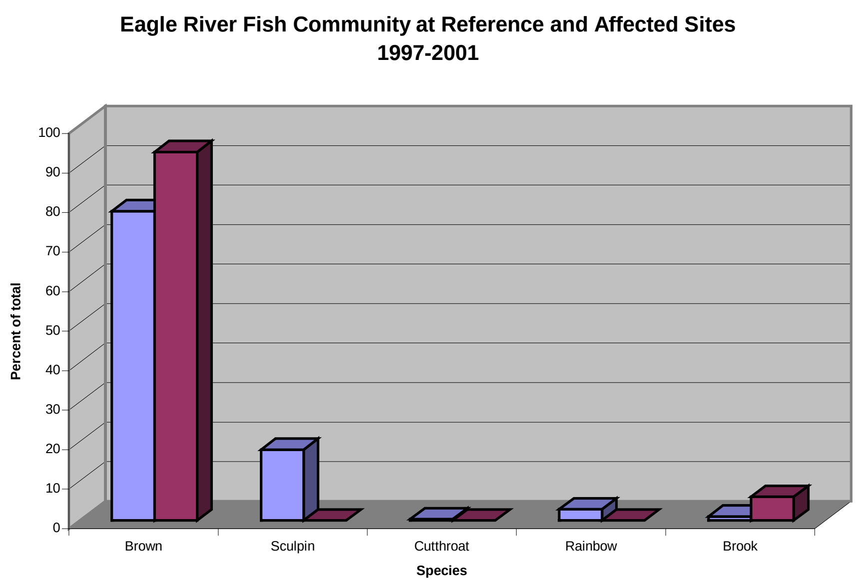


Figure 4.97: Eagle Mine fish monitoring: number of fish caught summed for all sites during the period 1997 to 2001. Blue bars represent reference sites, and maroon represents affected sites. Eighteen percent of fish caught at the reference sites were sculpin. At affected sites, brown trout comprises over 90% of the total individuals caught, with the remainder being brook trout. Data from Woodling and Ketterlin (2002).

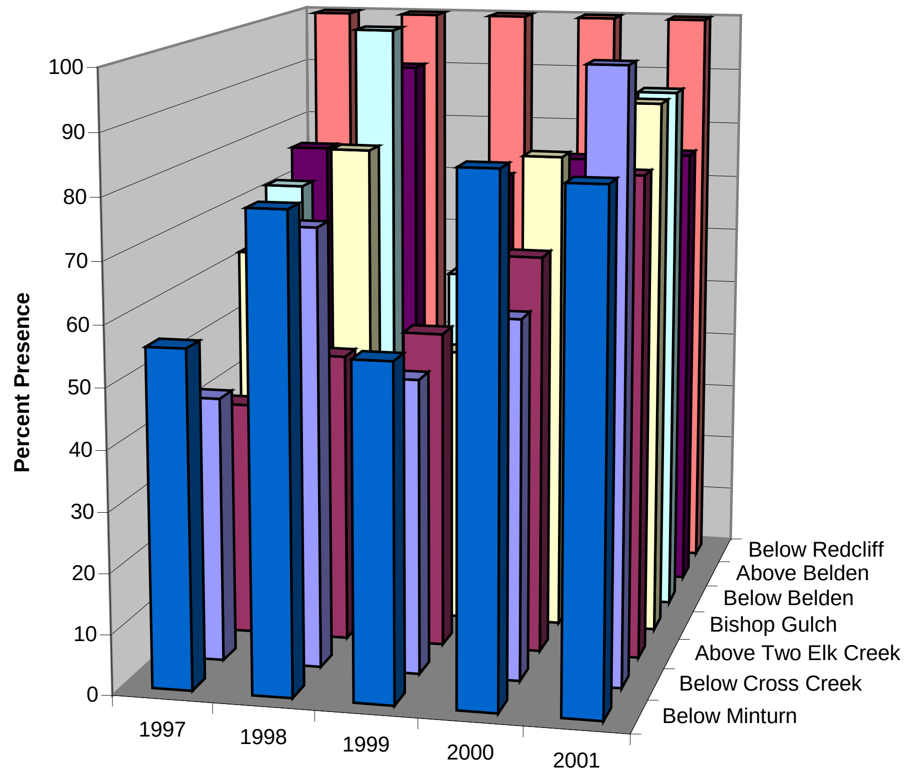


Figure 4.98: Number of fish and benthic macroinvertebrate genera present at each site expressed as a percentage of the genera found at the reference site below Red Cliff. For example, in 2001, the site below Red Cliff had 31 genera, while the site at Belden had 24, or 77% of the reference site. Three items are particularly noteworthy in this chart: (1) despite the fact that the site below Red Cliff often has reduced numbers of trout, presumably from high angling pressure, it is still a good reference since it almost always has the highest diversity of fish and invertebrates; (2) although there exists large variability in the number of genera between sites and years, all sites are showing a general increase in the number of genera relative to the reference site; and (3) no site regularly has 95% of the number of genera at the Red Cliff reference site. Data from annual monitoring by Woodling *et al.* (2002).

In 1996, the CDPHE, USEPA, and Viacom agreed upon the use of biological criteria to assess the success of Eagle Mine remediation. The specific biological criteria to be met were proposed after construction of the remedy was deemed complete. One criterion was subsequently removed (relative fish weight); the rest were recently adopted (CDPHE and USEPA, 2004b). The water quality existing during the compliance period will be used to define new water quality standards and the new standards will be applied to the segment of the Eagle River between Belden and Gore Creek. It should be noted that since no further cleanup activities are planned at this time, water quality is not expected to improve from current conditions (CDPHE and USEPA, 2004a). Thus, the biological criteria chosen are thought to be attainable given the current water quality conditions and level of mine cleanup. The CDPHE and USEPA have not yet fully determined what standards for zinc and other metals will be set.

Water quality between Belden and the Gore Creek confluence has clearly improved – zinc levels have decreased, some sensitive insect taxa have returned, and brown trout have largely recovered in terms of abundance. The biological criteria adopted by the USEPA and CDPHE include one fish metric and a benthic Index of Biotic Integrity (B-IBI) for aquatic insects (CDPHE and USEPA, 2004a; Fore, 2001, 2002). Seven metrics were chosen for the aquatic insect B-IBI: (1) total taxonomic richness (excluding midges); (2) mayfly richness; (3) stonefly richness; (4) caddisfly richness; (5) metal intolerant taxa richness; (6) clinger richness; and (7) percent Heptageniid mayflies. Most mayflies and almost all heptageniid mayflies are very sensitive to metals. Some stonefly and caddisfly taxa are also reduced in abundance as a result of metals concentrations similar to current levels in the Eagle River. In particular, abundances of the mayflies *Rhithrogena robusta*, *Cinygmula* sp., and *Drunella doddsi*, the stonefly *Sweltsa* sp., and the caddisfly *Rhyacophila* sp. are likely to be reduced at current levels of metals loading as compared to reference sites (Clements *et al.*, 2000).

Due in part to the Colorado Division of Wildlife's decision to manage the upper Eagle River as a brown trout fishery, this non-native fish species was used to determine water quality standards for the affected river segments. Brown trout (*Salmo trutta*) are relatively tolerant to zinc compared to native fishes inhabiting the Eagle River. Seven sites have been monitored for compliance, four affected by the Eagle Mine and three reference sites. In order for water quality to be deemed sufficiently recovered, population estimates of brown trout at the affected sites must be at least 95% of the estimates for reference sites for three consecutive years. The compliance period began in 2002; Table 4.34 summarizes the status of this metric. The Colorado Department of Wildlife (CDOW) proposed an additional metric known as "relative weight" in 2002. This metric assumes that brown trout of a given length will weigh more in a healthy stream than one affected by heavy metals (Albeke *et al.,* 2001). Relative weights of trout at the mine monitoring sites have been significantly lower than reference sites in four of the last five years. This metric was later removed by the USEPA and CDPHE because *"[w]e cannot predict if compliance with the relative weight metric can ever be achieved on a consistent basis and reducing metals concentration to a point where compliance is achieved may not be feasible*" (CDPHE and USEPA, 2004a). The current focus on a single abundance metric may not reflect differences in brown trout health between reference and mine sites, and among mine sites.

The CDPHE and USEPA did not develop a multimetric Index of Biotic Integrity (IBI) for fishes due to the dominance of brown trout relative to other fish species, especially in areas contaminated by the mine (Figure 4.97; Table 4.37; CDPHE and USEPA, 2004a). In contrast, Mebane (2002) developed a fish IBI for cold water, forested streams in Idaho, some of which had only two fish species. Mebane's IBI included the following metrics: (1) number of cold water native species; (2) percent cold water individuals; (3) percent sensitive native individuals; (4) number of sculpin age classes; (5) number of selected salmonid age classes; and (6) relative abundance. Given current levels of zinc, utilization of such an IBI, although much more indicative of fish community health, is a moot point within the segment directly affected by the Eagle Mine. However, the recolonization of the downstream reference site at Arrowhead by multiple age classes of sculpin bodes well for using an IBI approach to quantify the gradient of improvement in fish communities *downstream* of the Eagle Mine segment, as well as the biological benefits that could result from additional reductions in zinc loading.

Table 4.37: Compliance monitoring of Brown Trout populations in the Eagle River. Reference sites include CDOW monitoring sites 1, 1.9, and 6, areas relatively unaffected by heavy metal contamination. Values for the other four sites are fish per acre, and whether the site has 95% of the population of the reference sites. Compliance period is shown in gray. Table data reproduced from CDPHE and USEPA (2004b).

Year	Ref. Sites Fish/Acre	95%	Site 2.2	95%?	Site 2.9	95%?	Site 3	95%?	Site 4.2	95%?
1997	252	239	69	No	130	No	203	No	194	No
1998	321	305	440	Yes	196	No	201	No	291	No
1999	302	287	613	Yes	198	No	310	Yes	267	No
2000	360	342	569	Yes	341	Yes	467	Yes	493	Yes
2001	429	407	568	Yes	234	No	390	No	468	Yes
2002	442	420	938	Yes	451	Yes	558	Yes	996	Yes
2003	526	500	766	Yes	218	No	563	Yes	561	Yes
2004										

4.6.5 Water Temperature

Water temperature is a critical ecological factor that is linked to many variables in a watershed. During the summer, water temperatures naturally increase due to longer days and more direct solar radiation. Toward late summer when snowmelt decreases, water temperature increases more rapidly because flow rates are lower. A number of fish kills have occurred on the Eagle River in recent years between Edwards and Wolcott (WQCC, 2002b). These kills often occur, in part, because of high water temperatures.

Temperature is directly related to the amount of oxygen water can absorb (Table 4.38) and high temperatures mean less oxygen is available for fish. In a high mountain river system like the Eagle, water is cold and constantly aerated by flows through riffles and rapids. Because trout are adapted to high dissolved oxygen levels, decreases in O_2 can be a major factor in fish kills. The upper lethal limit of water temperature has been estimated as high as approximately 82 degrees (Lee and Rinne, 1980) but the *duration* of elevated temperatures is undoubtedly a key factor in fish stress. Physiological stress from elevated temperatures, especially when combined with other factors such as chronic metals loading and poor catch and release practices, can substantially increase susceptibility to pathogens such as furunculosis (*Aeromonas salmonicida*). Although furunculosis is ubiquitous in aquatic environments, elevated temperatures dramatically increase the susceptibility of trout, with large brown trout being most vulnerable. The sores that result from furunculosis infections have been clearly evident in many of the temperature related fish kills observed on the Eagle River (Czenkusch, pers. comm., 2004).

Table 4.38: Solubility of oxygen as a function of water temperature.

Temperature °C (°F)	Saturated Dissolved Oxygen (ppm)
0 (32)	14.62
5 (41)	12.80
10 (50)	11.33
15 (59)	10.15
20 (68)	9.17
25 (77)	8.38
30 (86)	7.63

The maintenance and protection of forest riparian zones is a key strategy to protect coldwater fishes from excessive temperatures. In an east-west oriented river like the Eagle, mature riparian trees on the south bank of the channel can be especially important for stream shading. Restoring forested riparian zones along tributaries of the lower Eagle can provide refugia and inputs of cool water during summer low flow periods. Livestock grazing can also increase water temperature. Cattle with unfettered access to stream banks can eat and trample streamside vegetation that otherwise shades water and stabilizes the stream bank. Allowing cattle in streams and rivers can alter channel morphology, increasing sedimentation, and widen the river channel. Widened channels result in shallower water levels that flow more slowly, both of which result in increased heating from the sun (Platts, 1982).

Abnormally high sediment loads, such as those introduced from the Milk Creek drainage, also affect water temperature because sediments suspended in the water column or deposited on the bed absorb solar energy, which is then conducted to the water.

4.6.6 Sedimentation Impacts

Excessive sedimentation degrades the quality of aquatic habitat, diminishes watershed functions and services, and limits the aesthetic, social, and economic value of aquatic ecosystems. The adverse impacts of suspended and deposited sediment include increased water treatment costs for municipal supply and industrial processes, diminished reservoir capacity, increased costs for maintenance of irrigation canals, and reduced habitat for fish and benthic macroinvertebrates. Sediment is not only a critical pollutant, but also serves as a catalyst, carrier, and storage agent of other forms of pollution. For example, stream bank materials often have a TP concentration of approximately 300 ppm (Bledsoe *et al.*, 2000). This means that for every ton of bank erosion, over a half a pound of phosphorus can directly enter the stream.

4.6.6.1 Milk, Alkali, and Ute Creeks

The extensive geomorphic instability occurring in the Milk, Alkali, and Ute Creek drainages is described in Section 4.7. Sediment concentrations as high as 12,000 mg/L have been recorded by the BLM during spring runoff and impacts to the fisheries in the Eagle River have been documented by the DOW in 1971, 1982, and 1989 (NWCCOG, 2002). These inputs of fine sediment diminish fish production by an order of magnitude and often reduce the fishing season by approximately 50% (Czenkusch, Heichen, and Clark, pers. comm., 2004). These findings are consistent with research by Newcombe and Jensen (1996) that examined the acute and chronic effects of total suspended solids (TSS) on several species of fishes (Figure 4.99, Table 4.39). This research provides a direct linkage between the duration of varying sediment concentrations and trout health and could, therefore, be used to quantify targets for sediment concentrations and durations to achieve fisheries goals below the Milk, Alkali, and Ute Creek drainages.

Duration* of Exposure to Suspended Sediment

LOGe (hours)

mg/L	0	1	2	3	4	5	6	7	8	9	10	LOGe (mg/L)
	Predicted Severity-of-Ill-Effect Scores											
162755	10	10	11	12	12	13	14	14	>14	>14	>14	12
59874	9	9	10	11	12	12	13	13	14	>14	>14	11
22026	8	8	9	10	11	11	12	13	13	14	>14	10
8103	8	8	8	10	10	11	11	12	13	13	14	9
2981	7	7	8	9	9	10	11	11	12	12	13	8
1097	6	6	7	8	9	9	10	10	11	12	12	7
403	5	5	6	7	8	9	9	10	10	11	12	6
148	5	5	5	7	7	8	8	9	10	10	11	5
55	4	4	5	6	6	7	8	8	9	9	10	4
20	3	3	4	5	6	6	7	8	8	9	9	3
** 7	3	3	3	4	5	6	6	7	7	8	9	2
3	2	2	2	4	4	5	5	6	7	7	8	1
1	1	1	2	3	3	4	5	5	6	7	7	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

* Note dual calibration of scales for duration and concentration: hours and mg/L; and $\log_e$ (hours), and $\log_e$ (mg/L).

**Instantaneous SS concentrations based on any sample should be reconciled with generally accepted water quality criteria which state: "Induced non-filterable residue should not exceed 10 mg/L when background non-filterable residue is ≤100 mg/L, nor should induced non-filterable residue be more than 10% of background when background is >100 mg/L" (Singleton, 1985).

Figure 4.99: Predicted severity of ill effect for salmonoid fishes exposed to suspended sediment (adapted from Newcombe and Jensen (1996)). See Table 4.39 for an explanation of severity of ill effect numbering scheme.

Table 4.39: Scale of the severity (SEV) of ill effects associated with excess suspended sediment (adapted from Newcombe and Jensen (1996)).

	SEV	Description of Effect
Nil Effect	0	No behavioral effect.
Behavioral Effects	1	Alarm reaction.
	2	Abandonment of cover.
	3	Avoidance response.
Sublethal Effects	4	Short-term reduction in feeding rates, short-term reduction in feeding success.
	5	Minor physiological stress, increase in rate of coughing, increased respiration rate.
	6	Moderate physiological stress.
	7	Moderate habitat degradation, impaired homing.
	8	Indications of major physiological stress, long-term reduction in feeding rate, long-term reduction in feeding success, poor condition.
Lethal and Paralethal Effects	9	Reduced growth rate, delayed hatching, reduced fish density.
	10	0-20% mortality, increased predation, moderate to severe habitat degradation.
	11	>20 - 40% mortality.
	12	>40 - 60% mortality.
	13	>60 - 80% mortality.
	14	>80 - 100% mortality.

4.6.6.2 Traction Sand Loading to Black Gore Creek

Sediment loading from I-70 has resulted in widespread channel aggradation and habitat loss in Black Gore Creek. Numerous studies have focused on this issue and the development of a Total Maximum Daily Load (TMDL) strategy aimed at restoring designated uses is currently underway. Because this issue is receiving a great deal of attention at both the State and local level, projects associated with mitigation of traction sand loading were not a focus of the ERIA. However, a few points are worthy of discussion. First, the TMDL strategy focuses on reductions in new loading of sand and does not address the sand load that already resides in the channel and valley bottom of Black Gore Creek. This sand load will undoubtedly continue flushing downstream over time. Research from other regions indicates that 'slugs' of sediment may translate downstream as waves in some geomorphic contexts or may diffuse and attenuate in other instances. Of particular concern is the uncertainty surrounding the response of downstream segments with milder slopes and lower sediment transport capacities than the upstream supply reaches draining Vail pass. Field reconnaissance and aerial photo analyses indicate that there already exists substantial in-channel storage of sediment and bar formation in segments of Gore Creek in East Vail below the confluence with Black Gore Creek. Additional loading of sediments currently stored in Black Gore Creek could increase aggradation and substrate embeddedness and decrease channel capacity. These changes could potentially increase the risk of bank erosion and overall planform instability, as well as shift benthic macroinvertebrate composition to taxa that are more tolerant of fine sediments. Moreover, Wilcock and McArdell (1993) have shown that sand intrusion into a gravel matrix substrate like that of Gore Creek can significantly alter the stability of the coarser substrates and increase bedload transport intensity during high flows. It is therefore plausible that the channel could alternate between periods of fine sediment storage and deposition and periods of higher intensity bed disturbance resulting from increased mobility of the coarser fractions of the substrate. This self-regulating mechanism could possibly increase fine sediment flushing potential but nonetheless have negative consequences for instream biota.

In general, the development of a TMDL requires the selection of goals and criteria that are likely to result in waterbody restoration. In the case of Black Gore Creek, there is a chain of cause and effect that links increases in traction sand loading to the response of the benthic macroinvertebrate communities. The chain of cause and effect includes processes such as snowmelt runoff, hillslope sediment delivery, trapping of sediment by vegetation and best management practices, sediment transport capacity of the stream, and seasonal variations in stream substrate. The Clean Water Act also requires that TMDLs include a margin of safety that reduces the risk that water quality will remain impaired. We were unable to locate documentation describing how the target of a 20% reduction in traction sand loading to Black Gore Creek is linked through the causal chain described above to the probable recovery of aquatic life uses and an associated margin of safety.

4.6.7 Urban Nonpoint Source Pollution

In addition to mining related impacts, metals loading and other forms of polluted runoff result from urbanization and impervious surfaces. An uncertain but substantial proportion of the existing development in the Eagle River watershed was constructed without established runoff quality controls for long-term protection of receiving waters. Tables 4.40 and 4.41 summarize data on pollutant concentrations measured in urban runoff in other parts of the U.S. to illustrate the composition of curb loading and stormwater.

Table 4.40: Traffic emissions (adapted from Novotny and Olem (1994)).

Pollutant	Percent of Total Solids by Weight
Volatile solids	5.1
BOD_5	0.23
COD	5.4
Grease	0.64
TP	0.06
TKN	0.016
Nitrate	0.008
Asbestos	$3.6 * 10^5$ fibers/g
Lead	1.2
Chromium	0.008
Copper	0.012
Nickel	0.019
Zinc	0.15
Emission rates of total solids	0.671 g/(axle•km)

Source: Based on data from Shaheen (1975)

Table 4.41: Overall water quality characteristics of urban runoff (USEPA, 1983).

Constituent	Typical coefficient of variation	Site median EMC[a]	
		For median urban site	For 90th percentile urban site
TSS, mg/L	1 – 2	100	300
BOD, mg/L	0.5 – 1	9	15
COD, mg/L	0.5 – 1	65	140
TP, mg/L	0.5 – 1	0.33	0.70
Soluble P, mg/L	0.5 – 1	0.12	0.21
TKN, mg/L	0.5 – 1	1.50	3.30
NO_{2+3}-N, mg/L	0.5 – 1	0.68	1.75
Total Cu, μg/L	0.5 – 1	34	93
Total Pb, μg/L	0.5 – 1	144	350
Total Zn, μg/L	0.5 – 1	160	500

[a]event mean concentration.

Components of urban nonpoint source pollution in the Eagle River watershed include:

1. Autos – gasoline, grease, oil, petroleum derivatives, exhaust emissions (e.g., nitrate, polyaromatic hydrocarbons), brakes (copper, asbestos), tires, corrosion of metal parts and paints (various metals)
2. Erosion from construction and sparsely vegetated areas
3. Fertilizers and pesticides in landscaping
4. Spills of toxics – fuels, solvents, pesticides, etc.
5. Street asphalt, salts and deicers, ethylene glycol
6. Septic tanks

Loading of the pollutants listed in Table 4.41 generally increases with impervious area and curb length in a watershed. Thus, connected impervious areas along the I-70, Eagle River, and Gore Creek corridors increase the conveyance of these pollutants to the receiving waterbodies.

In managing stormwater, smaller storms, as opposed to annual snowmelt peaks, are often most important from a *quality* standpoint because they cause considerable washoff of pollutants without much dilution. The most effective runoff quality controls reduce both the volume and peak of runoff. Stormwater systems are often designed to deal with larger storms and may not be effective for quality control. Most important pollutants in urban runoff can be settled out, but sometimes the dissolved form is also important. Control of dissolved pollutants can be more difficult than for adsorbed forms, which settle out. Applicability of BMPs is site specific and longevity is a problem for some urban BMPs that tend to fill up with sediment. There are several references for design of urban BMPs. However, secondary impacts, either positive or negative, are significant for some BMPs and cost-effectiveness of these practices has not always been clearly demonstrated.

4.6.8 Red Cliff Wastewater Discharge

It is widely known that the Red Cliff wastewater treatment facility does not comply with CDPS permit conditions and degrades the quality of the Eagle River at the confluence with Homestake Creek (Figure 4.100). Discharges from this facility contain elevated levels of pollutants including nutrients and biochemical oxygen demand. Despite impacts to the river immediately downstream of the outfall, biomonitoring data collected at the Belden E-3 reference site do not indicate substantial impacts to fish and benthic macroinvertebrates at this location. Potential solutions to this problem under consideration include (1) rehabilitation and upgrading of the existing facility, and (2) connecting the Red Cliff sewer system to an existing ERWSD facility.

Figure 4.100: Wastewater treatment facility at Red Cliff.

4.7 GEOMORPHOLOGY OF THE EAGLE RIVER AND ITS TRIBUTARIES

4.7.1 Introduction

Fluvial geomorphology is the study of the form and structure of the surface of the earth as affected by flowing water. Because rivers may be effectively thought of as ecosystems that integrate everything occurring within the watershed, an examination of fluvial forms and processes is essential to understand the influences of land use changes, flow regime modifications, river stability and response, physical habitat characteristics, and many other factors relevant to the health and integrity of the Eagle River. Fluvial processes create and maintain the physical habitat template for instream species such as fish and benthic macroinvertebrates, establish connections between channels and floodplains, constrain channel geometry, influence the recreational and navigational potential of channels, and determine how water is conveyed through a watershed. Factors that have altered these processes in the Eagle River watershed include grazing, channelization, mining for metals and gravel, dam construction, diversion/flow alteration, urbanization, and agriculture. Modification of channel morphology and streamflow characteristics can degrade physical stream habitat in a variety of ways (Jacobson *et al.*, 2001). Furthermore, disturbances at one location can propagate upstream and downstream through a watershed over time. A river is only part of a dynamic system, and perhaps the single most important concept from fluvial geomorphology is the interconnectedness and complexity of processes that operate throughout a watershed. Hans Albert Einstein (1972) summarized these ideas nicely in the following quote from the keynote address of a symposium in his honor:

> *"If we change a river we usually do some good somewhere and 'good' in quotation marks. That means we achieve some kind of a result that we are aiming at but sometimes forget that the same change which we are introducing may have widespread influences somewhere else. I think if, out of today's*

emphasis on the environment, anything results for us it is that it emphasizes the fact that we must look at a river or a drainage basin or whatever we are talking about as a big unit with many facets. We should not concentrate only on a little piece of that river unless we have some good reason to decide that we can do that."

The geomorphology of the Eagle River watershed has been shaped by processes acting over several temporal scales. Geology and climate are major long-term controls in the basin. The landscape as determined over geologic time by tectonic processes and bedrock geology dictates how water can shape the watershed. For example, many reaches of the Eagle and its tributaries are contained in deep confined valleys that were naturally established by the erosion of relatively resistant bedrock. As lithology changes to softer sedimentary rock below Edwards, there are concomitant changes in valley type and channel morphology. Geology and historical climate set the 'background condition' of the watershed. Adjustments are made to the watershed over shorter time scales in response to changes in flow regime and anthropogenic land use changes. For example, the Eagle River is subject to numerous diversions and accompanying reductions in peak flows that can have geomorphic consequences, as discussed below. Land use changes, both historic and current, have also played an important role in shaping the current forms and responses of channels. Historical impacts to the watershed include extensive cattle and sheep grazing, channelization at Camp Hale and at scattered locations throughout the watershed for highway and railroad construction, mining, and vegetation removal. All of these activities have localized consequences that can potentially propagate to other locations over time. In more recent times, rapid development in the watershed has altered geomorphic processes and connections. For example, channel adjustments are limited by bank armoring along urbanized corridors of the Eagle River and impervious surfaces increase peak flows to tributaries.

Processes that shape the watershed also occur over several spatial scales, which can be correlated to temporal scales. Frissell *et al.* (1986) identify a hierarchy of processes controlling geomorphology and stream habitat acting at different spatiotemporal scales. Processes acting at larger scales influence patterns at smaller scales. The largest of these scales occurs at the river basin level and includes events such as tectonic uplift or subsidence, base level changes, volcanism, and long-term climate shifts. These processes influence geomorphology at the watershed scale, for example drainage network development. At the other end of the hierarchy is the microhabitat system that includes small-scale characteristics such substrate stability, near bed velocities, and transport of organic material. This scale is important to habitat for benthic macroinvertebrates, accumulation of fine sediment, periphyton growth, and organic matter retention. The scales intermediate to these two endpoints (segment, reach, and habitat units) are often what come to mind in the realm of channel improvement or restoration. Restoration efforts are frequently (all too often) focused only on a specific reach of channel. However, all of these scales are relevant to river restoration and geomorphic analysis. Restoration should not solely focus on piecemeal channel modification, but should include efforts to reestablish geomorphic processes and improve connections between habitats at all scales.

A common trend throughout the Eagle River watershed is a preponderance of high quality physical habitat in the watershed in smaller tributaries and headwater areas and an increasing prevalence of impacts along the mainstem Eagle and along tributaries as they approach and traverse the Eagle Valley. In several degraded areas of the watershed, channels have been disconnected from the historic floodplain and lack the associated organic inputs and water storage functions. Bank armoring limits lateral adjustability in many areas where channels were once more free to meander. However, areas still exist in the watershed where the Eagle can freely adjust, typically where threats to adjacent infrastructure and development are not an issue. Overall, the Eagle River has remained vertically and laterally stable in most segments, despite the historical and ongoing pressures described in previous sections. This stability is largely attributable to the armoring of coarse material in the channel bed and along bank 'toes,' as well as natural lateral confinement in many segments. Where substrate and bank materials become finer relative to upstream segments, such as lower in the basin below the Brush Creek confluence, the Eagle displays a greater tendency towards over-widening and braiding.

The Eagle valley has experienced rapid urbanization over the last three decades. The tendency for impervious areas (roads, parking lots, roofs, driveways, and sidewalks) to result in 'flashier' peak flows of a greater magnitude, frequency, and/or duration is well documented in the scientific literature. The effects of these flow increases can have geomorphic consequences over two separate phases. As impervious area is being constructed and bare soil is available for erosion, runoff can input a spate of sediment into the channel leading to aggradation. Once the impervious area is established, the channel can be starved of sediment resulting in degradation (Roesner and Bledsoe, 2002). However, impervious areas, at least at their current extent, most likely have not had a significant geomorphic effect in the Eagle River watershed. The watershed is dominated by a snowmelt flow regime and summer thunderstorm runoff events that would be most affected by impervious area are typically short-lived and occur over small areas. Thus, the effects of storm runoff are localized. Furthermore, because of the coarse bed material and resistant boundaries occurring in much of the watershed, the large snowmelt peaks occurring during late spring and early summer perform most of the geomorphic work in the watershed.

4.7.2 Purpose

The purpose of this section is to provide a broad description of geomorphology and physical habitat features in the Eagle River watershed and discuss the methods used to evaluate the geomorphic condition of the watershed. The following topics are discussed in Section 4.7:

- Geomorphology with respect to physical habitat and channel stability
- Qualitative response and channel evolution and how it pertains to the Eagle River
- Methods of analysis
- A geomorphic overview of the entire Eagle River
- A description of the major tributaries of the Eagle
- Geomorphic impacts of changes to the flow regime
- A survey of hydraulic geometry of the Eagle River
- An analysis of meander geometry and risk of braiding of the lower Eagle
- Specific gage analysis

4.7.3 Geomorphology, Physical Habitat, and Channel Stability

Throughout this section, physical habitat is described in conjunction with geomorphology. Physical habitat may be defined as the combined quality, quantity, and distribution of instream, riparian, and watershed characteristics that influence aquatic community structure and function. The following is a list of physical habitat elements, all of which are influenced to some extent by geomorphology:

- Channel morphology, type, and stability
- Channel hydraulics
- Channel substrate sizes, sorting, and mobility
- Presence and heterogeneity of habitat units, patches, and refugia
- Retention and transport of organic inputs
- Riparian condition and connectivity including bank stability
- Disturbance regime
- Human alterations and structural features such as armoring, channelization, or damming

The volume, quality, and disturbance patterns of instream habitat are constrained by the physical characteristics of a stream channel (discharge, velocity, width, depth, and shape). Factors at smaller scales also influence habitat features given the interaction of sedimentation processes with channel features such as vegetation, large woody debris, bedrock outcrops, bed and bank material, and bedforms (Jacobson *et al.*, 2001). Sediment deposition can potentially smother larger substrate and affect fish spawning and habitat for benthic macroinvertebrates. Degradation and aggradation can also affect macroinvertebrate habitat as well as reduce the complexity of channel bed sediments and structural elements for fish cover.

Furthermore, an understanding of channel equilibrium and the temporal stability of a channel are necessary to evaluate trends in stream communities (Jacobson *et al.*, 2001). Equilibrium as applied to channel stability can be defined in several ways, each definition relying on an implicit spatial and time scale (Schumm and Lichty, 1965). Table 4.42 presents several definitions of channel stability at the reach scale. Fluvial systems are dynamic systems, which frequently adjust their forms to pass a range of flows of sediment and water (Knighton, 1998). Over relatively short time scales, such as those frequently dealt with in engineering, channels in equilibrium that are said to be stable may appear to be relatively static. However, over longer periods of time a channel will often approach different states of equilibrium through adjustments to channel geometry. The channel that appears static over the short term can be very dynamic over longer time frames.

Table 4.42: Definitions of channel stability.

Mackin (1948): "A graded stream is one in which, over a period of years, slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin. The graded system is a system in equilibrium."
Schumm (1977): "The stable channel is one that shows no progressive change in gradient, dimensions, and shape. Temporary changes occur during floods, but the stable channel, if the classification were not restricted to short segments of the river, would be identical to the graded stream as defined by Mackin (1948)."
Leopold and Bull (1979): "A graded stream is one in which, over a period of years, slope, velocity, depth, width, roughness, pattern and channel morphology mutually adjust to provide the power and efficiency necessary to transport the load supplied from the drainage basin without aggradation or degradation of the channels."
Rosgen (1996): "The ability of a stream, over time, in the present climate, to transport the flows and sediment from its watershed in such a manner that the stream maintains its dimension, pattern and profile without aggrading or degrading."
Biedenharn *et al.* (1997): "In summary, a stable river, from a geomorphic perspective, is one that has adjusted its width, depth, and slope such that there is no significant aggradation or degradation of the stream bed or significant plan form changes (meandering to braided, etc.) within the engineering time frame (generally less than about 50 years)."

4.7.3.1 Qualitative Response and Channel Evolution

Equilibrium concepts from fluvial geomorphology are invoked throughout this section in examining the qualitative response of channels to changes in flows of water and sediment. Lane (1955) examined river morphology in terms of water discharge (Q), slope (S), sediment discharge (Q_s), and grain size (d_s) and related these factors in the following proportionality:

$$Q \cdot S \propto Q_s \cdot d_s$$

This relationship allows one to make qualitative predictions about how a channel will respond to changes in any one of these parameters. For example, if the sediment load to a channel decreases due to a reservoir and the grain size and water discharge remain constant, slope must correspondingly decrease. Thus, incision occurs as the channel erodes its bed to decrease the slope. Conversely, should the sediment load to a channel reach increase with water discharge and grain size remaining unchanged, slope must increase in the form of aggradation.

Several incised tributaries in the Eagle River watershed, particularly below Wolcott, are discussed below. Schumm *et al.* (1984) developed a channel evolution model to describe the channel incision sequence (Figure 4.101). The model has been successfully applied in geomorphic assessment studies in a variety of contexts. When sediment transport capacity exceeds the sediment supplied to the channel, erosion of the bed or banks occurs, depending on the relative resistance to erosion between the bed material and bank material. If the bank material is cohesive and resistant to erosion, incision will occur. At a certain point, bank height may exceed a critical value for geotechnical failure and rapid widening of the channel will occur. Channel widening decreases the stream power available to move sediment and aggradation occurs. Eventually a new stream channel with an associated floodplain may form in the bottom of the old incised and widened channel (Harvey and Watson, 1986; Simon and Darby, 1997; Watson *et al.*, 2002).

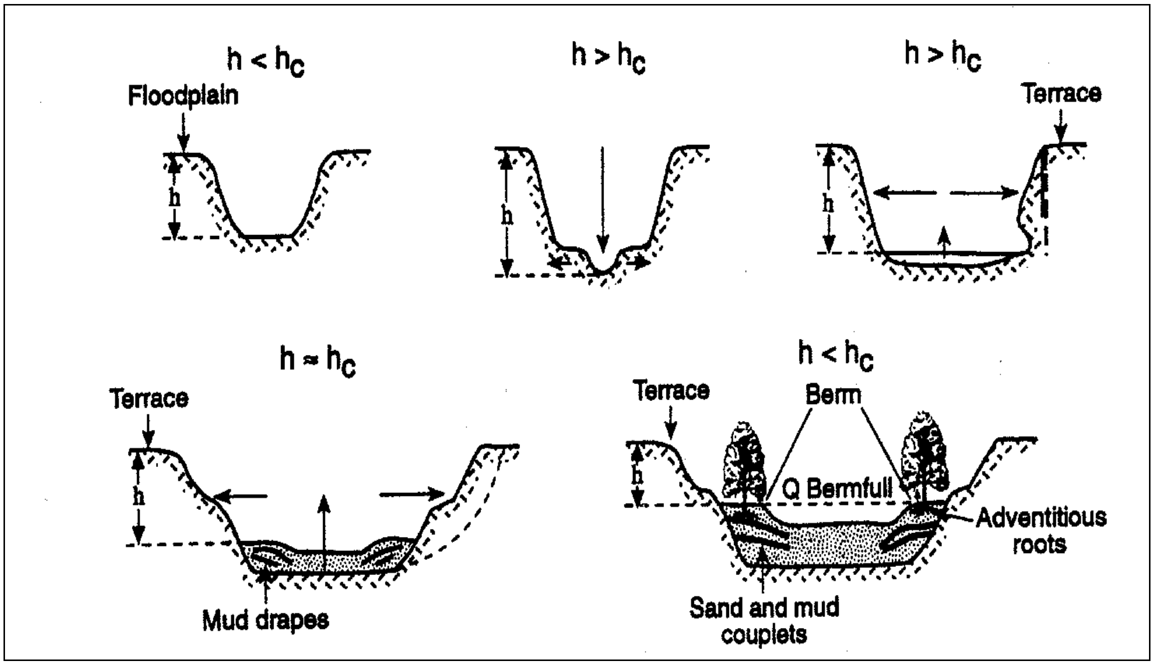


Figure 4.101: Channel evolution of an incising channel (after Schumm *et al.* (1984)). Bank height and critical bank height are denoted by h and h_c, respectively.

During incision, the floodplain, which can be defined as the active depositional surface adjoining a river channel that is constructed by overbank flows that occur in the current climatic regime (Dunne and Leopold, 1978), becomes hydrologically disconnected from the channel. This abandoned floodplain becomes a terrace. A number of locations throughout the Milk, Alkali, and Ute Creek watersheds reflect the different adjustment stages in this channel evolution model. Watson *et al.* (2002) discuss the importance of understanding where a channel is with respect to this evolution model to potential restoration design. The model essentially presents a connection between bank stability (geotechnical stability and failure) and hydraulic stability (aggradation and degradation). For an incised channel, the ideal restoration approach provides the quickest response towards geotechnically stable banks and sediment continuity. Meeting these criteria will reduce channel widening and deepening, minimize habitat loss, and reduce sediment input to the stream. The evolutionary stage of a channel dictates the type and extent of restoration efforts (local bank stabilization, grade control, flow control, etc.). In the case where banks are geotechnically unstable and failing and the channel bed is degrading, localized bank stability methods will need to be combined with grade control to address both problems and guide the stream towards stability. Potential channel restoration efforts in the Eagle along incising reaches should be conducted with these principles in mind; prior to design, it should be noted if the bed is actively incising and/or if the banks are geotechnically stable.

4.7.4 Methods

Thorne (2002) presents a component-based, hierarchical framework for geomorphic analysis of large watersheds. In this framework, various topics of analysis are divided into manageable, semi-independent components that can be studied simultaneously. These components help simplify the complexity involved in large fluvial systems. Thorne also recommends an analysis approach that begins by looking at the watershed from a general perspective in what he terms a “Catchment Baseline Survey.” Following this overview, the next phases of analysis, the “Fluvial Audit” and the “Geomorphic Dynamics Assessment,” explore the watershed in greater detail. In general, our approach to the Eagle River watershed followed a similar pattern. Our first task was to get a feel for the watershed by reviewing previous reports, available data including aerial photographs, and conducting a screening survey throughout the watershed to identify specific issues. Once this was accomplished, specific elements of the assessment were identified including hydraulic geometry, planform, and specific gauge analyses, cross-section and pebble count locations, and segments warranting additional field reconnaissance. These semi-independent components were then studied in more detail as described below.

Geomorphic analysis of the watershed was conducted using visual surveys and rapid assessments in the field supplemented with aerial photographs, cross-section surveys, pebble counts, USGS flow data and 9-207 forms, and other data sources. Field observations were made wherever access was possible. This includes all of the mainstem Eagle and the accessible reaches of major tributaries including: Gore Creek, Red Sandstone Creek, Homestake Creek, Turkey Creek, Cross Creek, Lake Creek, Squaw Creek, Milk Creek, Alkali Creek, Brush Creek, Eby Creek, and Gypsum Creek. Sites of particular interest were documented with photographs and field notes and located with a handheld GPS receiver. Observations in the field were based on identifying key elements of physical habitat and geomorphic condition including, but not limited to, the following: substrate size and distribution, embeddedness, width to depth ratios, cross sectional shape, habitat complexity, velocity to depth combinations, riparian vegetation with respect to shade and bank stability, woody debris, bank condition, floodplain connectivity, sediment deposition, channel planform, channel alteration, riparian zone width, mining impacts, and grazing impacts. A number of sources provide guidance in measuring these elements quantitatively and qualitatively with respect to rapid assessments of habitat, stream channel, and/or riparian condition (USEPA Rapid Bioassessment Protocols – Barbour *et al.*, 1999; Watershed Professionals Network, 1999; Platts *et al.*, 1983, 1987; NAWQA Protocols – Fitzpatrick *et al.*, 1998, USDA-NRCS Stream Visual Assessment – Newton *et al.*, 1998; Suren *et al.*, 1998). Although many of the aforementioned elements of habitat and geomorphology exist at the cross-section or pool-riffle scale, our main focus was to use observations to infer processes occurring over the reach to basin scale. Understanding these larger scale processes is essential to understanding the extent of influences that restoration and policy changes will have in the watershed. Field observation was primarily conducted on the ground. We did float the Eagle River from above Avon to the Hillcrest Drive bridge downstream of Edwards to examine how development in Avon and Edwards has affected the channel and riparian corridor through this reach and to inventory stormwater outfalls and other features. We also flew the watershed in a small aircraft to examine the drainage network and riparian corridors from a broader perspective and document areas of interest with photographs.

Beyond simply making observations, we conducted field measurements at locations of interest throughout the watershed. These measurements include cross sections through Eagle-Vail, Avon, Edwards, Red Cliff, and Camp Hale and Wolman pebble counts (Bunte and Abt, 2001; Wolman, 1954) at Camp Hale and Red Cliff. We were able to supplement our cross section data with data available from Eagle County and the Colorado Division of Wildlife. Eagle County provided us with a HEC-RAS model of the Eagle from Dotsero to Minturn, which includes 100 surveyed cross sections and 325 cross sections interpolated from 2-foot contour data available for the Eagle corridor. An unpublished report conducted for the Division of Wildlife provided seven cross sections in the Gypsum Ponds State Wildlife Area (SWA).

Field observations and measurements were supplemented with aerial photography available from 1998, 1964, and 1962. Aerial photographs from 1998 were obtained from Eagle County and extend along the mainstem Eagle River from Dotsero to Minturn, including a segment through Red Cliff, and along Gore Creek from the confluence with the Eagle to the confluence of Gore and Black Gore Creeks. The photographs also show the downstream reaches of tributaries such as Lake Creek, Squaw Creek, Brush Creek, and Gypsum Creek. The 1998 photographs were used to complement field observations to classify the Eagle using the classification proposed by Montgomery and Buffington (1997), identify reaches of channelization, identify sediment storage areas, locate structures and diversions, measure channel widths for hydraulic geometry analysis, quantify the geometry of lower Eagle meanders, identify riparian planting opportunities, identify bank stability issues, examine urban encroachment, and locate gravel mining along the floodplain. J.F. Sato and Associates provided aerial photographs from 1962 extending from Eagle-Vail to Minturn along the Eagle and from the confluence to Vail Pass along Gore Creek and Black Gore Creek. These photographs were compared to 1998 photographs to examine planform and land use changes of the Eagle and Gore Creek over time. The Colorado Department of Transportation provided aerial photographs from 1964 of the lower Eagle near Gypsum. These photographs were used to examine changes in meander geometry of the lower Eagle, especially in the Gypsum SWA.

Hydraulic geometry analyses required an estimate of the 1.5-year discharge ($Q_{1.5}$) at locations throughout the watershed. At gaged locations with sufficient period of record, $Q_{1.5}$ was estimated using Weibull plotting positions. To transfer these discharge estimates to ungaged sites, we used regional regression equations for Colorado that predict flood frequency and magnitude (Jennings *et al.*, 1993) based on a power function of drainage area and average basin slope. To use this equation for estimating $Q_{1.5}$, published exponents were used but the coefficients were scaled for use with the smaller discharge based on calibration using data at the nearest USGS gage. This same procedure was used to estimate $Q_{1.1}$, $Q_{1.3}$, $Q_{1.4}$, $Q_{1.7}$, and Q_2 in order to determine potential design flows for restoration work at the Edwards/Lake Creek segment.

The estimated values of $Q_{1.5}$ were used in conjunction with bankfull channel widths measured in the field, estimated from available cross section data, and/or measured from the 1998 aerial photographs to compare the Eagle to streams of a similar geomorphic type based on published hydraulic geometry relationships (Andrews, 1984, Hey and Thorne, 1986). Using the discharge estimates near Gypsum with estimates of valley slope from 2-foot contour data and a range of median grain sizes (D_{50}), the lower Eagle was plotted against data compiled by van den Berg (1995) to evaluate the risk of braiding. Radii of curvature for lower Eagle meanders were measured from the 1998 aerial photographs. The ratio of radius to channel width was calculated for each meander, the average of which was compared to data from Nanson and Hickin (1986) to predict meander migration rate.

Effective discharge (Andrews, 1980; Emmett and Wolman, 2001) was calculated at Red Cliff to illustrate the reduction in geomorphic effectiveness due to diversion and drought. The calculations were based on the surveyed cross section and Wolman pebble count done in Red Cliff. The relationship presented by Wilcock and Kenworthy (2002) was applied to estimate sediment transport. The Red Cliff gage was chosen for this analysis because it has a long period of record that extends prior to much of the upstream diversion. Because the Red Cliff gage is upstream of most of the major tributaries in the basin, the effect of diversion on the flow record is not masked by free-flowing, or nearly free-flowing tributaries. The findings of Webb *et al.* (2004) complicate the matter of estimating the geomorphic significance of diversion in the watershed. Results from dendrochronology suggest that 1906 to 1930, which contains the early period of record for the Red Cliff gage, was the highest period of runoff in 450 years (Stockton and Jacoby, 1976; Webb *et al.*, 2004) and that the current drought may be more severe than the largest-known drought in 500 years (Webb *et al.*, 2004).

We used GIS analysis based on the 10- and 30-m digital elevation models (DEMs) available for the watershed to estimate parameters such as drainage areas, channel slopes, valley slopes, and entrenchment. These parameters were used to predict stream classifications (Montgomery and Buffington, 1997; Watershed Professionals Network, 1999); 1.1-, 1.3-, 1.5-, 1.7-, and 2-year discharges; and stream power. We also extensively used GIS combined with Global Positioning System (GPS) points, other collected data, and available coverages to create maps of the watershed to illustrate points of discussion.

The effects of impacts on a watershed are often manifested in the form of aggradation or degradation. One method of identifying aggradation or degradation that can be used to supplement field observation is specific gage analysis. We conducted a specific gage analysis for 12 selected gages of interest throughout the watershed to look for evidence of aggradation or degradation. This analysis involved collecting independent data files of unit discharge and stage measurements from the USGS and matching the values by date and time of measurement. An average discharge or range of discharges was calculated from the matched data set and the stage corresponding to this discharge was plotted over time. Thus aggradation will appear as an upward trend in stage over time and degradation will appear as a downward trend in stage over time. Five sites were identified as potentially having significant aggradation or degradation at some point over the period of record. To evaluate whether the shifts in stage were real, we obtained the 9-207 rating forms from the USGS office in Grand Junction, Colorado, and examined them for datum shifts near the time of the shift in stage.

A number of medial bars, meander cutoffs, and diversions have been located from the 1998 aerial photography and are discussed below. To illustrate the distribution of bar formation, meander cutoffs, and diversions, observations were plotted over the aerial photographs and categorized using a GIS (Figure 4.102). Every bar, cutoff, and diversion along the Eagle is not discussed; however, the major points of interest have been geolocated with GPS and are referred to using river miles.

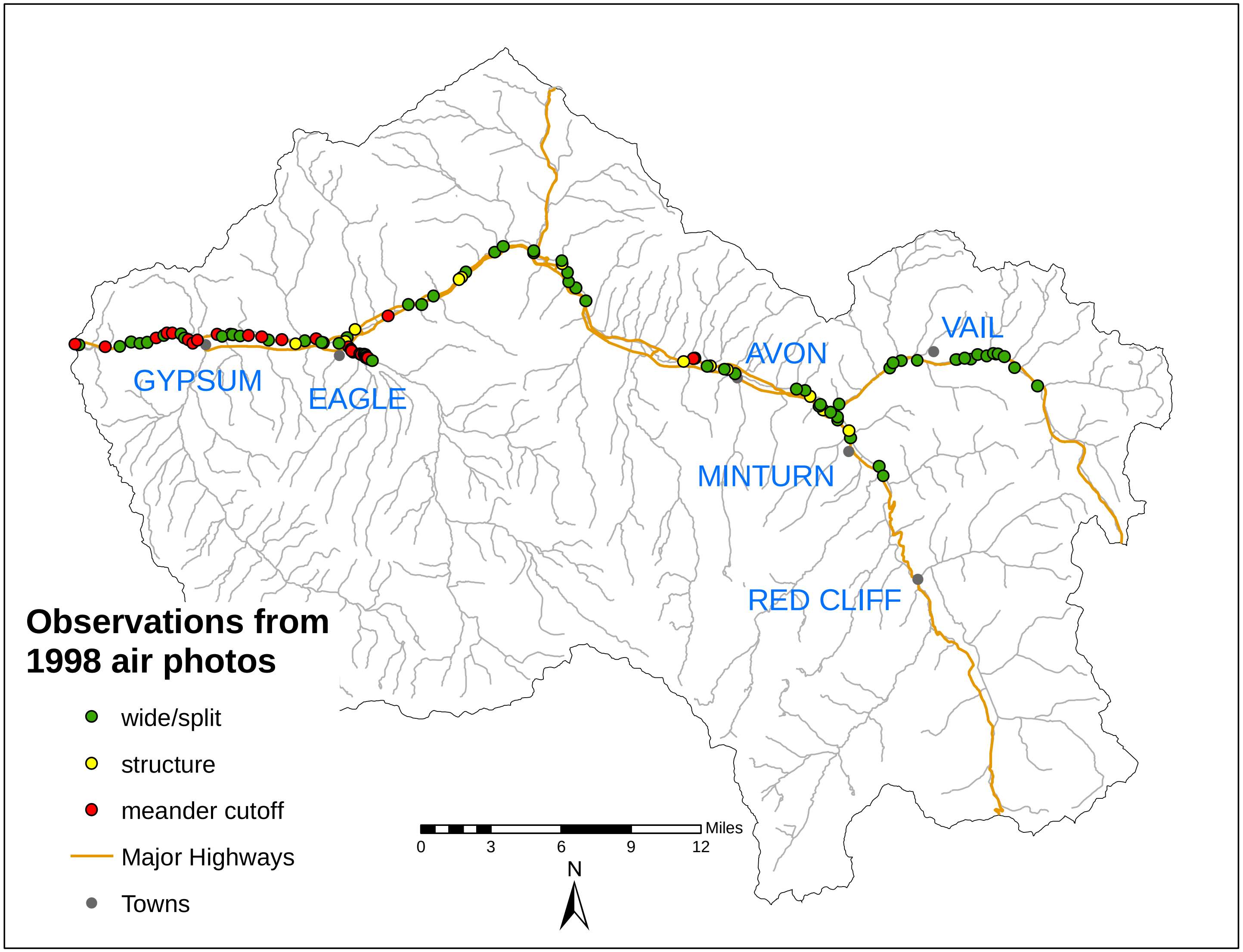


Figure 4.102: Categorized aerial photograph observations.

4.7.5 Main Stem Eagle River Survey

For the purpose of this assessment, the main stem Eagle River was divided into the following three segments: headwaters to Gore Creek, Gore Creek to Ute Creek near Wolcott, and Ute Creek to the confluence with the Colorado. This analysis was greatly enhanced by 1998 aerial photography obtained from Eagle County. This discussion frequently refers to specific locations on these photographs along the channel. These locations are identified by river mile (rm), with the convention of 0 rm located at the mouth of the Eagle at Dotsero.

4.7.5.1 Headwaters to Gore Creek

Of the three segments of the Eagle, this reach is the least developed. The main stem Eagle River forms at the South Fork and East Fork confluence near the south end of the Camp Hale site. From Tennessee Pass to the confluence, the South Fork is relatively free from impacts. Highway 24 and the railroad run along its entire length and encroach on the stream in several places. The main impact on the East Fork is Climax Mine at its headwaters (Figure 4.103). The combined effects of Eagle Park Reservoir, the Chalk Mountain Interceptor, and the Columbine Ditch alter flows into the East Fork.

Figure 4.103: Eagle Park Reservoir at the Climax Mine.

As the South Fork and East Fork of the Eagle reach the confluence, they enter the relatively flat valley known as Camp Hale. Before the construction of Camp Hale, almost five miles of the Eagle River meandered through the valley with a sinuosity of 2.0 and an average slope of 0.004. The current channel runs straight through the valley with a slope twice that of the historical channel, and half the channel length. The current channel is incised up to 15 ft and the instream habitat is generally degraded and homogenized. The channel cross section is trapezoidal in shape and is fairly consistent throughout the valley (Figure 4.104). The channel has remained stable in some reaches and has incised in others since its construction. One might expect the increase in stream power caused by doubling the slope of a channel to cause widespread instability as the channel attempts to balance its geometry and sediment transport; however, the Camp Hale channel consists of coarse, armored bed and bank material that is resistant to channel migration. Aside from channel stability, a major geomorphic issue at Camp Hale is the lack of a connected floodplain. Due to the incision of the channel, floodwaters do not spill out onto the floodplain. This lack of inundation has several geomorphic implications: water storage in the floodplain is greatly reduced, riparian vegetation needed for bank stability and habitat does not have the necessary available water, soils comprising the floodplain are not replenished with nutrients, and flood flows are conveyed more rapidly downstream. Specific habitat issues include: poor epifaunal substrate, poor range of velocity and depth combinations, a lack of pools associated with the low sinuosity, bank stability issues, and poor vegetation protection. A much more detailed description of geomorphic processes at Camp Hale and potential restoration alternatives for this site are provided in Appendix A.

Figure 4.104: Incised trapezoidal channel at Camp Hale.

Downstream of Camp Hale, the Eagle flows through the town of Red Cliff. The river is channelized through much of the town. Structures in Red Cliff are built immediately adjacent to the river leaving little room for channel adjustment. There are several places through Red Cliff and just upstream of Red Cliff where riparian vegetation is particularly sparse. These locations offer potential opportunities for stabilizing banks and providing shade and cover for fish. Substrate quality and habitat structure through Red Cliff is poor, providing little cover for fish. Turkey Creek and Homestake Creek enter the Eagle at Red Cliff, essentially doubling its flow.

Immediately downstream of Red Cliff, the Eagle enters a narrow canyon. Through the canyon, the river is confined on both banks by the steep valley walls and the railroad. The deeper pools associated with the confinement benefit trout habitat. The river has been channelized through the Eagle Mine facilities at Belden, as evidenced by the retaining walls in Figure 4.105. Channelization tends to reduce the spatial heterogeneity of habitats, which has been shown to be critical for fish populations (Schlosser, 1991). Although riparian vegetation is minimal through the canyon, the large variation in substrate size provides cover and a range of velocity/depth combinations.

Figure 4.105: Retaining walls along the banks of the Eagle River through Belden.

The major impact in this reach is metals loading from the Eagle Mine and adjacent sites. Piles of waste rock are evident throughout the canyon that can contribute metals to the Eagle from surface runoff. There is also the potential for waste rock to slough into the river should one or several of the mine cribbings fail. Other unaccounted-for sources of metals, such as fill material for the railroad grade on both sides of the river and scattered waste rock piles, also potentially contribute to toxic metals loading.

Once the Eagle exits the canyon, entrenchment of the river decreases. The valley widens, giving the river more opportunity to meander. Correspondingly, the channel slope decreases and the width to depth ratio increases. Between the exit of the canyon and Minturn, a connected floodplain has developed. The former site of the 'old' tailings pile, Bolt's Lake, and the consolidated tailings pile associated with the Eagle Mine cleanup are located on the left bank. This reach also flows through the Rex Flats area which is a well connected floodplain on the right bank with a relatively high water table associated with abrupt change in hydraulic gradient in this segment. The sediment transport capacity abruptly decreases through this reach resulting in aggradation and an increase in embeddedness. The embedded substrates serve as poor quality macroinvertebrate habitat.

Cross Creek and Two Elk Creek enter the Eagle before it flows through the Town of Minturn, where houses and apartments are located adjacent to the river. Minturn represents the beginning of the urbanized corridor of the Eagle. In 2003, Minturn and Ecological Resource Consultants began restoration efforts along a 0.8-mile reach through town to increase habitat features, reduce channel width, confine split flow into a single channel, and establish riparian vegetation (Figure 4.106).

Figure 4.106: Minturn restoration showing the reduction in channel width.

Below the town, the railroad yard confines the right bank and Highway 24 confines the left bank. Fill material used to construct the railroad yard and litter in the area are free to wash into the river; and gullies and erosion rills were observed along this section (Figure 4.107). Riprap has been used to stabilize the left bank along the highway (Figure 4.108). Along this reach, bank stability, bank vegetation protection, and riparian zone width are the key habitat issues.

Figure 4.107: One of the larger erosion features along the railroad yard downstream of Minturn.

Figure 4.108: Riprap and drainage outfall along Highway 24 downstream of Minturn.

Near the confluence with Gore Creek is a popular public access point along the Eagle at the U.S. Forest Service office. This reach is marked by lightly vegetated and eroding banks and homogenous substrate with little hydraulic diversity and habitat value. This location is an area where channel and riparian restoration could be effectively incorporated with a formalized access point so that habitat value is protected while still providing access to the river. However, water quality is a limiting factor in improving aquatic life and habitat in this reach. As the river approaches the I-70 bridge, it becomes more channelized with riprap along the banks. Gore Creek enters the Eagle at the I-70 bridge and marks the end of this upper segment of the main stem Eagle.

4.7.5.2 Gore Creek to Ute Creek

The Eagle doubles in flow again at the confluence with Gore Creek. This segment is characterized by development and encroachment from Eagle-Vail, Avon, Edwards, Highway 6, I-70, and the railroad. Aerial photography from 1962 extending from Gore Creek to Avon, obtained from J. F. Sato and Associates, indicates the drastic change in land use over the past 40 years (Figures 4.109 and 4.110). What was once primarily agricultural land is now mostly developed. Development has increased the percentage of impervious area adjacent to the channel, leading to a decrease in sediment input to the channel and an increase in the direct runoff from precipitation events (Figure 4.111).

Figure 4.109: Eagle-Vail in 1962.

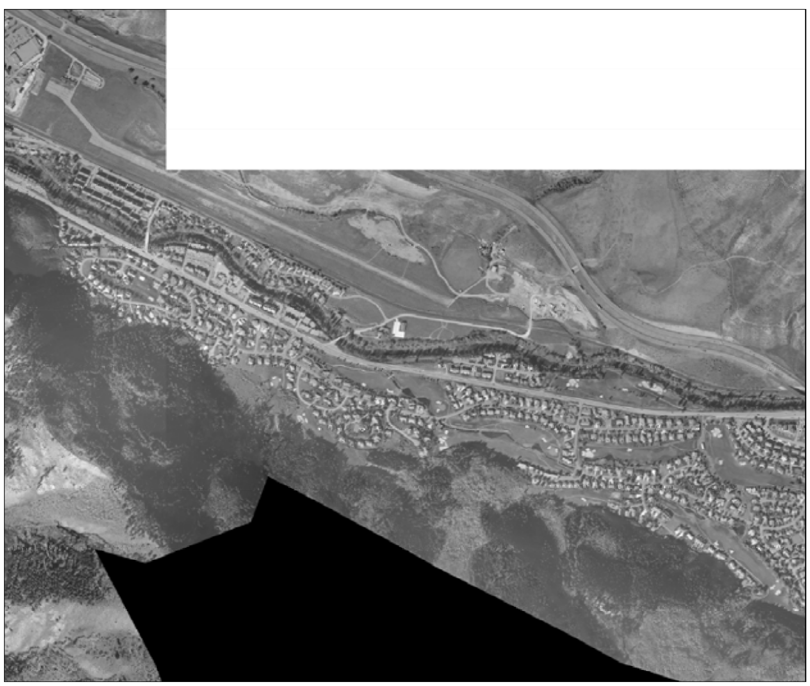


Figure 4.110: Eagle-Vail in 1998.

Figure 4.111: Construction in Eagle-Vail with poorly functioning silt fence.

Immediately downstream of the confluence with Gore Creek, the Eagle goes through Dowd's Chute, a narrow, steep segment where the river is constricted by the valley. Confinement of the river through Dowd's Chute is compounded by the railroad to the north and I-70 and Highway 6 to the south. Immediately below Dowd's Chute, the river becomes wide and shallow with a mid-channel bar and a diversion on the left bank (42.80 rm) (Figure 4.112). A cross section was measured at this location (Figures 4.113 and 4.114) with an estimated median grain size of the bed material of 350 mm and a slope of 0.03. There is another mid-channel bar upstream of the downstream railroad bridge (42.64 rm), with a wide reach located just below the bridge. Downstream of the railroad bridge is a heavily armored location where I-70 and Highway 6 encroach the river. There is another diversion at 41.84 rm on the left bank. From this point, the river enters Eagle-Vail where there are also a couple overly wide spots with mid-channel bars (41.49 rm and 41.09 rm). A cross section was measured in Eagle-Vail (Figures 4.115 and 4.116). We estimated the median grain size of the bed material to be 250 mm and the slope to be 0.02. A narrow floodplain (less than 15-ft wide) has developed between the terraces at this location.

Figure 4.112: Diversion at the bottom of Dowd's Chute and the upstream end of a mid-channel bar.

Figure 4.113: Cross section XS-1 looking from left bank to right bank.

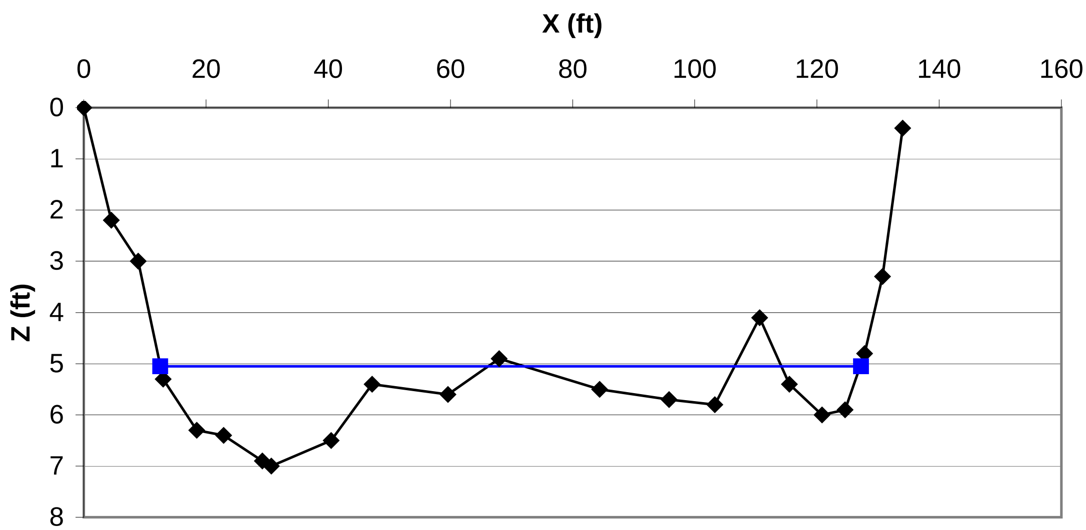


Figure 4.114: Measured cross section XS-1 (looking downstream – river left is at X = 0).

Figure 4.115: Cross section XS-2 at Eagle-Vail looking downstream.

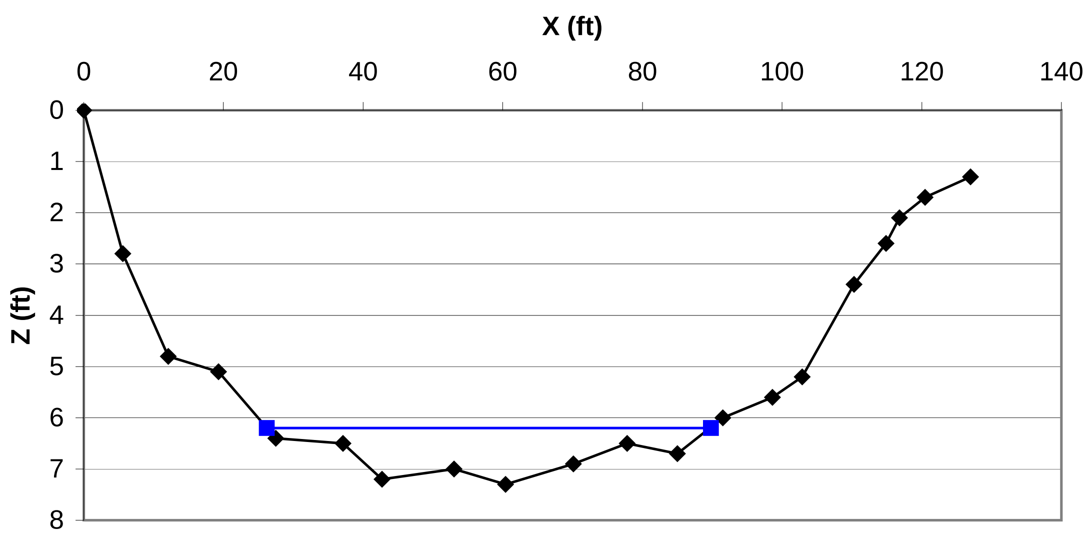


Figure 4.116: Measured cross section XS-2 (looking downstream – river left is at X = 0).

Through Eagle-Vail to Edwards, the Eagle River is fairly consistent in bed character in that the river primarily falls under plane-bed classification (Montgomery and Buffington, 1997). There is a diversion on the right bank at 39.40 rm, at 37.87rm on the left bank opposite of the Avon wastewater treatment plant, and at 37.02 rm on the right bank at Arrowhead Golf Course. Throughout this stretch, there are several overly wide sections where mid-channel bars have formed (38.22 rm, 37.72 rm, 36.88 rm – wide only, 36.13 rm, 35.66 rm, and 34.57 rm). The bar at 36.13rm is a chute cutoff along the Arrowhead golf course (Figure 4.117). The bar at 37.72 rm is a classic example of aggradation caused by a downstream constriction (Figure 4.118). In this case, a dilapidated bridge causes the constriction. The bridge has since been removed, but the constriction and piling remain. We measured a cross section across this bar (Figure 4.119) and estimated a median grain size of the bed material of 120 mm and a slope of 0.03 to 0.04. The plot of the cross section illustrates the mid-channel bar and lack of floodplain. We measured another cross section in Avon approximately 600 ft downstream of XS-2 (Figures 4.120 and 4.121) with an estimated median grain size of the bed material of 250 mm and slope of 0.02. Of the four surveyed cross sections, this section had the most defined floodplain within the bounds of the terraces.

Figure 4.117: Chute cutoff at Arrowhead golf course.

Figure 4.118: Mid-channel aggradation and divergent flow upstream of an old bridge piling at Avon (XS-3, looking upstream).

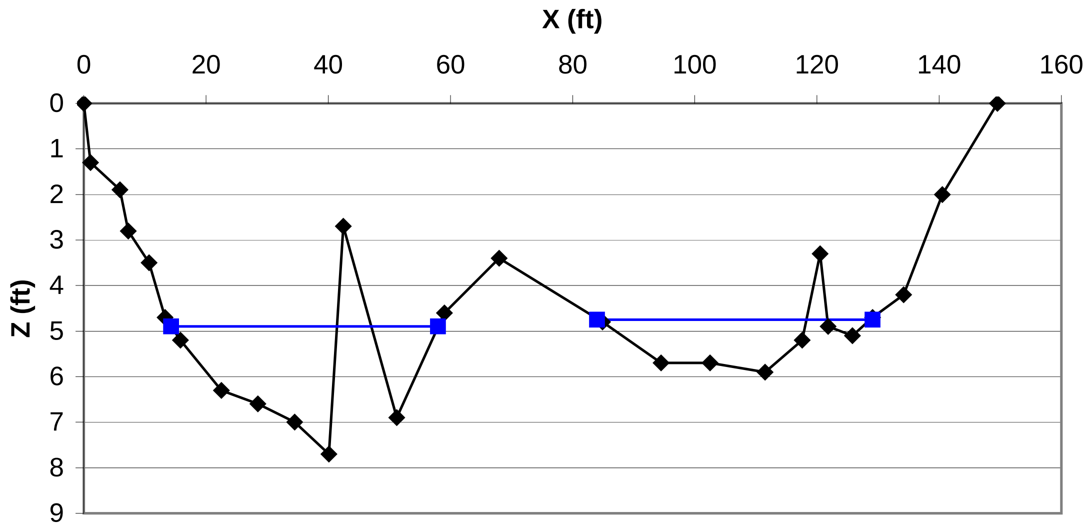


Figure 4.119: Measured cross section XS-3 (looking downstream – river left is at X = 0).

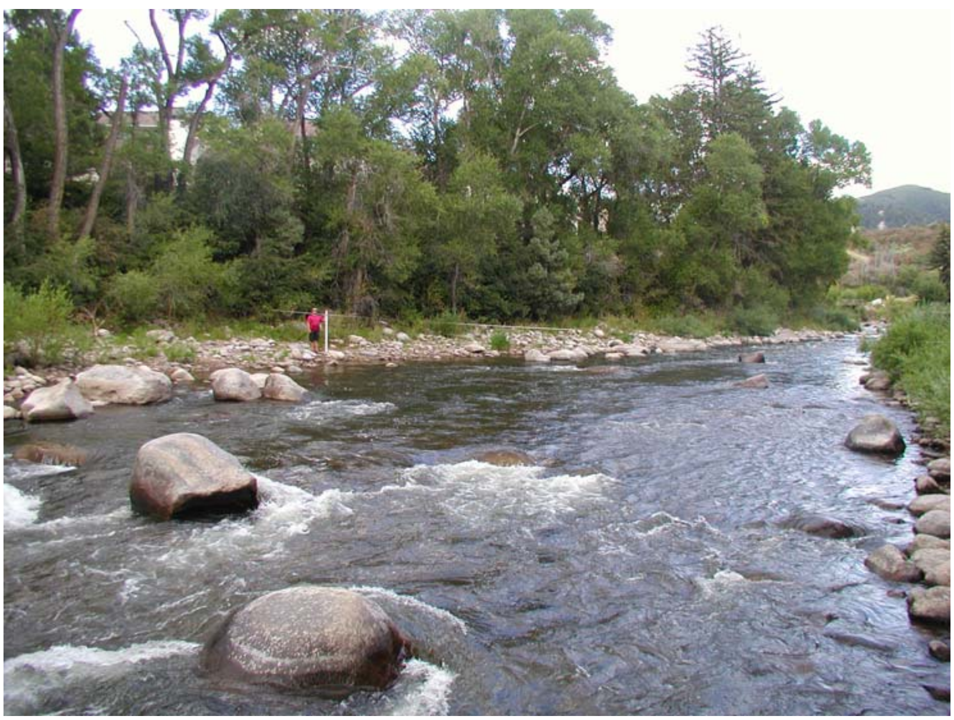


Figure 4.120: Cross section XS-4 in Avon looking upstream.

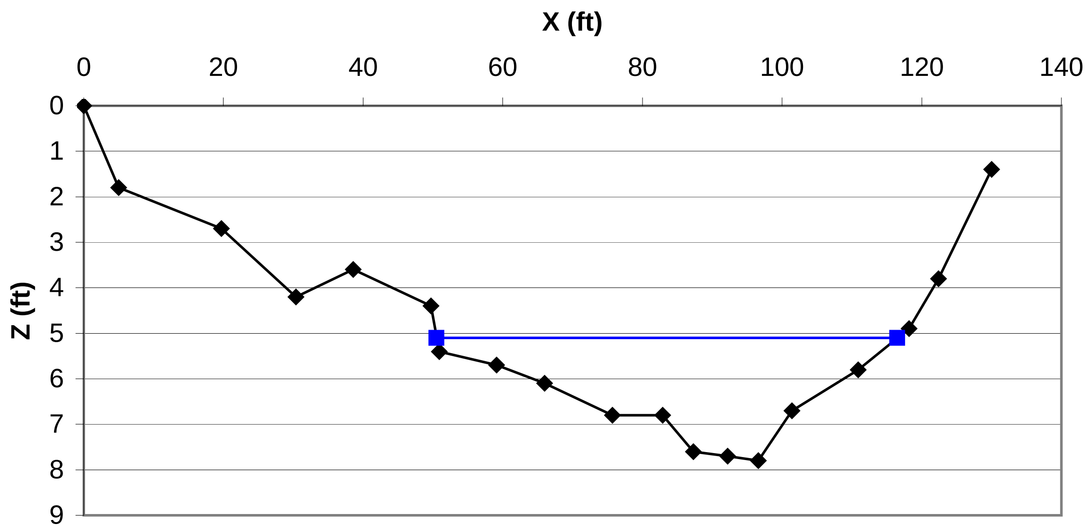


Figure 4.121: Measured cross section XS-4 (looking downstream – river left is at X = 0).

Much of the river through this reach is confined with structures within 40 ft of the channel banks. The river is also entrenched through most of the reach with no occurrences of an extensive connected floodplain. The areas of floodplain that do exist are narrow, as the river is bound by terraces. Despite the confinement and development, riparian vegetation still exists fairly consistently through this reach. The riparian zone is narrow, but trees along the banks provide shade. The variety of substrate sizes benefits the habitat through this developed reach.

Downstream of Edwards, the Eagle enters the Edwards/Lake Creek segment. Habitat concerns through this segment include: poor substrate quality, embeddedness of substrates, aggradation, bank stability concerns, and a lack of riparian bank protection. The present channel is wide, with aggradation at the upstream end of the reach. We measured one section that is 278 ft across with a 72-ft wide mid-channel bar. The average depth of this section at the flow in early August was 1.4 ft. Another section near the upstream end of the site was measured from the 1998 aerial photographs at 368 ft with a 295-ft mid channel bar. The banks through much of the site undercut and show signs of cantilever and slab failure (Figure 4.122).

Figure 4.122: Undercut banks through the Edwards/Lake Creek segment.

At the upstream end, the valley abruptly widens and the slope changes over a short distance. One possible explanation for this flat valley involves a localized area of uplift at the downstream end of the valley. Uplift at this end of the valley would reduce the valley slope, essentially forcing the Eagle into a backwater profile. Folded and faulted strata at the downstream end of the valley support this explanation. A steep bedrock control zone is located towards the downstream end of the site (32.25 rm to 32.12 rm), possibly caused by a fault intersecting the valley, where the flow has been locally confined. The abrupt changes in valley slope and backwater effects behind the bedrock control zone are associated with widespread aggradation. Accompanying the abrupt slope change is a significant change in sediment transport capacity. Thus, there must be a transition zone where mobilized sediment drops out of the flow, as is currently evident in the aggradation at the upstream end (Figure 4.123). The confluence of Lake Creek with the Eagle is located just downstream of this transition zone (32.91 rm). Gravel mining is active in this segment but is limited to the floodplain and does not affect bedload transport to downstream segments (Figure 4.124).

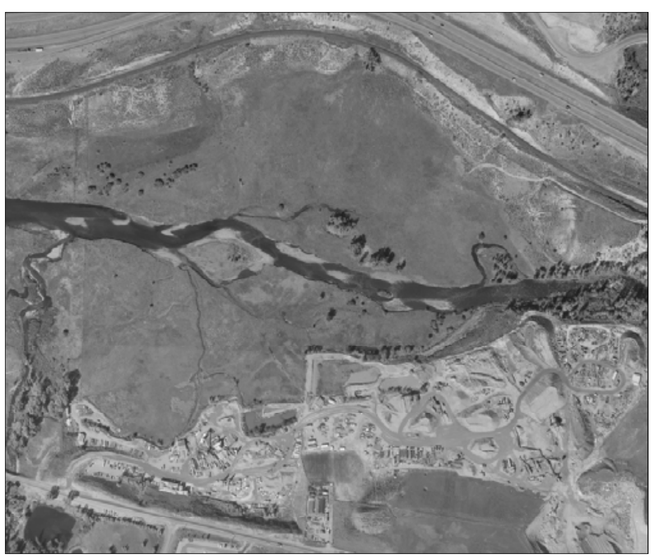


Figure 4.123: Sediment transport transition zone at the upstream end of the Edwards/Lake Creek segment.

Figure 4.124: Gravel mine at the upstream end of the Edwards/Lake Creek segment.

This valley has been identified as a candidate restoration project that would involve narrowing the channel and improving habitat, reestablishing the riparian vegetation that was once removed, and enhancing public access. This project must be implemented in conjunction with future development and has a high potential of restoring depth and refugia for fish habitat, reducing temperature increases through the site, and enhancing public access to the river. A detailed discussion of potential restoration of the Edwards/Lake Creek segment is provided in Appendix A.

Downstream of this valley, the Eagle is free of urban encroachment until Wolcott; however, Highway 6, I-70, and the railroad still parallel the river. Squaw Creek enters the Eagle at 31.16 rm. This stretch contains the Cordillera and Eagle Springs golf course properties. These two properties are considered high quality trout habitat. A healthy riparian zone and high quality substrate benefit habitat in this segment. The channel form and substrate sizes result in a variety of velocity/depth combinations. From the Edwards/Lake Creek segment to Ute Creek near Wolcott, the river begins to display a meandering planform with more pool-riffle sequences. From 31.53 rm to 31.31 rm, the river is narrow and channelized; immediately downstream of this stretch is a localized area of braiding with multiple lateral and mid-channel vegetated bars. At 30.65 rm and 27.54 rm, there are mid-channel bars with possible diversions on the left bank. There is a large mid-channel bar that is heavily vegetated at 29.70 rm. At 28.89 rm, there is a debris obstruction with aggradation upstream (Figure 4.125). Finally, at 27.41 rm, Ute Creek enters the Eagle with a mid-channel bar at the confluence.

Figure 4.125: Constriction and associated aggradation at 28.89 rm.

4.7.5.3 Ute Creek to Dotsero

The morphology of the downstream segment of the Eagle River main stem is plane-bed and pool-riffle. Here, the Eagle is freer to meander as urban encroachment is primarily limited to the towns of Eagle and Gypsum. Milk, Alkali, and Ute Creeks all enter the river near Wolcott. These tributaries can dramatically increase the suspended sediment concentration in the river during spring runoff or summer thunderstorms, which reduces water quality and fish habitat (Figure 4.126). At the upstream end of this reach is a 100-m bank failure on the right bank (Figure 4.127).

Figure 4.126: The Eagle River at Milk Creek immediately after a summer thunderstorm.

Figure 4.127: Bank failure upstream of Wolcott.

Between Wolcott and Eagle, the river undergoes a transition from a plane-bed morphology (a plane bed lacks alternating bars and periodic bed forms in the vertical dimension) to a pool-riffle morphology. There are a number of mid-channel bars in this reach as the river has more room to make lateral adjustments (25.96 rm, 25.85 rm, 24.26 rm, 23.81 rm, 22.16 rm, 21.16 rm, 19.55 rm, 19.36 rm, 18.92 rm, and 17.90 rm). Two of the mid-channel bars through this reach (19.55 rm, 19.36 rm, and 17.90 rm) are chute cutoffs of old meanders. At 21.82 rm, there is a large split in the flow with a diversion on the left bank. There is another split and diversion on the right bank at 21.65 rm. The increasing number of mid-channel bars indicates a tendency towards braiding in this lower segment. Where mid-channel bars have formed, flow in the wider channel does not have sufficient stream power to transport the supply of sediment and material is deposited in the channel. With some exceptions, the riparian zone in this downstream segment is typically narrow increasingly influenced by agricultural land uses. This stretch also contains the Diamond S Ranch conservation easement, a 1,450-acre easement donated to the Eagle Valley Land Trust for the preservation of open lands for deer and elk habitat.

At the Town of Eagle, the river is once again confined, but not to the same extent as in Eagle-Vail, Avon, and Edwards, as evidenced by the sinuous planform at the downstream end of the developed corridor. At the Eagle rest area (16.21 rm), a bend in the river is attacking the road and is stabilized by riprap. There is little vegetation at this site; this area would be a good opportunity to use stone toe protection with a softer, vegetated treatment on the bank. This sort of treatment is more aesthetically pleasing and provides bank protection while maintaining some of the ecological functions of the bank. Downstream of this site, extensive riprap is evident from 15.98 rm to 15.90 rm. A mid-channel bar followed by a straight, channelized reach is located from 15.59 rm to 15.45 rm. At 15.32 rm, there is an extensive mid-channel bar with a possible diversion. Just downstream of this bar, Brush Creek enters the Eagle at 15.09 rm.

Several gravel mines are located between Eagle and Gypsum. Gravel mines are of particular concern to fluvial geomorphology; similar to the Eagle at the Edwards/Lake Creek segment, should the river migrate and capture one of these mines, the shape and character of the channel will be greatly altered. Two possible diversions are evident between Eagle and Gypsum: one on the right bank at 14.36 rm and one on the left bank at 13.05 rm. At 11.33 rm, a meander is migrating towards the north and has been armored with riprap. From 10.97 rm to 10.80 rm, the right bank has been armored to protect I-70. At 10.83 rm, there is a contraction that might be an old attempt at grade control. Another structure that appears to be emplaced grade control is located at 9.50 rm.

Between Eagle and Gypsum, the river completes its transition from a plane-bed river to a pool-riffle river. The sinuosity of the Eagle from Eagle to Gypsum is 1.26. Downstream of Eagle, the river shows a trend towards braiding, as evident by the numerous mid-channel bars, lateral bars, and chute cutoffs (14.34 rm, 14.04 rm, 13.54 rm, 12.44 rm, 11.78 rm, 11.33 rm, 11.08 rm, 10.57 rm, 9.92 rm, and 9.60 rm). Near 10.72 rm, there is an extensive area of braiding and meander cutoffs. At 9.60 rm, the Eagle enters the Gypsum Ponds State Wildlife Area (SWA). The river through this stretch is wide and braided (Figure 4.128). The average cross-sectional width at a discharge of close to 4,100 cfs of the 7 cross sections presented in the CDOW report (Section A.3 in Appendix A) is 252 ft with a range from 122 ft to 375 ft. One of these sections indicated 15 ft of bank erosion from runoff in 2003. Figures 4.129 and 4.130 show a segment of the SWA in 1964 as compared to the same segment in 1998, respectively.

Figure 4.128: Braiding at the Gypsum Ponds SWA.

Figure 4.129: A segment of the Eagle River in 1964 through what is now the Gypsum Ponds SWA.

Figure 4.130: The same segment of the Eagle River in 1998.

Construction of I-70 has truncated several of the meanders from upstream of the Wildlife Area to downstream of the town of Gypsum. The squared-off meanders force the river into bends that are too tight, which can lead to chute cutoffs. The SWA has an excellent example of a chute cutoff at one of these squared-off meanders (Figure 4.131). The SWA is a potential area for land conservation and restoration work. This project is discussed in detail in Appendix A.

Figure 4.131: Large chute cutoff at Gypsum Ponds SWA.

The town of Gypsum encroaches on the Eagle downstream of the Wildlife Area. Some of the newer housing developments towards the downstream end of town are built on terraces directly adjacent to the river (Figure 4.132). Gypsum Creek enters the Eagle in the middle of town at 7.95 rm and is the final major tributary in this segment of the river.

Figure 4.132: Homes at Gypsum built on terraces near banks.

Between Gypsum and the Dotsero, the sinuosity of the river increases to 1.44. Bar formation and meander cutoffs are extensive in this stretch, further indicating a tendency towards braiding. The major instances are located at 7.71 rm, 7.14 rm, 6.08 rm, 5.82 rm, 5.49 rm, 4.75 rm, 3.13 rm, 2.42 rm, 1.74 rm, 1.00 rm, 0.80 rm, and 0.22 rm. Meanders have been truncated by I-70 at 5.00 rm, 4.28 rm, and 2.92 rm. The outsides of bends that threaten Highway 6 and I-70 have been armored. Vegetation from Gypsum to Dotsero is sparse, primarily consisting of sagebrush. Tamarisk is working its way up the lower river, with the greatest concentration being downstream of Gypsum. Bank stability and embeddedness are other habitat concerns in this downstream reach. At Dotsero, the Eagle River meets the Colorado River (Figure 4.133).

Figure 4.133: The confluence of the Eagle with the Colorado at Dotsero.

4.7.5.4 Major Tributaries to the Eagle River

In assessing the geomorphology and physical habitat of tributaries of the Eagle River, the intensity of the field effort was by necessity proportionate with the degree of human influence. Both current influences and areas thought to be potentially influenced by historical legacy effects were given highest priority for field reconnaissance. Accessibility was a limiting factor in assessing smaller tributaries, especially in remote areas not accessible by vehicle. Major tributaries (Turkey Creek, Homestake Creek, Cross Creek, Gore Creek, Red Sandstone Creek, Lake Creek, Squaw Creek, Milk Creek, Alkali Creek, Eby Creek, Brush Creek, Gypsum Creek) were examined to the extent that accessibility would allow. A common thread of all of the tributaries to the Eagle, with the exceptions of Homestake, Milk, and Alkali Creeks, is the tendency for higher quality habitat with increasing distance from the Eagle valley. Degraded habitat in the watershed occurs primarily in areas of greatest development concentrated along the Eagle River.

A general summary of tributary impacts identified during field reconnaissance is provided in Table 4.43.

Table 4.43: Summary of tributary impacts identified during field reconnaissance and geomorphic assessment.

Tributary Segment	System-Level Instability	Channel-ization	Excessive Width-Depth Ratio	Poor Physical Habitat	Fine Sediment Source or Storage	Medial Bars / Braiding Tendency	Peak Flow Reduction	Dis-connected Floodplain	Extensive Encroachment and/or Riparian Vegetation Removal
Turkey Creek - upper									
Turkey Creek - lower		✓							✓
Homestake Creek							✓		
Cross Creek									
Gore Creek above Black Gore									
Gore Creek between Black Gore and Vail Golf Club			✓			✓	✓		
Gore Creek from Vail Golf Club to Eagle River		✓					✓	✓	✓
Black Gore Creek	✓			✓	✓		✓		
Red Sandstone Creek					✓				✓
Lake Creek - upper, East, West									
Lake Creek - lower		✓				✓			✓
Squaw Creek - upper									
Squaw Creek - lower				✓	✓				✓
Milk Creek - upper									
Milk Creek- lower	✓			✓	✓			✓	✓
Alkali Creek	✓			✓	✓			✓	✓
Ute Creek	✓			✓	✓			✓	✓
Eby Creek				✓	✓				✓
Brush Creek - upper, East, West									
Brush Creek - lower	✓			✓					✓
Gypsum Creek - upper									
Gypsum Creek - lower		✓		✓				✓	✓

4.7.5.5 Turkey Creek

Turkey Creek enters the Eagle River at Red Cliff. The downstream end of the creek is channelized where it flows through Red Cliff. Through Red Cliff, the substrate is homogenous, providing little habitat value. The creek also lacks a healthy riparian zone through town. Upstream of Red Cliff, the primary impact is from the forest road that runs along its length. Turkey Creek also provides water for the town of Red Cliff (Figure 4.134).

Figure 4.134: Municipal diversion at Red Cliff on Turkey Creek.

4.7.5.6 Homestake Creek

Aside from Homestake Reservoir, Homestake Creek is fairly unaltered along most of its length. The only major development along its length is Highway 24 at the downstream end and the unpaved forest road that leads to Homestake Reservoir. There are also a couple ranches located downstream of the reservoir. The primary geomorphic issue along Homestake Creek is the alteration of the flow regime. Historic peak flows have been reduced to less than half of historic values. As discussed later in this chapter, reducing peak flows can have important geomorphic effects. As a result of this reduction in flood peaks, the effectiveness of Homestake Creek in transporting sediment and the average extent of floodplain inundation have been reduced. Homestake Creek is generally characterized as having high quality substrates and good riparian protection. Wetlands exist along Highway 24 upstream of the steep downstream terminus of the creek.

4.7.5.7 Cross Creek

For most of its length, Cross Creek flows through the Holy Cross Wilderness Area and consists of high quality habitat. The stream offers excellent examples of highly functional riparian wetlands (see Figure 4.135). We visited several of these wetlands that were accessible from the adjacent hiking trail. Extensive beaver activity was observed along Cross Creek with the resulting ponds acting as sediment storage areas. According to the Colorado Natural Heritage Program (Armstrong, 2000), the Cross Creek drainage was identified as a Potential Conservation Area for the occurrence of genetically pure populations of Colorado River Cutthroat, Peregrine Falcon, northern twayblade, and high quality riparian forests and wetlands. CNHP identified a number of sensitive plant communities, all of which occur in areas with subtle geomorphic differences in valley and channel type. Cross Creek offers diverse geomorphic settings, from broad flat valleys with extensive wetlands to narrow steep valleys with “pocket water” fish habitat. Except near the confluence with the Eagle, there is no development along its entire length. Lower Cross Creek flows through areas impacted by mine tailings and this segment has been placed on the 303(d) list due to impairment by metals. The broad floodplain area of Maloit Park has been the focus of remediation activities and re-vegetation efforts as part of the Eagle Mine cleanup.

Figure 4.135: Well-connected floodplain wetlands along Cross Creek.

4.7.5.8 Gore Creek and Black Gore Creek

Gore Creek below the confluence with Black Gore Creek and Black Gore Creek are under significant constraint from I-70 and the town of Vail. A major issue associated with Black Gore Creek is the well-documented problem of traction sand from Vail Pass (Figure 4.136). Large amounts of sand enter the channel with runoff from I-70. Gore Creek east of Vail and through East Vail has a flatter slope than through West Vail. As evidenced by the extensive bar formation (Figure 4.137), Gore Creek east of Vail is more capacity limited than through Vail and West Vail. This capacity limitation indicates that the addition of more sediment in the form of traction sand could cause a more significant geomorphic response in terms of aggradation, habitat loss, and other morphologic change along Gore Creek east of Vail. A slug of traction sand transported through Vail has a higher potential to flush through the system due to the greater transport capacity associated with the steeper slope.

Figure 4.136: Sediment basins along Vail Pass for trapping traction sand.

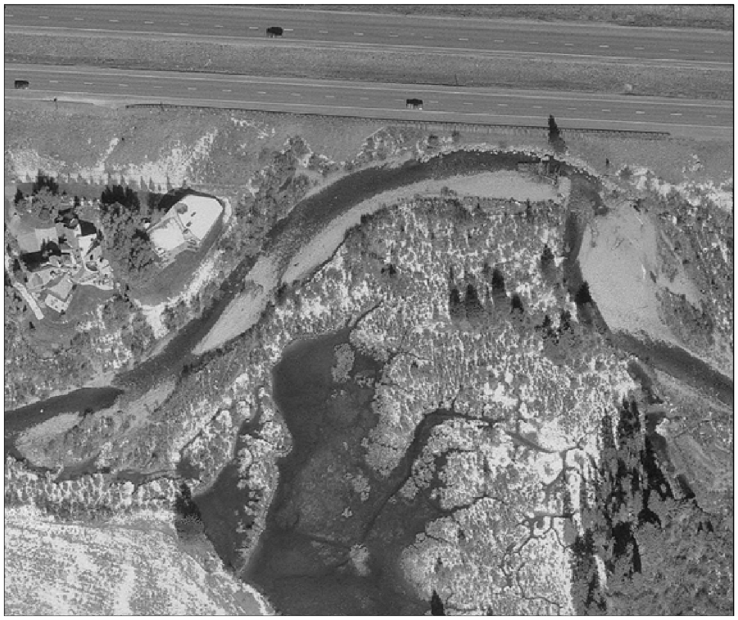


Figure 4.137: Bar formation and aggradation along Gore Creek near East Vail.

Residential development in Vail encroaches the length of Gore Creek. Based on comparisons between aerial photographs from 1998 and 1962, the planform of much of Gore Creek today is similar to its planform in 1962 (Figures 4.138 and 4.139). The present channel, however, is no longer free to meander. Because of the development, the riparian zone is narrow. Gore Creek through Vail does, however, consist of high quality substrates. A few sections of Gore Creek have been channelized, such as through the Vail Golf Club and downstream of West Vail.

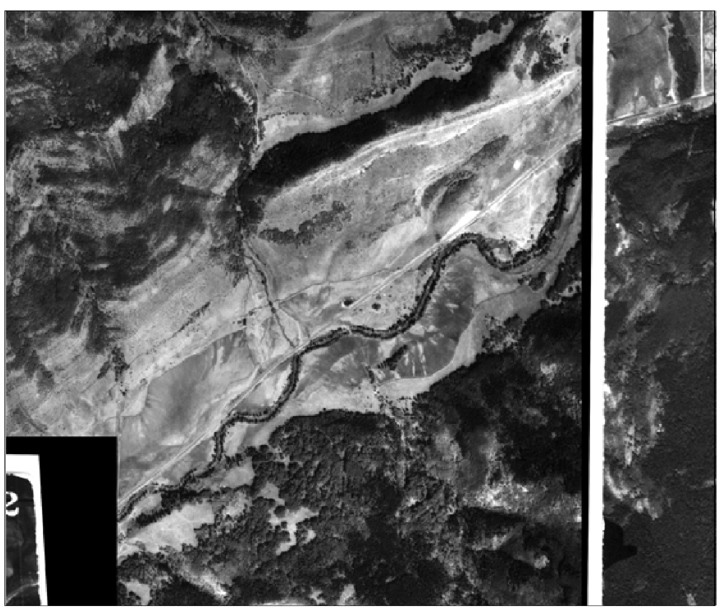


Figure 4.138: Selected reach of Gore Creek in 1962 showing a similar planform to Gore Creek in 1998.

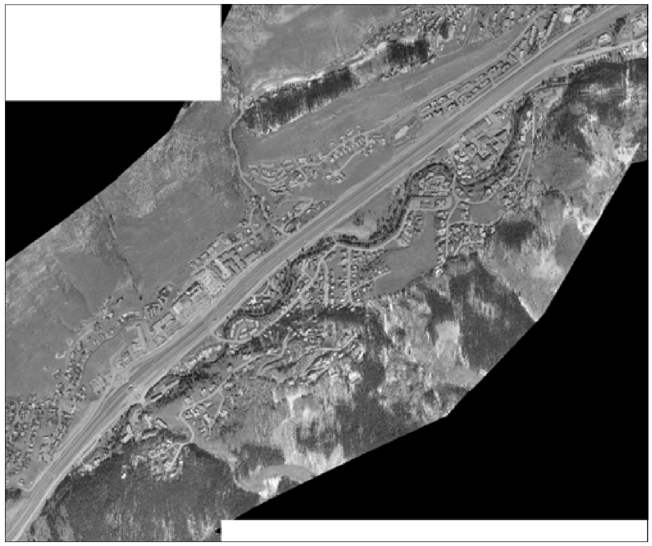


Figure 4.139: Selected reach of Gore Creek in 1998 showing a similar planform to Gore Creek in 1962.

4.7.5.9 Red Sandstone Creek

Red Sandstone Creek is a tributary of Gore Creek from the north (Figure 4.140). Forest roads adjacent to the stream and historic logging are the main impacts to the stream. Both of these impacts have the potential to increase sediment input into the channel. Similar yet more extensive effects from logging roads can be found along Mill Creek, which is a tributary to Gore Creek on the opposite side of the Vail Valley.

Figure 4.140: Red Sandstone Creek showing a forest road along the left bank.

4.7.5.10 Lake Creek

Lake Creek enters the Eagle at the Edwards/Lake Creek segment described above and has little to no public access along the lower part of the stream (Figure 4.141). There are numerous private ranches and homes along the lower segment of the stream; the road that follows the valley is on the opposite side of the valley from the stream, thereby limiting visual assessment of the stream. From what can be seen from the 1998 aerial photographs and Highway 6, this lower segment has not undergone much channelization but, due to the proximity of structures, is not free to migrate within the floodplain. There are still dense stands of cottonwoods along the banks to provide shade for fish. Downstream of the ranches, Lake Creek is channelized as it passes under Highway 6 and enters the Edwards/Lake Creek segment. At the confluence with the Eagle, the stream displays extensive lateral and mid-channel bars. Upper Lake Creek flows through the White River National Forest and the Holy Cross Wilderness Area. A population of Colorado River Cutthroat trout has been identified in East Lake Creek (Armstrong, 2000).

Figure 4.141: Downstream segment of Lake Creek photographed from Highway 6.

4.7.5.11 Squaw Creek

Squaw Creek enters the Eagle west of Edwards. The lower portion of the stream is private as it runs through Cordillera property. This part of the stream is vertically stabilized due to grade control at several culverts (Figures 4.142, 4.143, and 4.144) and displays the effects of livestock grazing (Figure 4.145). Riparian vegetation through this portion is generally sparse. The upper end of Squaw Creek flows through the White River National Forest and the Holy Cross Wilderness Area. Topographic maps indicate the presence of logging roads in the headwaters of the subbasin, but the condition and sediment production potential of the roads were not assessed.

Figure 4.142: Downstream culvert on Squaw Creek.

Figure 4.143: Middle culvert on Squaw Creek.

Figure 4.144: Upstream culvert on Squaw Creek.

Figure 4.145: Grazing impacts along Squaw Creek.

4.7.5.12 Milk/Alkali/Ute Creeks

Sedimentation problems associated with Milk, Alkali, and Ute Creeks are well known by the angling community in the watershed because suspended sediment and turbidity from these tributaries dramatically limit the coldwater fishery of the Eagle River below Wolcott. These streams input large amounts of fine sediment into the Eagle during both spring runoff and summer thunderstorm events. The geology of the area is dominated by Pierre shale, Niobrara formation (calcareous shales and marly limestone), and Benton shale. These tributaries probably delivered relatively high sediment loads prior to settlement, but natural background levels have been markedly increased. Highly erodible soils, southerly aspects, and overgrazing have combined to initiate widespread geomorphic instability including incision, mass wasting of channel banks, and headward migration of channel networks. Incision is especially pervasive in the Milk Creek drainage (Figure 4.146) although the headwaters of Milk Creek near Castle Peak are still in good condition. Stream segments in all five of the incised channel evolution stages depicted in Figure 4.146 can be observed in these watersheds. Geologic grade control has limited incision in some segments and maintained bank heights below critical values for geotechnical failure. In other segments incision and mass failure are both prevalent.

Figure 4.146: Incision of Milk Creek.

Data describing past channel geometry and suspended sediment concentrations are very sparse. We located seven suspended sediment data from these tributaries collected over the last three decades. A maximum total suspended solids (TSS) value of 1330 mg/l was recorded in Milk Creek in 1976. This sample is clearly not representative of TSS levels that occur during precipitation-runoff events. According to NWCCOG (2002), sediment concentrations as high as 12,000 mg/L have been recorded during spring runoff and impacts to the fisheries in the Eagle River were documented by the CDOW in 1971, 1982, and 1989. A few cross-sections have been surveyed in the Milk Creek drainage (Scheidt, BLM, pers. comm., 2003) but we were unable to obtain these data. Field reconnaissance and anecdotal observations by BLM hydrologists suggest that there is widespread and ongoing headward migration of drainage networks in the Milk Creek drainage.

The pervasive nature of these problems necessitates a comprehensive geomorphic assessment to identify incised channel types, gauge the relative importance of these processes and upland sources in sediment production, and establish geomorphic design criteria such as slope-drainage area-grain size relationships from quasi-equilibrium segments (e.g., Bledsoe *et al.*, 2002). Adequate reductions would likely necessitate a multi-year effort involving grade control, detention basins, drop pipes to check headward migration of channels, 'brush-beating,' and reduced grazing. Given the soil types and large amounts of fine sediment stored in the channel networks of these drainages, reductions needed to significantly reduce negative effects of suspended sediment and turbidity on trout could require more than a decade of intensive effort. The effects of suspended sediment concentrations of varying durations on trout are presented in Section 4.6 and could provide a biological basis for linking predicted reductions in sediment delivery with expected possible in the Eagle River main stem.

4.7.5.13 Eby Creek

Eby Creek enters the Eagle from the north at the town of Eagle (Figure 4.147). Our assessment of the stream was limited to the couple miles of public road along the lower reaches. This lower reach has been heavily degraded by livestock. The soft sedimentary material dominating this drainage suggests that Eby Creek could potentially input substantial amounts of sediment into the Eagle during spring runoff or summer thunderstorms.

Figure 4.147: Poorly functioning diversion structure Eby Creek.

4.7.5.14 Brush Creek

Brush Creek is highly developed near its confluence with the Eagle River. Brush Creek is a meandering stream near Eagle, but is not free to migrate due to bank armoring and adjacent development. Upstream of the urbanized segment of Brush Creek and along Salt Creek, there are a number of private ranches. Viewing access for much of this length of stream is limited to road crossings (Figures 4.148 and 4.149). Extensive channel rehabilitation activities are currently underway along Brush Creek upstream of Eagle (Bill Clark, CDOW, Kent Rose Eagle Ranch, pers. comm., 2004). A genetically pure population of native Colorado cutthroat trout is located in Abrams Creek, a tributary to lower Brush Creek. An instream barrier consisting of a 4-ft vertical spill with no pool prevents the upstream movement of non-native trout into Abrams Creek. The Johnson easement is located near Eagle Ranch and is in good condition.

Figure 4.148: Cut bank on lower Brush Creek where migration is limited by root reinforcement.

Figure 4.149: Grazed area on lower Brush Creek.

Farther up the drainage, Brush Creek splits into East and West Brush Creeks, both of which flow through State Park land acquired in 1999. Downstream of this confluence, Brush Creek flows through some degraded holdings, where potential future development along these reaches could be combined with habitat improvement projects. Topographic maps indicate the presence of logging roads in the headwaters of the subbasin, but the sediment production potential of the roads was not assessed.

4.7.5.15 Gypsum Creek

Like Brush Creek, Gypsum Creek is influenced by urban land uses. The lower portion of the creek flows through housing developments surrounding the town of Gypsum, and the creek is channelized through town at the confluence. Immediately upstream of the housing developments, the creek flows through several kilometers of a broad valley that consists of ranch and farmland. Upstream of the agricultural land, the Gypsum Creek valley becomes narrower and the stream flows through smaller ranches and White River National Forest. The habitat quality is quite variable in these upstream reaches. Some of the reaches are in good condition; whereas some of the ranch reaches that are grazed more intensely are clearly degraded (Figures 4.150 and 4.151).

Figure 4.150: High quality habitat along Gypsum Creek.

Figure 4.151: Degraded habitat along Gypsum Creek downstream of a small, private reservoir.

4.7.6 Potential Geomorphic Effects of Flow Regime Changes

Maintaining habitat features is sometimes thought of in the context of minimum or instream flows. Indeed, this is an important concern and is discussed at length in Section 4.4. However, high flows also play a critical role in shaping stream channels and maintaining habitat for fish and benthic macroinvertebrates. High flows are required to scour fine sediment from pools and spawning gravel and for inundating floodplains to maintain riparian communities and terrestrial habitat (Whiting, 2002). The Eagle River has been subjected to transmountain diversions that primarily remove water from the peak of the hydrograph. Consequently, the magnitudes of flood peaks along the Eagle River have been reduced from historical levels as described in Section 4.4. However, this flow reduction is not entirely due to diversion; the findings of Webb *et al.* (2004) indicate that climate explains part of the pattern in flows recorded at Red Cliff. Results from dendrochronology studies on the Colorado River suggest that 1906 to 1930, which contains the early period of record for the Red Cliff gage, was the highest period of runoff in 450 years (Stockton and Jacoby, 1976; Webb *et al.*, 2004). Thus, the Red Cliff record underscores the combined effects of climate and flow modification in determining channel forms and habitats in the watershed over long time scales.

Rivers act as self-regulating systems that constantly adjust themselves to match channel geometry and sediment transport to the input flow regime and the available sediment (Knighton, 1998; Whiting, 2002). High flows that approach and exceed the floodplain elevation do most channel maintenance work (Andrews and Nankervis, 1995). By reducing the magnitude of peak flows, the capacity to transport sediment and perform work on the channel boundary is also reduced. When flows are reduced, the high flow part of the channel and floodplain are inundated less frequently, which allows vegetation to stabilize depositional surfaces and reduce the size and flood conveyance of channels. However, even under the altered conditions of diversion, a high-flow year may occur, albeit less frequently, and resemble the mean state of the pre-diversion high flow regime. Depending on the 'return period' of these wet years, relatively infrequent high flows may be sufficient to negate morphologic changes due to diversion (Ryan, 1997). Thus, the extent of morphologic change depends on the time between channel-forming events relative to the time over which morphologic change can occur due to vegetation establishment, aggradation, or other factors (Wolman and Gerson, 1978).

Sustained high flows can play an important role in determining the percentage of fine sediment in the stream substrate. Fewer high flow events reduce "flushing" of the substrate. Flushing flows, as defined by Whiting (2002), are flows that maintain the sizes of sediment on the river bed. Fine sediment deposition over gravels can have a significant negative impact on the habitat of aquatic macroinvertebrates and spawning substrate for fish. However, in coarse bed channels with slopes comparable to those occurring in much of the Eagle River watershed, sediment transport is supply limited and diversions may not have a significant impact on channel maintenance (Whiting, 2002). According to Ryan (1997), who studied subalpine streams in the Rocky Mountains affected by diversions, morphologic effects of the diversions are typically subtle. She found that periodic high flow years mimicking the unaltered flow regime were often enough to maintain the channel capacity. In general, morphologic and substrate changes in response to diversions in the Eagle River watershed are most likely to occur where sediment transport is limited by capacity (flatter slopes / wider channels), sediment supplies are greater (erodible materials / land disturbance), and conditions are favorable for woody vegetation establishment.

High flows are essential to maintain connections between the floodplain and the channel. Energy input to the channel consists, in large part, of organic debris and vegetation on the floodplain (Cummins, 1974; Minshall *et al.*, 1985) and of dissolved organic material in riparian soils (Wharton and Brinson, 1978). The rich soils deposited on the floodplain during flood events support riparian vegetation. These connections have been lost due to urban encroachment and entrenchment of the channel in some locations in the Eagle River watershed. However, in a few places such as Camp Hale and the Eagle River / Lake Creek confluence segment, these connections can be restored and/or protected on a relatively large scale.

4.7.7 Reduced Flows and Their Effect on Effective Discharge at Red Cliff

Many of the downstream hydraulic geometry and sediment transport relationships used by geomorphologists are based on one single discharge that represents a surrogate for all of the discharges in the flow regime. Perhaps the most notable form of this is bankfull discharge, which is essentially a field-estimated parameter that represents the flow in a channel where the water surface is just at the floodplain level (Dunne and Leopold, 1978; Knighton, 1998; Williams, 1978). Another form of this surrogate flow is effective discharge, which is derived from sediment transport computations as opposed to field indicators. Effective discharge is the flow in a channel that transports the greatest amount of sediment over time (Andrews, 1980; Emmett and Wolman, 2001). High flows in a river transport a large amount of sediment but occur infrequently. Low flows occur frequently but do not transport much sediment. Taking the product of sediment transport rate and flow frequency of occurrence yields a maximum value, known as the effective discharge. Effective discharge and bankfull discharge are often used interchangeably but frequently do not occur at the same flow.

To illustrate the potential effects of diversions in the watershed, an analysis of effective discharge was performed for the Eagle at Red Cliff. This site was chosen because the gage has a long enough period of record to predate the bulk of the diversions, and the site is upstream of most of the major tributaries that mask the effects of diversions. The effective discharge analysis is based on the Wilcock and Kenworthy (2002) sediment transport relationship. Using a grain size of 50 mm, flow effectiveness curves were plotted for the periods pre-1925 and post-1944 (Figure 4.152). The effective discharge is represented by the maximum value of sediment transport rate for each series. This analysis suggests that the changes in discharge recorded for the two periods at Red Cliff differ in cumulative sediment transport capacity by much more than 50%. The estimated effective discharge values associated with the pre-1925 and post-1944 periods are 428 cfs and 228 cfs, respectively.

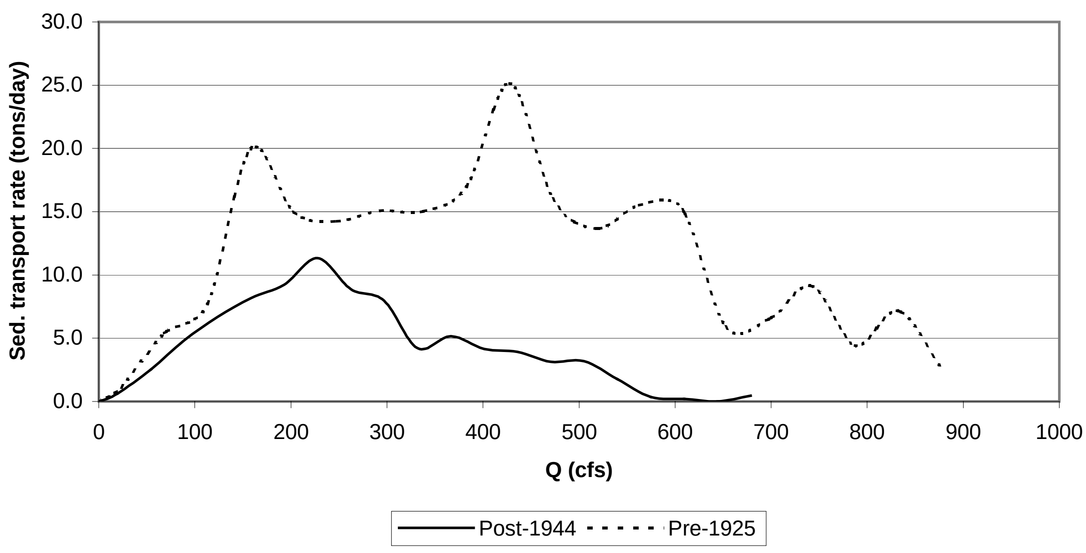


Figure 4.152: Flow effectiveness curves at for the USGS at Red Cliff, pre-1925 and post-1944.

Bankfull discharge is often estimated as the flow event with a return period of 1.5 years (Leopold, 1994). Using instantaneous peak data available for this gage from the USGS, the values of $Q_{1.5}$ for the period before 1925 and the period after 1944 were estimated by fitting the data to a Weibull distribution. These values are 489 cfs and 251 cfs, respectively, and correspond well with the estimated values from the effective discharge analysis. This reduction in effective discharge can be directly interpreted as a reduction in channel maintenance. By reducing the magnitude and frequency of flood events, the channel performs less geomorphic work and the balance between streamflow, sediment transport, and channel geometry is altered. Because the Eagle River has been channelized through Red Cliff, changes to channel geometry due to a reduction in effectiveness are difficult to decipher. However, there is less sediment transport over time and less reworking of the substrate.

4.7.8 Hydraulic Geometry Analyses

Channel dimensions (width and depth) adjust to the balance between discharge and sediment supply. Cross sectional area generally increases in the downstream direction in response to the greater discharges associated with increasing drainage area (Knighton, 1998). Several researchers have developed downstream hydraulic geometry relationships that describe river width as a function of the bankfull flow. For this analysis, the downstream width relationships proposed by Andrews (1984) and Hey and Thorne (1986) for gravel and cobble bed rivers were used, and are presented in Table 4.44. The erosive resistance of banks can strongly influence the equilibrium width of rivers, and channels with more erodible bank material or sparser vegetation often tend to be wider than a channel with bank material that is resistant to erosion or heavily vegetated (Anderson *et al.*, 2004). With the exception of Gore Creek, the "Erodible Banks" equations were used for this analysis. Although bankfull channel widths can vary widely in individual reaches of stable river channels, the estimates provide by the selected hydraulic geometry relationships provide a relative benchmark for scaling and comparing average channel widths in the Eagle River watershed.

Table 4.44: Downstream width relationships (w in meters, Q in cms).

	Erodible	Resistant
Andrews (1984)	$w = 4.18\ Q^{0.50}$	$w = 3.88\ Q^{0.46}$
Hey and Thorne (1986)	$w = 4.25\ Q^{0.46}$	$w = 1.85\ Q^{0.57}$

The bankfull widths of selected channels in the Eagle River watershed were compared to these relationships at several locations throughout the basin where adequate gage data exist and where widths could be measured from field data and/or the 1998 aerial photography. The aerial photography was used in conjunction with GIS software so that multiple widths could be rapidly measured. The 1.5-year flow event was estimated from instantaneous peak data for the period of record at each gage available from the USGS. The peak data was fit to a Weibull distribution to estimate the value for $Q_{1.5}$ as a surrogate for bankfull discharge. Table 4.45 summarizes the gage data and predicted widths used to examine channel widths. A description of results for the main stem Eagle River, Gore Creek, and Lake Creek is provided below.

Table 4.45: Estimated values of $Q_{1.5}$ and widths at selected gages.

	$Q_{1.5}$ (cms)	Predicted Width (m) for Erodible Banks		Predicted Width (m) for Resistant Banks		Average Width
		Andrews	Hey-Thorne	Andrews	Hey-Thorne	
Eagle River below Gypsum	84.1	38.3	32.6	29.8	23.1	40 m
Eagle River at Avon	61.9	32.9	28.3	25.9	19.4	25 m
Eagle River at Red Cliff – before 1944	13.8	15.6	14.2	13.0	8.3	unknown
Eagle River at Red Cliff – after 1944	7.1	11.1	10.5	9.6	5.7	8 m
Gore Creek, Lower Station, at Vail	25.1	20.9	18.7	17.1	11.6	13 m

4.7.8.1 Eagle River below Gypsum

The Eagle below Gypsum is locally braided and overly wide in many places. The banks are sparsely vegetated and erodible. Andrews' equation for these types of banks predicts a width of 38.3 m and Hey and Thorne's equation predicts 32.6 m. The average width along this reach is approximately 40 m. However, some of the wider, braided sections have widths in excess of 100 m. Narrower cross sections (as narrow as 25 m) do exist in this reach. These sections typically occur in areas where the river is confined by I-70, Highway 6, and/or the railroad.

4.7.8.2 Eagle River at Avon

In the vicinity of the Avon gage, the Eagle is generally entrenched and confined by adjacent urban land uses. Therefore, the downstream width equations are not as applicable. The average width through this stretch is 25 m to 30 m, which falls between the values predicted by the equations for resistant and erodible banks. The banks along this part of the Eagle are more resistant than the lower river due to very large material providing bank toe stability and more vegetation in the riparian corridor. There are a few sections with widths in excess of 60 m, which is considered overly wide regardless of the equation used for comparison. There are also narrow sections where the river has been confined to less than 13 m, which is narrower than any of the predicted widths.

4.7.8.3 Eagle River at Red Cliff

The gage at Red Cliff is one of the oldest gages in the basin. The gage record extends back to 1910, which is before the bulk of the upstream diversions. There is a break in the data from 1925 to 1944. In this time period, the Wurtz and Columbine ditches began diverting water from the basin. Table 4.45 shows two estimates of $Q_{1.5}$; one estimate is for the record prior to the Wurtz and Columbine diversions and the other for the record after the diversions.

The average width through Red Cliff is about 8 m, which is narrower than all of the predicted values except that predicted by Hey and Thorne's resistant bank equation. The sparse vegetation through this stretch suggests that the erodible bank equations should be used in this case. The narrow channel through Red Cliff is the result of past channelization in the reach containing the USGS gage.

4.7.8.4 Gore Creek at Vail

Gore Creek through Vail fits fairly well with the predicted values of width for resistant banks. Because of the coarse bank material and the fairly extensive stands of vegetation along the banks, the resistant bank assumption seems valid. The average width is approximately 13 m. The channel width in the vicinity of this gage does, however, locally exceeds 20 m. These wide sections typically correspond to areas with less vegetation. Urbanization has encroached upon Gore Creek; however, much of the stream still has a planform similar to that of 1964, before most of the development at Vail. The major exceptions are channelized stretches through the Vail Golf Club and downstream of West Vail.

4.7.9 Lower Eagle Meander Geometry and the Risk of Braiding

Aerial photography provides an efficient method of analyzing the risk of braiding and meander geometry for the lower Eagle River. For most of its length, the Eagle River is a single-thread channel that begins to meander actively near the town of Eagle. However, the river displays local areas of braiding where the channel becomes overly widened and sediment deposits as mid-channel bars. Researchers have correlated stream power to median grain size in an attempt to find a threshold that discriminates single-thread, meandering channels from braided channels. Using the data set compiled by van den Berg (1995), Bledsoe and Watson (2001) fit a logistic regression to the data to estimate the risk of braiding (Figure 4.153).

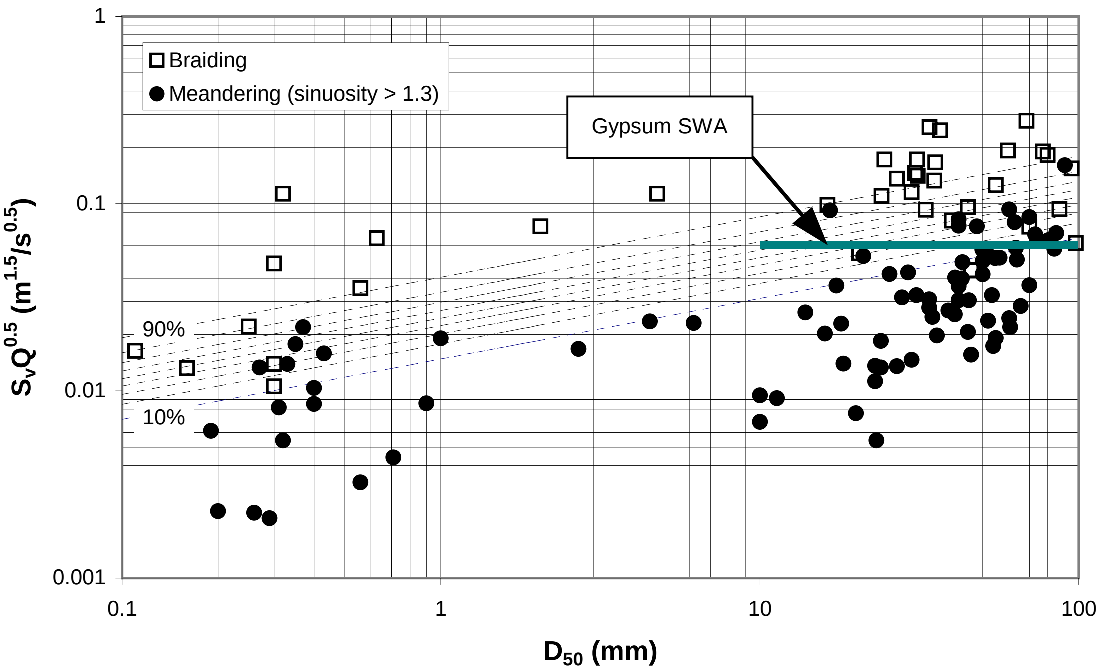


Figure 4.153: Logistic regression analysis of the van den Berg (1995) data set depicting the stream power of the Eagle River at Gypsum SWA on the plot (Bledsoe and Watson, 2001).

The results of this regression were applied to the Eagle at the Gypsum Ponds State Wildlife Area. Using a valley slope of 0.0066 as estimated from 2-foot contour data available for the area, the results at Gypsum are plotted on Figure 4.153 against van den Berg's data. Detailed grain size distribution data are not available at this time to give an accurate estimate of the median grain size; therefore, the results are plotted at the estimated stream power over a range of gravel and cobble sizes for D_{50} at the Gypsum site. At this valley slope and with the median grain size of the channel, the data suggest that the Eagle River in this part of the watershed is near the threshold for braiding. This tendency towards braiding is evident in the field along the lower Eagle River at localized areas of channel widening, chute formation, and mid-channel bar development (Figure 4.154).

Figure 4.154: Braiding of the Eagle River at the Gypsum Ponds SWA.

The geometry of the meanders of the lower Eagle can be used to evaluate channel stability or the tendency for the channel to migrate. The migration rate of a meandering river is controlled, in large part, by the scale-dependent curvature of the meanders (Knighton, 1998). This curvature is typically expressed as a ratio of the radius of curvature (r_c) to channel width (w). Migration rate reaches a maximum when the value of r_c/w is between 2 and 3 (Hickin and Nanson, 1975, 1984; Knighton, 1998). Curvature was measured for the lower Eagle using aerial photographs and GIS. The average value of r_c/w is 2.4 with a standard deviation of 0.96. This average value falls in the middle of the range for maximum migration.

The potential for braiding and high meander migration rates are evident in the field. Cross-section surveys (CDOW) from the Gypsum area suggest that meander bends in the SWA have migrated up to 15 ft in one year. Channel geometry along the lower Eagle River can respond rapidly to change. The extent of meander migration is also evident in the extent of the meander cutoffs along the lower Eagle. The lack of dense vegetation along the riparian corridor of the lower Eagle increases the risk of chute cutoffs, elevated migration rates, and braiding. Should restoration efforts attempt to force the lower Eagle into a static single-thread channel, the high migration rates and risk of braiding imply that this might require ongoing maintenance to offset the river's natural tendencies.

4.7.10 Specific Gage Analysis

To identify potential trends in aggradation or degradation, specific gage analyses were performed for the following 12 USGS gaging sites in the watershed:

- *Black Gore Creek near Minturn*
- Cross Creek near Minturn
- Eagle River at Avon
- Eagle River at Red Cliff
- *Eagle River below Gypsum*
- Eagle River below Wastewater Treatment Plant at Avon
- Eagle River near Minturn

- *Gore Creek above Red Sandstone Creek at Vail*
- *Gore Creek at Upper Station, near Minturn*
- Gore Creek, Lower Station, at Vail
- Homestake Creek near Minturn
- *Red Sandstone Creek near Minturn*

The five gages in the above list that are in *italics* are the sites of interest that we identified as having potential trends or shifts. The analysis involved matching unit stage and discharge data throughout the period of record for each gage, calculating a range of average discharges, and plotting the corresponding stage over time. In this analysis, aggradation will appear as an upward trend in stage over time and degradation will appear as a downward trend in stage over time. The USGS periodically updates the rating at gaging sites, which complicates this style of analysis. For the five locations, we obtained 9-207 rating forms from the USGS office in Grand Junction, Colorado, to evaluate whether the trend in stage was due to aggradation/degradation or unrelated changes in the rating at the gage. Of the five sites, only the Eagle River below Gypsum showed a trend that was potentially due to actual aggradation (Figure 4.155). The upward shift in stage between 1994 and 1998 potentially corresponds to aggradation instead of rating changes.

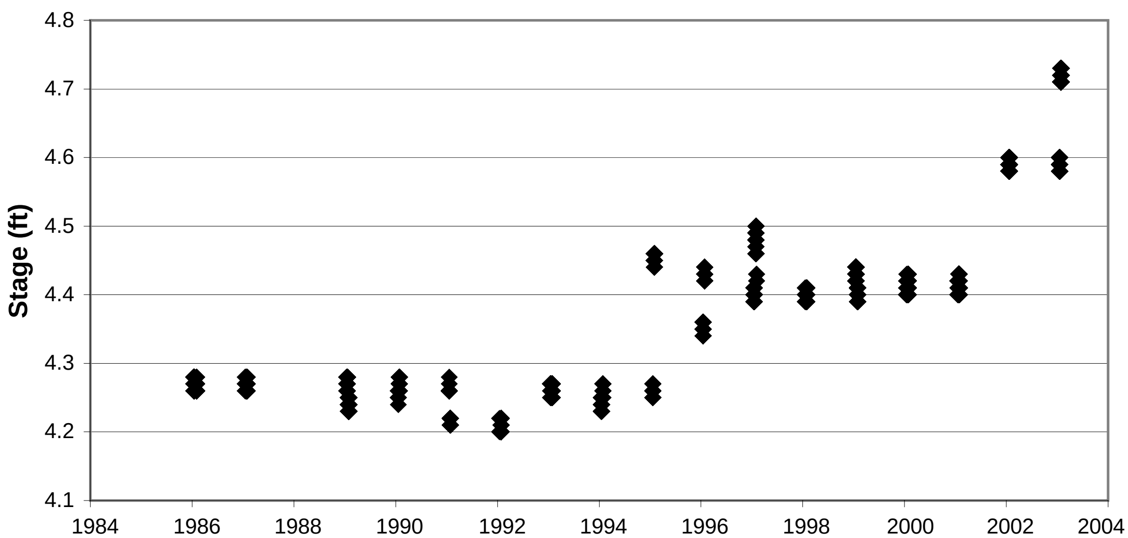


Figure 4.155: Specific gage results for the Eagle River below Gypsum for 531 to 551 cfs.

4.7.11 Summary

From a geomorphic standpoint, the Eagle River main stem and tributaries are largely stable and resilient in most segments due to lateral confinement and coarse armored bed material. There are many documented areas of local instability; these areas tend to occur in relatively low gradient segments of the main river, in smaller streams where tributary valleys enter the Eagle valley, and in stretches passing through the highly erodible materials present in the lower basin. Many human influences including channelization, riparian vegetation removal and grazing as well as fluvial processes such as meander migration affect geomorphic stability and physical habitat in the watershed. A common trend among almost all of the tributaries to the Eagle River, with a few exceptions including Homestake, Milk, and Alkali Creeks, is the tendency for higher quality habitat with increasing valley confinement and distance from the Eagle valley.

Field reconnaissance was focused in areas where past and current human influences are most prevalent and where these influences have degraded habitat. Rapid surveys of physical habitat examined substrate characteristics including embeddedness, channel hydraulic complexity, fish cover, riparian condition, bank stability, woody debris, overall stability, and other attributes. These surveys revealed several localized instances and a few large-scale occurrences of geomorphic instability, riparian disturbance, and physical habitat degradation (Figure 4.134 and Table 4.43). In general, the most egregious and large-scale examples of disturbance and/or geomorphic instability occur at Camp Hale, in the Milk, Alkali, and Ute Creek subbasins near Wolcott, and in Black Gore Creek. A few segments of Gore Creek have also been channelized and straightened. Lower Brush Creek has also been disturbed over relatively long segments but rehabilitation projects addressing some of these sections are currently underway. Aside from Camp Hale, the Eagle River has been channelized in Red Cliff, through portions of Gilman Gorge, and below Minturn through the I-70 interchange. Although the Eagle is laterally armored and entrenched through much of the urban corridor between Minturn and Edwards, it is hydraulically diverse and frequently shaded by at least a narrow forest riparian buffer in much of this segment. Localized reaches with excessive width to depth ratios were identified along the Eagle main stem, primarily near Avon.

In general, the broader, lower elevation valleys of several tributary segments altered by grazing or other riparian disturbance present opportunities to improve channel stability and physical habitat. As described above, these include Lake Creek, Squaw Creek, Eby Creek, Brush Creek, and Gypsum Creek. Given the large number of private landowners along these stream corridors, planning and implementation of stream improvement activities in these areas will require both extensive landowner involvement and more focused analyses at the sub-basin scale.

The Eagle River and Homestake Creek have been subjected to transmountain diversions that remove water from the peak of the annual snowmelt hydrograph. High flows play a critical role in shaping the form of channels, maintaining habitat for fish and benthic macroinvertebrates, and inundating floodplains for maintenance of riparian functions and habitats. When peak flows are reduced, the high flow part of the channel and floodplain are less frequently inundated, which enables vegetation to stabilize depositional surfaces and reduce the size and flood conveyance of channels. However, even under the altered conditions of diversion, a high flow year may occur and resemble the mean state of the pre-diversion high flow regime. Depending on the 'return period' of these wet years, relatively infrequent high flows may be sufficient to negate morphologic changes due to diversion. Thus, the extent of morphologic change depends on the time between channel-forming events relative to the time over which morphologic change can occur due to vegetation establishment, aggradation, or other factors. In general, morphologic and substrate changes in response to peak flow reductions in the Eagle River watershed are most likely to occur where peak flow reductions are most pronounced, sediment transport is limited by capacity (flatter slopes / wider channels), sediment supplies are greater (erodible materials / land disturbance), and conditions are favorable for woody vegetation establishment. No pre-diversion geomorphic data were available for a comparison with current conditions.

The geologic controls that shape the Eagle and its tributaries change dramatically in the vicinity of Wolcott. The broader valleys and more erodible material of the lower basin result in higher sediment loads, greater floodplain widths and connectivity, and a more dynamic river planform. Suspended sediment and turbidity from Milk, Alkali, and Ute Creeks severely limit the coldwater fishery of the Eagle River below Wolcott. In these sub-basins, highly erodible soils, southerly aspects, and overgrazing have combined to initiate widespread geomorphic instability including incision, mass wasting of channel banks, and headward migration of channel networks. The pervasive nature of these problems necessitates a comprehensive geomorphic assessment to identify incised channel types, gauge the relative importance of these processes and upland sources in sediment production, and establish geomorphic design criteria. Adequate reductions would likely necessitate a long term effort (one or more decades) involving grade control, detention basins, drop pipes to check headward migration of channels, 'brush-beating,' and improved grazing management.

Planform analyses were conducted to examine the risk of braiding in the lower river and meander geometry as it affects lateral migration. The analysis of braiding risk suggests that the Eagle River in this part of the watershed is near the threshold for braiding. This tendency towards braiding is evident in the field along the lower Eagle River at localized areas of channel widening, chute formation, and mid-channel bar development. Therefore, restoration activities designed to establish a narrower, single-thread geometry must carefully account for this tendency and the accompanying prospects of chute cutoff formation and aggradational trends. The widths and radii of curvature of several meander bends of the Eagle River below Eagle are in the range associated with the most rapid lateral migration rates.

4.8 RIPARIAN ZONES

4.8.1 Ecological Significance of Riparian Zones

Riparian areas are ecosystems adjacent to watercourses and water bodies that are distinctly different from surrounding uplands due to unique soil, vegetation, and hydrologic characteristics. Riparian zones perform key ecological functions in the maintenance of healthy aquatic and terrestrial ecosystems (Figure 4.156). Native riparian vegetation shades the stream channel, which helps to keep temperatures optimal for aquatic biota during summer months. Organic matter, leaves, and woody debris from riparian vegetation provide a basis for the aquatic food web (Wallace *et al.*, 1997). The riparian area also provides valuable habitat for wildlife. In addition to serving as a food resource for terrestrial species, a large percentage of all wildlife species depend on riparian areas – for mating, nesting, or cover – for some portion of their life cycle (Thomas *et al.*, 1979; Johnson *et al.*, 1977).

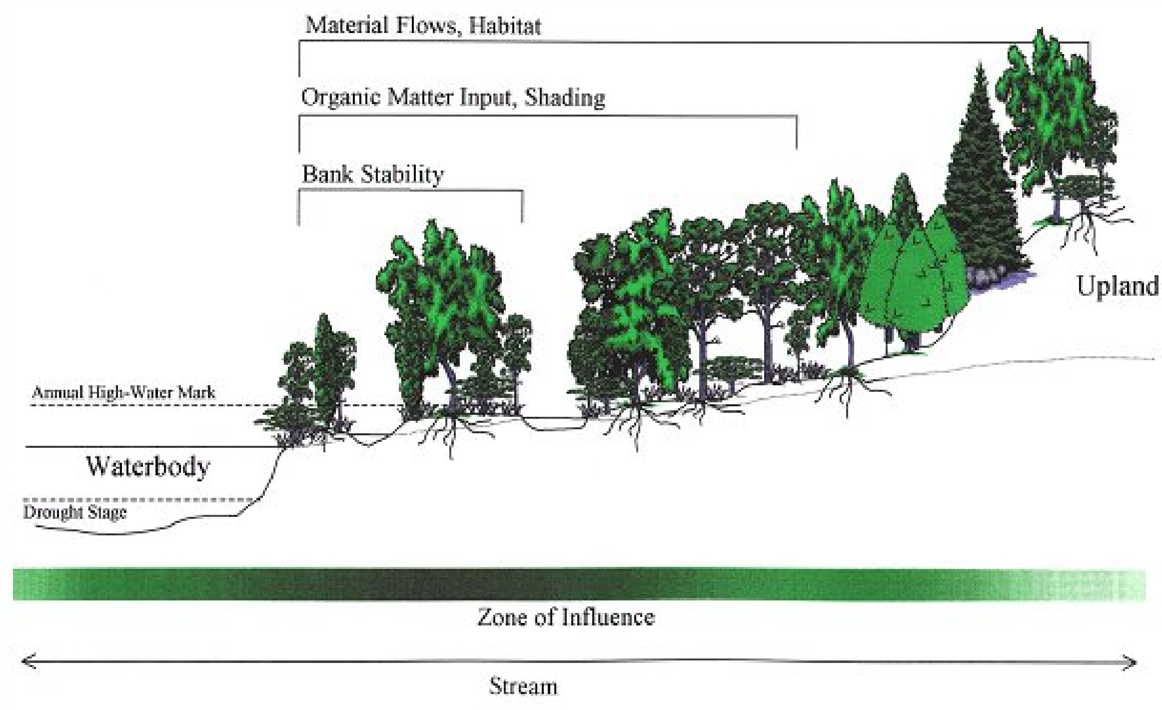


FIGURE 1 Schematic of a generic riparian area showing a zone of influence relative to aquatic and upland areas. The intensity of riparian influence is depicted with shading. "Material flows" refers to energy, organic matter, water, sediment, and nutrient flow.

Figure 4.156: Riparian zone importance (courtesy of the Colorado Riparian Association).

Riparian vegetation promotes geomorphic and chemical processes essential to healthy stream and rivers. Typically, riparian vegetation, inclusive of woody shrubs, grasses, and sedges, have higher root densities than upland vegetation. Assemblages of riparian vegetation and their dense root systems help to stabilize streambanks, reduce erosion, intercept sediment and other contaminants from overland flows, and remove excess nutrients from the water table. During high flow events, the riparian system acts as a buffer to the stream and assists in rapid recovery from disturbance.

4.8.2 Riparian Plant Communities in the Eagle River Watershed

A thorough biological assessment was performed by the Colorado Natural Heritage Program (Armstrong, 2000) to identify potential conservation areas in the Eagle River watershed, and is reviewed in Sections 3.3.19, 3.3.20, and 4.9. The survey provides detailed information regarding significant plant communities in the watershed. For each plant community, the document describes characteristics influencing their establishment, dominant successional and ecological processes, and recommendations for improved management.

Kittel *et al*. (1999) recently published a comprehensive, field-based classification of riparian wetland plant associations for the state of Colorado. The classification includes 150 natural, native riparian vegetation plant associations in Colorado. Significant riparian plant communities within Eagle County were identified and ranked according to their global and state imperilment (Table 4.46). This information does not provide an exhaustive list of all riparian plant communities in the Eagle River watershed, yet represents plant communities that have been identified as “significant” by the CNHP. As part of the classification of riparian wetland plant associations in Colorado, surveys were performed for various riparian areas within the Colorado River watershed (Kittel *et al.*, 1999). Riparian areas surveyed within the Eagle River subbasin have been compiled as a reference (Table 4.47). The data collected represent only a partial survey of the Eagle River watershed’s riparian zones.

Table 4.46: List of Riparian Wetland Plant Associations in Eagle County (sources: Fayette *et al.*, 2000; Kittle *et al.*, 1999).

Forest Type	Plant Community	Common Name	Global Rank	State Rank
Coniferous	*Abies lasiocarpa- Picea engelmannii/ Alnus incana*	Subalpine fir- engelmann spruce/ thinleaf alder	Very common	Very common
Coniferous	*Abies lasiocarpa- Picea engelmannii/ Mertensia ciliata*	Subalpine fir- engelmann spruce/ mountain bluebells	Very common	Very common
Coniferous	*Abies lasiocarpa- Picea engelmannii/ Salix drummondiana*	Subalpine fir- engelmann spruce/ drummond willow	Very common	Common
Coniferous	*Juniperus scopulorum/ Cornus sericea*	Rocky Mountain juniper/ red-osier dogwood	Common	Imperiled
Coniferous	*Picea pungens/ Alnus incana*	Colorado blue spruce/ thinleaf alder	Vulnerable	Vulnerable
Mixed Deciduous- Coniferous	*Populus angustifolia- Juniperus scopulorum*	Narrowleaf cottonwood/ Rocky Mountain juniper	Imperiled-Vulnerable	Imperiled
Mixed Deciduous- Coniferous	*Populus angustifolia- Picea pungens/ Alnus incana*	Narrowleaf cottonwood-Colorado Blue Spruce/ thinleaf alder	Vulnerable	Vulnerable
Deciduous	*Populus angustifolia/ Alnus incana*	Narrowleaf cottonwood/ thinleaf alder	Vulnerable?	Vulnerable
Deciduous	*Populus angustifolia/ Cornus sericea*	Narrowleaf cottonwood/ red-osier dogwood	Common	Vulnerable
Deciduous	*Populus angustifolia/ Salix eriocephala var. ligulifolia- Shepherdia argentea*	Narrowleaf cottonwood/ strapleaf willow- silver buffaloberry	Imperiled	Imperiled
Deciduous	*Populus balsamifera*	balsam poplar	Uncertain	Uncertain
Deciduous	*Populus tremuloides/ Acer glabrum*	Aspen/ Rocky Mountain maple	Imperiled	Critically Imperiled-Imperiled
Deciduous	*Populus tremuloides/ Alnus incana*	Aspen/ thinleaf alder	Vulnerable	Vulnerable
Deciduous	*Populus tremuloides/* tall forbs	Aspen/ tall forbs	Very common	Very common
Shrublands	*Alnus incana/* mesic forb	Thinleaf alder/ mesic forb	Watchlisted	Vulnerable
Shrublands	*Alnus incana- Cornus sericea*	Thinleaf alder-red-osier dogwood	Watchlisted	Vulnerable
Shrublands	*Alnus incana-* mixed *Salix* species	Thinleaf alder- mixed willow species	Vulnerable	Vulnerable
Shrublands	*Betula occidentalis/* mesic forb	River birch/ mesic forbs	Vulnerable	Imperiled
Shrublands	*Betula occidentalis/* mesic graminoid	River birch/ mesic graminoid	Vulnerable	Imperiled
Shrublands	*Cornus serciea*	Red-osier dogwood	Common	Vulnerable
Shrublands	*Salix boothii/ Carex utriculata*	Booth willow/ beaked sedge	Common	Vulnerable
Shrublands	*Salix boothii/* mesic forb	Booth willow/ mesic forb	Vulnerable	Vulnerable

Forest Type	Plant Community	Common Name	Global Rank	State Rank
Shrublands	*Salix drummondiana/ Calamagrostis canadensis*	Drummond willow/ bluejoint reedgrass	Vulnerable	Vulnerable
Shrublands	*Salix drummondiana/* mesic forb	Drummond willow/ mesic forb	Common	Common
Shrublands	*Salix exigua/ bare ground*	Coyote willow/ bare ground	Very common	Very common
Shrublands	*Salix monticola/ Calamagrostis canadensis*	Yellow willow/ bluejoint reedgrass	Vulnerable	Vulnerable
Shrublands	*Salix monticola/ Carex utriculata*	Yellow willow/ beaked sedge	Vulnerable	Vulnerable
Shrublands	*Salix monticola/* mesic forb	Yellow willow/ mesic forb	Vulnerable	Vulnerable
Shrublands	*Salix planifolia/ Calamagrostis canadensis*	Planeleaf willow/ bluejoint reedgrass	Vulnerable	Vulnerable
Shrublands	*Salix planifolia/ Caltha leptosepala*	Planeleaf willow/ marsh marigold	Common	Common
Shrublands	*Salix planifolia/ Carex aquatilis*	Planeleaf willow/ water sedge	Very common	Common
Herbaceous Vegetation	*Carex aquatilis*	water sedge	Very common	Common
Herbaceous Vegetation	*Carex scopulorum- Caltha leptospala*	Rock sedge- marsh marigold	Common	Common
Herbaceous Vegetation	*Carex utriculata*	beaked sedge	Very common	Common
Herbaceous Vegetation	*Eleocharis quinqueflora*	fewflower spikerush	Common	Watchlisted

Table 4.47: Survey locations of Kittel *et al.* (1999) that lie within the Eagle River watershed riparian zone.

Survey Site	Elevation (ft)	Plant Association
Antones Cabin Creek	9600	*Abies lasiocarpa-Picea engelmannii/Mertensia ciliata*
West Cross Creek	10190	*Abies lasiocarpa-Picea engelmannii/Mertensia ciliata*
Fish Pond Gulch	8240	*Abies lasiocarpa-Picea engelmannii/Mertensia ciliata*
East Brush Creek	10040	*Abies lasiocarpa-Picea engelmannii/Mertensia ciliata*
Milk Creek	8680	*Alnus incana*/Mesic Forbs
Two Elk Creek	8160	*Alnus incana-Cornus sericea*
S. Frk. Red Sandstone Crk	11120	*Carex scopulorum-Caltha leptosepala*
S. Frk. Red Sandstone Crk	11120	*Carex scopulorum-Caltha leptosepala*
Fall Creek	9520	*Carex utriculata*
S. Frk. Red Sandstone Crk	11120	*Eleocharis quinqueflora*
Gore Creek at Town of Vail	8100	*Picea pungens/Alnus incana*
Miller Creek	9220	*Picea pungens/Alnus incana*
Eagle River in Red Canyon	6800	*Populus angustfolia-Picea pungens/Alnus incana*
Sundell Creek	8200	*Populus tremuloides/Acer glabram*
Lime Creek	9080	*Salix drummondiana*/Mesic Forbs
Gypsum Creek at School House Gulch	8080	*Salix drummondiana*/Mesic Forbs
Berry Creek	8320	*Salix drummondiana*/Mesic Forbs
Third Gulch	9560	*Salix drummondiana*/Mesic Forbs
Buffehr Creek	8440	*Salix drummondiana*/Mesic Forbs
Gore Creek Between Booth and Pitkin Creeks	8340	*Salix monticola/Calamagrostis canadensis*
Gypsum Creek at School House Gulch	8000	*Salix monticola/Carex utriculata*
Lower Cataract Creek	10640	*Salix monticola*/Mesic Forbs
Upper Cataract Creek	10950	*Salix planifolia/Caltha leptosepala*
Jones Gulch	10360	*Salix planifolia/Caltha leptosepala*
Mitchell Crk	9920	*Salix planifolia/Carex aquatilis*
Fall Creek	9520	*Salix wolfii/Carex utriculata*

4.8.3 Condition of Riparian Areas in the Eagle River Watershed

Riparian areas in the Eagle River watershed have experienced both direct and indirect human alteration. Heavy historical grazing and land use changes associated with the rise of tourism led to rapid modification of riparian areas and native vegetation, while other actions initiated a slow process of barely discernible change. The conditions of the riparian zones in the Eagle River watershed have been most affected by riparian encroachment of urbanization, filling of wetlands, grazing and clearing activities, and flow modification.

Encroachment of riparian areas in the Eagle River watershed is primarily due to residential development and transportation corridors. Riparian encroachment is a concern in the Eagle River watershed because it removes native vegetation and alters critical ecological and geomorphic processes. Increases in impervious surface within the riparian zone from roadways and residences may be detrimental to stream stability and health. One of the most prominent examples of riparian encroachment in the Eagle River watershed due to development occurs on Gore Creek. Along a 4,560-ft segment of Gore Creek, the channel has been straightened, and the riparian area has been considerably altered. The creation of a golf course and the construction of I-70 have confined the riparian zone to such an extent most riparian vegetation has been eliminated. The river segment is currently confined on the south side by the golf course and on the north side by the frontage road and interstate 70 (Figures 4.157 and 4.158).

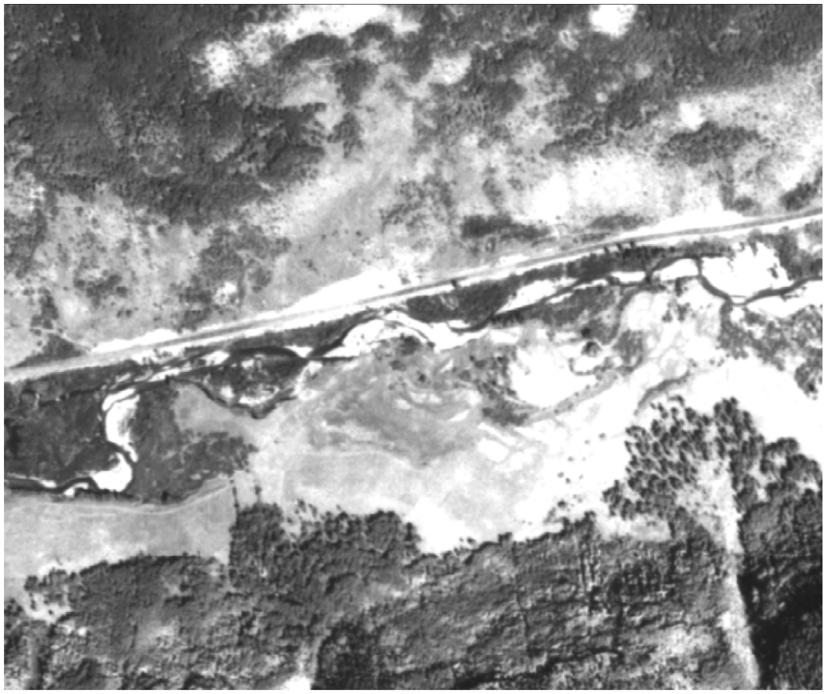


Figure 4.157: Gore Creek in 1962.

Figure 4.158: Same segment of Gore Creek in 1998 for comparison with Figure 4.157.

Human induced riparian encroachment is also evident in the Town of Minturn. The Eagle River is confined in this region by residences and Highway 24 on the west side of the river and by a railroad track on the east side (Figure 4.159). Development has left very little space for continued growth of riparian vegetation and limits future riparian establishment. Roads and other linear disturbances adjacent to or within the riparian zone act as dispersal corridors for invasive species. Most of the riparian areas in Minturn are dominated by non-native species for this reason.

Figure 4.159: Eagle River at Minturn, summer 2003. The picture illustrates encroachment of development into the riparian zone.

Surface gravel mining occurs within the floodplain of the Eagle River Valley between Eagle and Gypsum and also within the Edwards/Lake Creek segment. A riparian strip varying in width from 50 to 100 ft is vegetated between the mining activities and the river in some locations.

The Edwards and Lake Creek confluence segment along the Eagle River has been modified by a combination of development and grazing. Mechanical clearing, grazing, and development have altered the riparian zone along this reach of the Eagle River. The appreciable change in dominant plant communities over the past 100 years is observable through a comparison of photographs of the region taken recently and historically (Figures 4.160 and 4.161, respectively). Anecdotal reports suggest that the woody vegetation along Lake Creek (Figure 4.162) was mechanically cleared in the 1940s for grazing.

Figure 4.160: Gravel mining in the Edwards/Lake Creek segment of the Eagle River. Cattle grazing occurs on each side of the river and thus limits the riparian area.

Figure 4.161: The Eagle River just downstream of the confluence with Lake Creek sometime between 1886 and 1890 (photograph by W. H. Jackson, courtesy of Denver Public Library).

Figure 4.162: Close in location to the previous photograph, just downstream of the confluence of Lake Creek and the Eagle River, June 18, 2004.

4.8.4 Lower River Historical Grazing / Clearing

At Red Canyon, the nature of the Eagle Valley distinctly changes with the shift in lithology. The valley upstream of this geologic transition is relatively narrow and confined with the notable exceptions being the area at the confluence with Lake Creek and segment surrounding Wolcott. Downstream of Red Canyon, the valley becomes much broader with a corresponding change in land use to agriculture and residential development. Lower in the watershed, the agricultural land gives way to dry, un-irrigated sagebrush. Several cottonwood complexes can be found in this lower part of the watershed, of which the best example occurs in the Gypsum Ponds State Wildlife Area. The greatest density of tamarisk in the watershed is also located downstream of Eagle as discussed below.

Historical accounts describe extensive grazing in the watershed, with Wolcott being a major hub for livestock trade. Past overgrazing and current land use practices have degraded riparian vegetation along many reaches of the Eagle River below Wolcott, Brush Creek, and Gypsum Creek. A number of locations that lack riparian vegetation have been identified from field observation supplemented with analysis of the 1998 aerial photographs (Figure 4.163) and located with GPS.

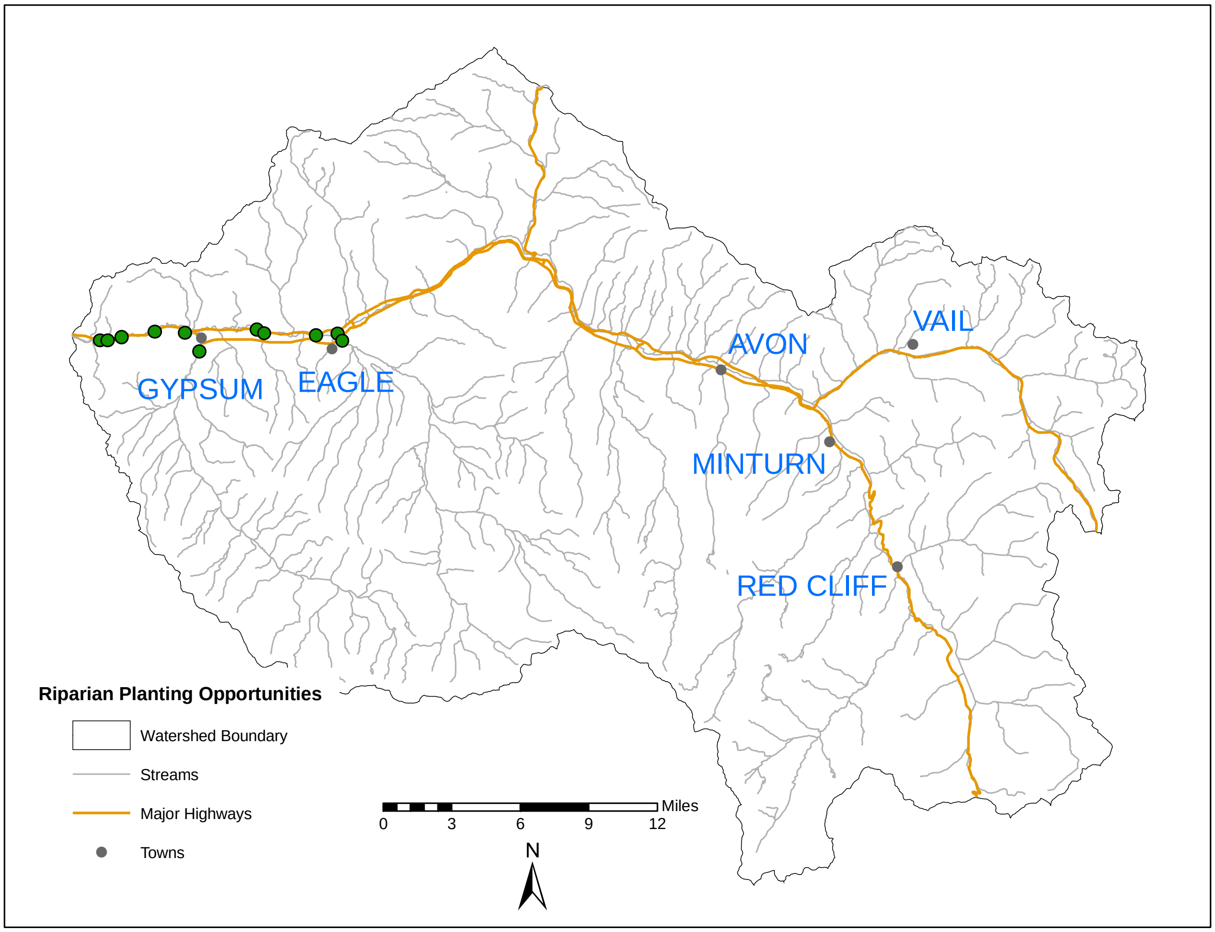


Figure 4.163: Major riparian planting opportunities identified in the lower watershed.

Riparian planting at these locations would protect streambanks while providing shade and cover for fish. These planting opportunities would require cooperation with multiple landowners to gain access to the site and manage grazing. Such a project could draw heavily on volunteer support. Several of the best sites are located along the Eagle River near Eagle (Figure 4.164). These sites consist of relatively large blocks (>10 acres) of private property that have little to no vegetation adjacent to the river. Establishing a riparian corridor at these sites would require changes in livestock management and fencing. One advantage of planting on irrigated land is that as irrigation water migrates to the river, it would benefit the newly planted riparian zone.

One location on Brush Creek is marked on the map in Figure 4.163. The aerial photographs show that nearly all of lower Brush Creek was void of vegetation taller than grasses in 1998. However, current planting opportunities along lower Brush Creek are complicated by ongoing development along the stream. Benefits of this type of project include: bank stability, increased shade along the stream banks to benefit stream temperatures, increased cover for fish, energy input to the channel, habitat for riparian wildlife, and support for native vegetation.

Figure 4.164: Agriculture land between Eagle and Gypsum with little vegetation.

The lower segment of Brush Creek is an area that could benefit significantly from riparian planting; however, a project along this stream would require establishing a riparian planting strategy to be implemented in conjunction with current and future development.

Gypsum Creek near the town of Gypsum has been heavily altered by the expansion of the town and agricultural land uses. Within the developed corridor of Gypsum, the stream is severely restricted and offers little opportunity for riparian improvement (Figure 4.165). However, riparian restoration on Gypsum Creek could be conducted along agricultural land upstream of Gypsum.

Figure 4.165: Gypsum Creek (approximate location noted by blue dashed line) is severely restricted and offers little opportunity for riparian improvement within the developed corridor of Gypsum.

4.8.5 Riparian Wetlands

Wetlands and riparian areas are often used interchangeably despite their distinctly different definitions. A location must meet three criteria in order to meet the regulatory definition of a jurisdictional wetland: (1) contain hydric soils, (2) have wetland hydrologic indictors including saturation by surface or ground water during a specific period of the growing season, and (3) support hydrophytic vegetation. Under the Clean Water Act, jurisdictional wetlands are defined as "*...those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas*." Riparian areas are more broadly defined as "*vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody*" (USEPA, 2001). Therefore, many wetlands are not riparian (e.g., depressional wetlands) and many riparian areas do not meet all of the criteria to be afforded protection under §404 of the Clean Water Act.

The United States Fish and Wildlife Service is currently completing a National Wetland Inventory (NWI). At this time, 90% of the United States has been surveyed, but only 42% of the wetland survey has been digitized (http://wetlands.fws.gov/hardcopymaps.htm). Wetlands in the Eagle River watershed are not yet included in the completed survey data.

Montane and alpine wetlands are common in several of the higher elevation valleys within the Eagle River watershed, including Homestake Creek, East Lake Creek, Brush Creek and Cross Creek. Although many of these wetlands remain pristine today, pressures from development and flow modification have threatened the abundance of these ecologically diverse riparian areas.

4.8.6 Cross Creek Study

The wetlands of Cross Creek represent a rich montane wetland environment. The Cross Creek Valley is part of the Holy Cross Wilderness Area, and has been identified as a potential conservation area (PCA) by the Colorado Natural Heritage Program (Armstrong, 2000). While the entire Cross Creek drainage area is approximately 33.5 square miles, the wetlands are only present at elevations between 9,500 ft and 10,060 ft (Rovey *et al.*, 1986). In the mid 1980s, ecological studies were performed to determine potential impacts of the controversial Homestake II project. Six major vegetation communities within the Cross Creek wetlands were identified (Rovey *et al.*, 1986).

1. *Ranunculus tricohyllus (water crowfoot) - Sparganium sp. community in shallow water averaging 10 cm in depth, but intermittently exposed during summer and fall;*
2. *Carex utriculata (bladder sedge) community is one of the most abundant communities in the wetlands. It occurs in both marshes with mineral soils and fens with largely organic soil. Depth to water table averaged 16 cm;*
3. *Carex aquatilis (water sedge) community occupies a variety of habitats and was observed at an average depth to water table of 31 cm;*
4. *Calamagrostis canadensis (Canada reedgrass) community occupies sites with an average water table depth of 56 cm;*
5. *Calamagrostis canadensis - Mertensia ciliata (bluebell) community occupies the tops of levees and is characterized by coarse herbaceous dicots. Average water table depth was observed at 65 cm; and*
6. *Salix planifolia (plane-leaf willow) community occupies the most well drained sites in the wetlands with an average water table depth of 70 cm.*

The results of these ecological studies indicated that the construction of a reservoir planned to extract 20,000 acre-ft annually from the Cross Creek drainage system during high flows, would have adversely affected the Cross Creek wetlands (Rovey *et al.*, 1986; Cooper, 1986). Fen and marsh wetland communities rely upon high spring flows for overbank flooding and stream meandering. Homestake II diversions from Cross Creek would have resulted in reduced peak flows during spring runoff, a main channel water level decline of approximately 1.5 ft during the growing season, and a regression in groundwater levels due to lower stream stage (Rovey *et al.*, 1986). Due to the dependence on groundwater levels, existing patterns of wetland plant species would have changed, and several of the wetland communities would have been unable to survive in the modified conditions (Rovey *et al.*, 1986). The results of this study imply that changes may have occurred along Homestake Creek as a result of the original Homestake Reservoir. The reduction in the peak flows of more than 70% may have caused a narrowing of the wetlands and a decrease in the abundance of wetland vegetation along Homestake Creek.

Beaver activity is important to maintain the health of many riparian ecosystems throughout the Eagle River watershed, including Cross Creek. Beavers feed on aspen, willow, and alder, all common in wetland environments (Cooper, 1986). Through the creation of dams, beavers aid in raising the water table, which provides hydrophytic plants access to water. Beaver dams are also geomorphically important in that they help trap sediment and temporarily raise the channel bed elevation. This facilitates the formation of wetlands and opportunities for plant recruitment (McNamee, 1994). By slowing seasonal flooding, beaver dams further help prevent erosion and channel downcutting (McNamee, 1994). Landowners in Eagle County may remove beavers from their property if they feel the beavers are a nuisance.

4.8.7 Maloit Wetlands

The wetlands of Maloit Park were previously contaminated due to high metal loadings from roaster materials, waste rock, and old tailings throughout the late 19th and first half of the 20th centuries. After removal of contaminated soils in the Maloit Park Wetlands, as part of the Eagle Mine cleanup, an effort began to monitor established vegetation. The revegetation standards required that reclaimed areas comprise a minimum of 50% of the reference area cover, with a minimum species similarity of 50%. As of 2001, the Maloit Park willow area and the Maloit Park sedge area met the requirement for cover, but did not meet the 50% similarity requirement due to dryness (NewFields, 2003). A more detailed analysis of the species diversity and the revegetation monitoring effort are presented in the *2003 Vegetation Report, Eagle Mine Site, Minturn, Colorado* (October 2003).

4.8.8 Camp Hale

The largest loss of wetlands in the Eagle River watershed has occurred in the area of Pando, currently known as Camp Hale. A 1989 U.S. Forest Service (USFS) report on Camp Hale indicates that, historically, wetlands were quite extensive throughout the valley (Figure 4.166). Early western settlers to the valley made their living by ranching, growing lettuce, and cutting blocks of ice for shipment to Denver. A large amount of wetlands were drained for the purpose of creating land suitable for these activities. By 1939, State Highway 24 and a railroad line crossed the valley. The 1939 extent of wetlands, according to USFS reports, are shown in Figure 4.167.

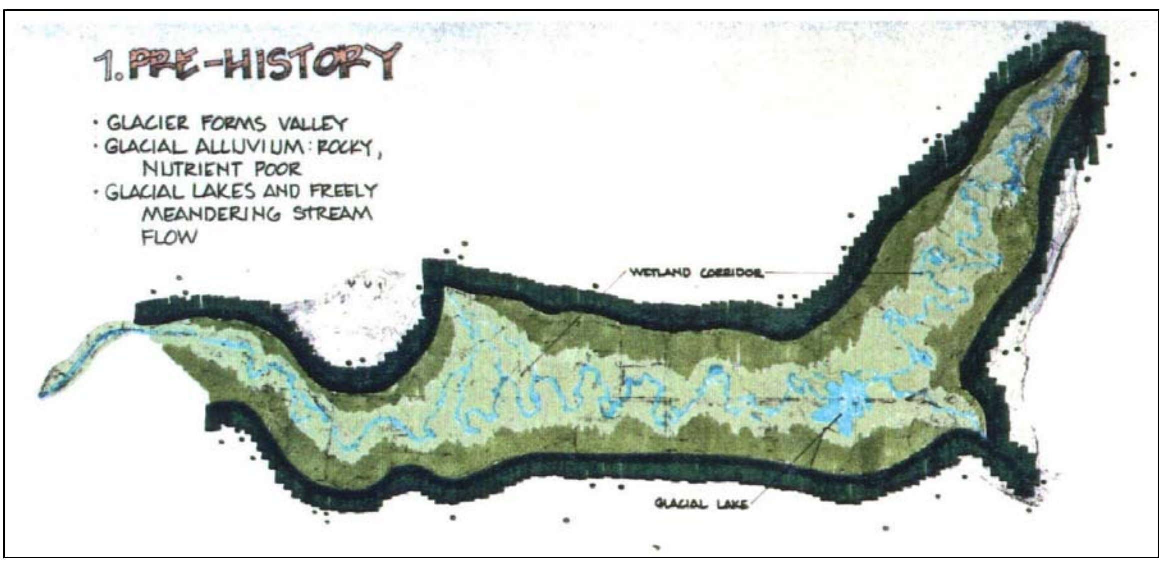


Figure 4.166: Historic Extents of Wetlands (from USFS (1989)). The light green areas represent wetlands.

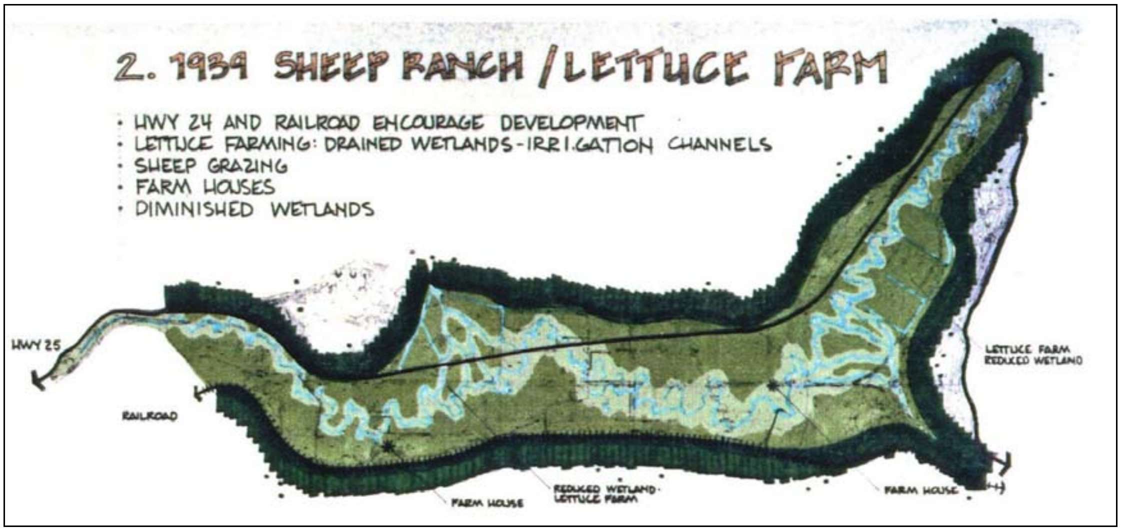


Figure 4.167: Extents of Wetlands in 1939 (from USFS (1989)).

The construction of Camp Hale in 1942 required that remaining wetlands be removed. To eliminate lands that created unsatisfactory conditions for buildings, equipment, and the training of mountain troops, the river channel was straightened and material from local hills was deposited within the ecologically rich wetlands. The river was channelized, the land drained, and fill brought in to make construction of Camp Hale feasible. It is estimated that 270,000 cubic yards of fill were use in the construction of Camp Hale (Wettstein, USFS, pers. comm., 2004). Other estimates range from 200,000 cubic yards (Best, 2003a,b) to 2,000,000 cubic yards (Denver Post, 1942). The end result is a lowering of the water table with respect to the land surface.

The straightening of the channel caused a reduction in the length of travel, but the slope of' the valley remained largely unchanged. Rather than meandering through the valley with a gradual reduction in grade, the flow of water traveled across a shortened reach with a more rapid drop in elevation. The modification to the channel increased its erosive force, resulting in an incised channel. Over time the channel bottom has lowered appreciably, and the flows that once overtopped the river's banks to sustain the wetland and riparian vegetation cannot access the floodplain. The river has been completely disconnected from the floodplain, which can no longer support the establishment of a native riparian community.

When the cycle of overbank flows was discontinued by channelization, the groundwater level in the adjacent floodplain was lowered. Water table data collected at Camp Hale are presented in Appendix A. As the water table lowered, riparian and wetland plant species no longer reached the moist soil they needed to survive. The altered geomorphic and hydrologic conditions favored the establishment of upland and non-native riparian species. Today, the valley is comprised of mostly dryland species and contains one of the worst infestations of invasive weeds in the Eagle River watershed.

The channelization and subsequent incision combined with the placement of fill material resulted in disconnection of the floodplain and a complete shift in the vegetation community from one that was annually flooded and maintained montane wetland species to conditions more suitable to upland and invasive species. A comparison of the environmental communities before and after modification to Pando clearly illustrates a major transformation in the dominant ecological processes (Figures 4.168 and 4.169, respectively).

Figure 4.168: Eagle Park, 1887 (photographed by William Henry Jackson, photograph courtesy of Denver Public Library, Western Geneology Department).

Figure 4.169: Camp Hale, 1998 (photograph courtesy of the Aspen Historical Society).

4.8.9 Invasive Species

Invasive non-native plants, "noxious weeds," are recognized as a danger to Colorado's agriculture and natural heritage. Forty-seven species of plants designated "noxious" by the Colorado Department of Agriculture have been confirmed to reside within the Eagle River watershed.

The following noxious weed species have had detrimental effects on riparian habitat in other areas of the west: russian olive (Figure 4.170), purple loosestrife (Figure 4.171), and tamarisk (Figure 4.172). Within Eagle County these three species of plants are present in levels that could merit an eradication strategy and are commonly found in yards and flowerbeds from Vail to Dotsero. According to Steve Elzinga, Eagle County Weed and Pest Coordinator, none have been designated "noxious" and therefore there is no tool to legally require removal.

Figure 4.170: *Elaeagnus angustifolia*, russian olive (photograph courtesy of J. S. Peterson at USDA-NRCS PLANTS Datatbase).

Figure 4.171: ***Lythrum salicaria*****, purple loosestrife (photograph courtesy of G. A. Monroe at USDA-NRCS PLANTS Database).**

Figure 4.172: ***Tamarix chinensis*****, fivestamen tamarisk or salt cedar stand near the confluence of the Eagle and Colorado Rivers (photograph courtesy of S. Elzinga, Eagle County Weed and Pest Department).**

Tamarisk is more tolerant of drought conditions and saline soils than native species such as willows and cottonwoods, and is displacing native species in many areas of the lower Colorado River. Livestock and wildlife grazing is also favorable to tamarisk because animals preferentially browse on native species such as willow and cottonwood saplings.

There is potential for tamarisk to spread in the lower Eagle River valley, but it is unlikely that it will invade elevations higher than 7,000 ft due to climatic influences, especially the rapid decreases in temperature associated with high elevation zones. Flow regulation in the Eagle River has not modified flows to an extent that favors tamarisk recruitment (Friedmann, USGS, pers. comm., 2004). Highly regulated rivers such as the lower Colorado, favor tamarisk development because of delayed and reduced peak flows. Native vegetation recruitment is dependent upon flow peaks occurring in June or early July. If flow regulation delays or diminishes peak flows, immature native vegetation will likely perish, but tamarisk will not.

The Colorado Weed Management Act tasks the "local governing authority" to design and implement a weed management plan. Within the Eagle River watershed, Eagle County has a weed management plan in place for all unincorporated lands. The following municipalities are responsible for overseeing an integrated weed management plan for all lands within their boundaries: Avon, Eagle, Gypsum, Minturn, Red Cliff, and Vail. Although there have not been cuts in the funding for weed management in Eagle County in recent years, resources are insufficient to address all weed problems. However, Eagle County has taken steps towards increasing its educational outreach. The weed and pest coordinator is available for property visits upon request, and an informative website provides educational assistance to county landowners: http://www.eaglecounty.us/weed.

4.8.10 Riparian Vegetation Recruitment

The most prevalent modification to the flow regime of the Eagle River watershed has occurred in the upper region of the watershed due to major transmountain diversions and the creation of multiple reservoirs. These changes have altered wetland and riparian ecosystems, although the extent of change is unknown. More subtle flow regime alterations in lower elevation regions of the watershed may have also affected native riparian vegetation recruitment. An analysis of required conditions for establishment and survival of native riparian vegetation provides a basis for understanding how flow alteration in the basin is related to changes in riparian vegetation.

Within the semi-arid regions of North America, riparian cottonwood forests are valuable resources that provide aesthetic, environmental, and recreational functions (Braatne *et al.*, 1996; Mahoney and Rood, 1998). The foundation and fate of riparian woodland ecosystems in western North America rely on riparian cottonwoods (Mahoney and Rood, 1998), and it is therefore important to protect and promote their continued establishment. Several factors have led to disruption of riparian zones, including altered flow patterns, deforestation, cattle grazing, and development. Unable to survive under different conditions, sensitive species, such as cottonwoods, have been replaced by more tolerant, non-native species, such as tamarisk and Russian olive. Establishment of non-native riparian vegetation has further decreased the availability of conditions suitable to less tolerant species. Recent efforts have addressed the recruitment of riparian cottonwoods, as a basis for riparian rehabilitation, through modification to the hydrologic flow regime.

4.8.11 Recruitment Box Model

Eagle River riparian zones are diverse, with a variety of cottonwood species. Many species of riparian cottonwoods are dependent upon periodic seedling recruitment, a principal method for seed dispersal and colonization, to counteract high mortality rates. Major hydrologic factors responsible for the decline in riparian cottonwood communities include flood flow attenuation, abrupt changes to flow, and inadequate flows throughout mid to late summer, all of which increase drought stress on new seedlings (Mahoney and

Rood, 1998). The reduction of peak flows alters the required streamflow and stage relationship and prevents the occurrence of erosion and sedimentation processes along riparian zones that are crucial to the establishment of riparian vegetation nursery sites. The alteration of the natural hydrologic and geomorphic processes in the Eagle River watershed may contribute to the decline of riparian cottonwoods.

A clear understanding of the importance of peak flows to the riparian cottonwood ecosystem is a critical management concern. Mahoney and Rood (1998) outlined the chief hydrologic requirements for the recruitment of sexually reproductive riparian cottonwood seedlings in their 'Recruitment Box' model (Figure 4.173).

- The seedling recruitment zone is located within 50 m (or approximately 160 ft) of the stream edge.
- Seedling recruitment usually occurs during streamflow events with recurrence intervals of 1 in 5 to 1 in 10 years. An event of this size stimulates the geomorphic processes that produce barren, alluvial substrates required for recruitment sites.
- Flood flows peak such that seedling dispersal occurs simultaneous to the recession of flow. The stream stage should be declining as to promote initial seeding on bare, saturated surfaces.
- The maximum rate of stream stage decline is 2.5 cm per day. The rate of drawn down of the riparian water table, typically lateral to the stream stage during summer, is critical to the survival of seedlings. Roots need to maintain connection with moist and aerobic soil conditions.

Cottonwood seedling recruitment can be accomplished through artificial flow management and the reconstruction of historic stream stage patterns that meet the requirements of the Recruitment Box model (Figure 4.174). Through application of the model to regulated streams – those altered by reservoirs and diversion structures like the Eagle River – cottonwood establishment within the riparian zone can be beneficial to terrestrial and aquatic ecosystems. This model also provides guidance in identifying and maintaining aspects of existing flow regimes that are relevant to cottonwood recruitment.

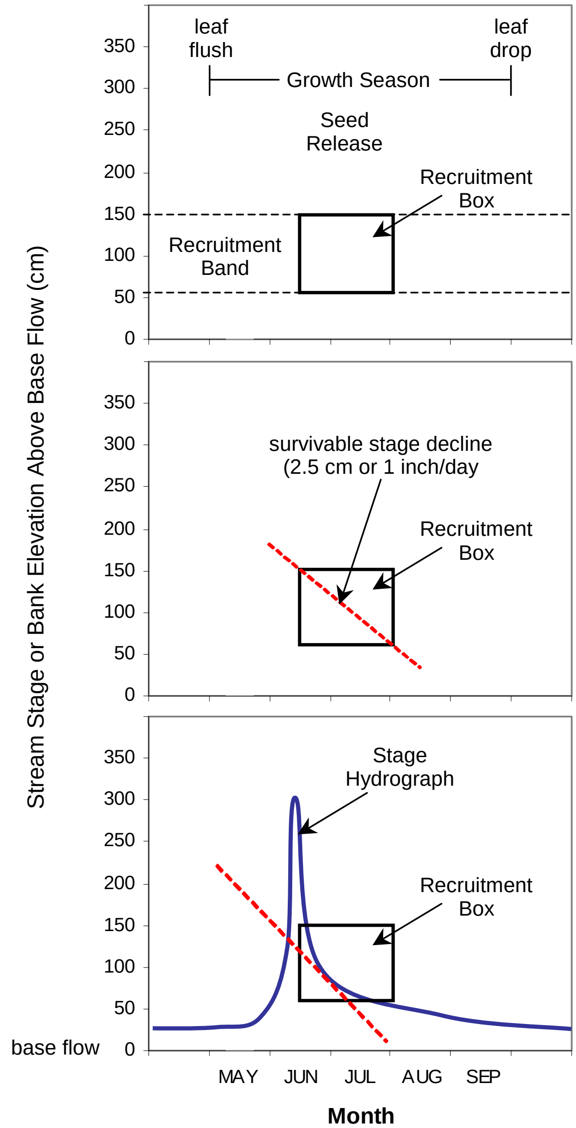


Figure 4.173: The 'Recruitment Box,' a zone defined in elevation and time in which riparian cottonwood seedlings are likely to become successfully established if stream flow patterns are favorable. The graphs represent phenology of components (top), survivable rate of stage decline (middle), and a hydrograph that satisfies requirements for seedling establishment (bottom) (adapted from Mahoney and Rood (1998)).

Figure 4.174: Three stages of riparian cottonwood establishment. Saplings are present in the foreground, and mature trees in the background. A large number of saplings do not survive due to drought stress and cattle browsing and trampling (photograph courtesy of D. Merritt, USFS).

4.8.12 Application of the Recruitment Box to Other Types of Riparian Vegetation

The hydrologic characteristics that encourage cottonwood establishment are comparable to those of other riparian plant species present in the Eagle River watershed. In a study comparing the tolerance of cottonwoods and willows, both of which are dominant riparian species across western North America, to water table decline, Amlin and Rood (2002) found strong similarities in their hydrologic requirements. While cottonwoods generally required gradual stream stage recession at a rate of 2.5 cm/day, willows were slightly more sensitive and required recession rates less than 1 cm/day (Amlin and Rood, 2002). As the foundation of riparian woodlands, the recruitment of cottonwood seedlings promotes the health and abundance of other riparian vegetation with comparable hydrologic demands, especially willows (Mahoney and Rood, 1998).

Many species, however, differ considerably in the timing of seed dispersal and the tolerance to flood events and stream stage recession. The rapidly invasive species *Tamarix*, commonly known as salt cedar, typically seed later and over longer time periods than native riparian woodland species, and thus have an advantage in the presence of modified flow conditions (Merritt and Wohl, 2002), such as those of the Eagle River watershed. For management purposes, the differences in seedling recruitment requirements among varied species of riparian vegetation can be utilized in favor of cottonwood and willow recruitment by modifying the hydrology to eliminate further recruitment of invasive species, such as salt cedar and Russian olive (Merritt and Wohl, 2002; Mahoney and Rood, 1998).

4.8.13 Application of the Recruitment Box Model to the Eagle River Watershed

Reproductive processes of various cottonwood species determine the utility of the Recruitment Box model alone versus its utility in conjunction with less frequent major flood flows, which promote clonal propagation of cottonwoods. The Recruitment Box model incorporates the hydrologic regime necessary for sexually reproductive cottonwoods, which are dominant at elevations less than 7,000 ft above sea level (Merritt, USFS, pers. comm., 2004). This would be specifically applicable to the riparian areas along the Eagle River downstream of Wolcott (Figure 4.173).

At higher elevations, flooding processes as described in the Recruitment Box play a lesser role in cottonwood establishment because asexual reproduction, such as clonal propagation from branch fragments and root suckering, is the dominant method of reproduction (Samuelson and Rood, 2004). Clonal propagation occurs when disturbances from floods, ice scours, and tree falls from wind and rainfall transport the existing vegetative structure, such as a tree branch, to a new location, where moist soil conditions permit reproduction of new saplings. Root suckering results when the roots of a tree produce new growth shoots, creating a complex root system capable of producing multiple trees. Of the two types of asexual reproduction, the propagation of branches can be artificially induced through the promotion of major flood events (Rood *et al.*, 2003; Samuelson and Rood, 2004).

Elevation is often used as an indicator of other environmental factors, including soil, water, and climate conditions, all of which tend to have strong correlation with elevation in the Eagle River watershed. The soil conditions are a decisive factor in the function of sexual reproduction of riparian cottonwoods, which require alluvium for the creation of seedling recruitment sites (Samuelson and Rood, 2004). Higher elevations tend to have appreciably more exposed bedrock than lower regions thereby sometimes necessitating asexual reproduction. Artificial factors, especially cattle grazing, further impact the distribution and survival of riparian saplings. Most severe impacts of cattle grazing are typically noted at lower elevations due to the availability of food, gentle topography, shade, and water, where cattle spend the vast majority of their time (Belsky *et al.*, 1999; Samuelson and Rood, 2004). Cattle browsing, trampling, and fecal material hinder initial seedling establishment (Samuelson and Rood, 2004), which necessitates increased management within the riparian zone for effective riparian cottonwood recruitment.

New research suggests that management techniques for the rehabilitation of riparian vegetation must integrate a clear understanding of the reproductive processes most dominant in the region (Samuelson and Rood, 2004). While the Recruitment Box model is effective for sexually reproductive riparian cottonwoods in the Eagle River watershed at elevations generally below 7,000 ft, asexual reproduction of riparian vegetation, typically prominent in higher elevations, would benefit from major disturbance events. However, riparian cottonwood establishment through seedling recruitment can only be successful if cattle grazing is excluded from the riparian zone during the early years of sapling maturation.

Potential Restoration Projects: Identification and Prioritization

"When those difficult cases occur, they are difficult, chiefly because while we have them under consideration, all the reasons pro and con are not present to the mind at the same time; but sometimes one set present themselves, and at other times another, the first being out of sight. Hence, the various purposes or inclinations that alternatively prevail, and the uncertainty that perplexes us." – Benjamin Franklin

The quotation used to introduce this chapter is excerpted from a letter written by Ben Franklin to a friend struggling with an important and multifaceted decision. Franklin suggested that by listing all aspects of the problem and making the pros and cons simultaneously "present to the mind" his friend would be empowered to make a sound decision through a structured and rational evaluation of the alternatives. Watershed management is certainly a context that challenges us to evaluate many complex and interrelated factors that are not easy to keep in sight at the same time. But an even greater challenge in the environmental decision-making arena is the expanding involvement of stakeholders with diverse preferences, institutional mandates, areas of expertise, and preconceived notions regarding outcomes. The pursuit of rational principles for decision-making in environmental management and other crucibles of democratic debate has spawned a field of study known as decision science or decision analysis. In accordance with the approach suggested by Franklin, formal decision analysis endeavors to structure all of the significant components of a problem and implement analytic techniques to achieve to the greatest extent possible, an unbiased, comprehensive, and justifiable solution (Haas, 2002).

Engineers, managers, and planners are frequently faced with deciding between multiple project alternatives. In the case of watershed restoration, environmental, social, technical, economic, and political considerations can become intertwined to the point of intractability. Accordingly, these criteria need to be systematically examined through an organizing framework for rational analysis and alternative comparison. A Multi-Criterion Decision Analysis (MCDA) approach (Pomerol and Romero, 2000) provides a flexible, rational, and transparent means to establish decision-making criteria and prioritize alternatives. Judgment could be used to accomplish the same task; however, judgment does not allow for others to examine and understand the underpinnings, criteria, and evaluation of a particular decision. The MCDA approach selected for the ERIA is a method intended to be more structured and defensible than 'best professional judgment' yet more interpretable and less complex/data intensive than sophisticated computer optimization schemes. One of the greatest strengths of MCDA is its flexibility. Users can adapt the system to different decision-making situations by adjusting the criteria and weights as knowledge and preferences evolve.

In the ERIA, the identification of several candidate watershed restoration and protection projects in the Eagle River watershed necessitated an MCDA approach that balances ecological, political, social, economical, and technical considerations associated with each project in prioritizing restoration projects and strategies. To build this framework and select a set of evaluation criteria, sources from the scientific literature were consulted, and input sought from stakeholders in the watershed. The result is a decision matrix that can be used to rank potential watershed projects. The matrix uses numerical and categorical ratings for each of several criteria to provide a combined weighted average, or score, for each project. This score is then used to rank and evaluate the set of projects under consideration.

5.1 MCDA FRAMEWORK

Project ranking using MCDA involves several steps (summarized in the flow chart in Figure 5.1). Once we assembled a group of projects we put each project through a collection of screening criteria.

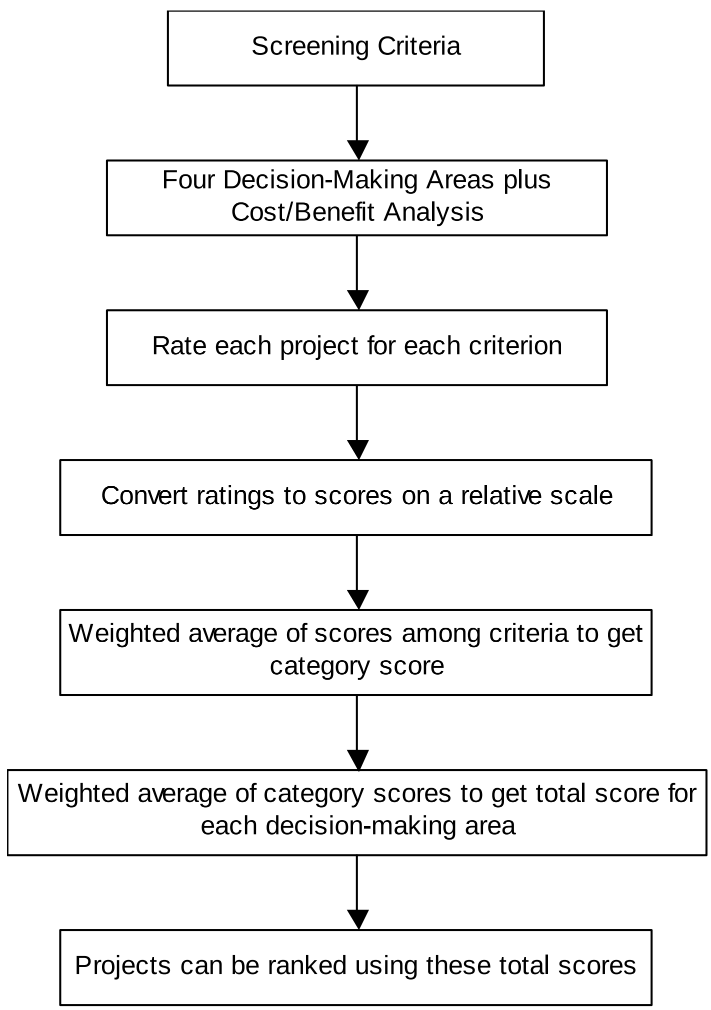


Figure 5.1: General procedure for MCDA.

If a project met all the screening criteria, we put it through a multi-tiered relative scoring process. The top tier included the following five broad decision-making components:

- Ecology
- Watershed Strategy
- Practicality
- Socioeconomics
- Cost (if available)

Note on Cost: This discussion of the MCDA framework makes reference to the organization of criteria for the four decision-making components, these four components being Ecology, Watershed Strategy, Practicality, and Socioeconomics. Cost is a fifth decision-making component but, as mentioned later in this chapter, project cost in this MCDA is addressed differently than the other four decision-making components in this analysis.

Each of these components contains a hierarchy of categories that encompass several specific criteria to which we assigned a rating for each project based on how the project affects each criterion. Table 5.1 contains the decision-making components (excluding Cost) and the categories of criteria within each component.

Table 5.1: Decision-making components and criteria categories.

Ecology	***Watershed Strategy***	***Practicality***	***Socioeconomics***
• Hydrology • Habitat/Geomorphology • Riparian • Biology • Water Quality • System-level Benefits	• Watershed Strategy Including: leverages, volunteer potential, fundraising, and visibility	• Complexity Including: legal, landowner, and technical aspects • Safety Improvement	• Economic Base • Education • Recreation • History

We then converted the rating to a relative scale from zero to one using linear interpolation between the maximum and minimum rating. A higher value corresponds to a higher positive benefit. The value of one is assigned to the project with the highest rating. Within each category, we decided on a relative importance or weight for each criterion based on knowledge of watershed processes and stakeholder feedback obtained throughout the ERIA process. Values representing relative importance are used to calculate a weighted average among the criteria to come up with a category score for each project. We also assigned a relative importance to each category for use in calculating a weighted average score for the four top-level components. These scores were used to rank the projects within each component.

It is important to keep in mind that this MCDA approach is designed to analyze a group of projects or alternatives. Due to the relative nature of some of the criteria, the resulting score for each individual project is only valid within the group of projects being analyzed. Should a certain project be analyzed in a different group, the score should be recalculated, as the value and resulting ranking could be different.

5.2 SCREENING CRITERIA

To screen projects for consideration, four criteria were identified as being "yes" or "no" in nature and determine if a project is a feasible alternative to pursue. The following is a list of these categorical criteria:

1. *Can the project be implemented without posing a significant risk to public health and safety?* No project was considered if it placed users of the Eagle River or its tributaries, inhabitants of the Eagle River

watershed, or the public at large at a significant risk in terms of health and safety. "Risk" includes, but is not limited to, such actions that could potentially degrade water quality to unhealthy levels, create excessively dangerous hazards to boaters in navigable waters, create structures that pose a significant safety hazard for the public, etc.

2. *Is the project potentially compliant with applicable laws?* All alternatives under consideration must be legally feasible. For some projects, the permitting process may be complex, but as long as the project can be legally implemented, it can be considered.
3. *Is the project technically feasible?* Any proposed alternative must appear to be feasible for implementation from an engineering standpoint given current technical information.
4. *Is the project within the Eagle River watershed and consistent with the mission of the Eagle River Watershed Council?* All projects considered for watershed restoration or protection must be consistent with this mission. Furthermore, projects under consideration must be located within the watershed.

If the answer to each of the aforementioned screening questions is "yes," then the project can proceed to the next phase of the MCDA.

5.3 ECOLOGY

The Ecology component of the MCDA is a set of criteria intended to analyze the environmental benefits of a project at multiple spatial scales. The criteria used in this analysis were based largely on the functions and concepts presented in Allan (1995), Angermeier (1997), Angermeier and Karr (1986,1994), Barbour *et al.* (1999), Black (1997), Doppelt *et al.* (1993), Faush *et al.* (2002), Fischenich (2003), Frissell (1997), Karr (1991), Karr and Chu (1999), Poff *et al.* (1997), Whiting (2002), and Wohl (2000). Among these sources, the framework presented by Fischenich (2003) was perhaps the most influential. It identifies fifteen functions outlining relationships between stream processes and ecosystem health identified by a multidisciplinary task force. These functions are organized into the following five categories:

- *System Dynamics* – channel evolution processes/fluvial geomorphology, energy management, riparian succession
- *Hydrologic Balance* – surface water storage processes, surface/subsurface water exchange, hydrodynamic character
- *Sediment Processes and Character* – sediment continuity, substrate and structural processes, quality and quantity of sediments
- *Biological Support* – biological communities and processes, necessary habitats for all life cycles, trophic structures and processes
- *Chemical Processes and Pathways* – water and soil quality, chemical processes and nutrient cycles, landscape pathway

These stream and river functions are assessed using indicators and measurements. Because the Fischenich approach is both complex and data intensive, it required streamlining to render the project evaluation process more interpretable. Based on the goals of the ERIA and data availability, criteria suggested in the scientific literature were adapted to the following categories: *Hydrology, Habitat/Geomorphology, Biology, Riparian, Physiochemical Water Quality,* and *System Level Benefits*. The criteria used in the resulting MCDA framework are designed to express the key ecological processes that indicate watershed health in an understandable framework. For some projects, certain criteria may not apply, but all criteria are needed in the MCDA to assess the full range of projects considered and their potential influence on critical watershed processes and ecological integrity. Table 5.2 summarizes the resulting categories and criteria in this MCDA framework. A range of potential ratings was assigned to each criterion. For most cases, this rating is on a scale from –1 to 1; negative for negative impacts, positive for positive impacts.

Table 5.2: Ecology categories and criteria.

Hydrology	***Habitat/Geomorphology***	***Riparian***
• Magnitude • Timing • Duration • Frequency • Rate of Change • Floodplain Storage • Impervious Area • Floodplain Connections	• Width:Depth • Flow Complexity • Substrate Quality/ Embeddedness • Channel Stability	• Riparian Zone Width/Shading • Energy Sources • Species Diversity

Biology	***Water Quality***	***System-level Benefits***
• Biological Integrity • Native Flora/Fauna • Trophic Structures • CNHP Biota • CNHP Conservation Areas	• Fine Sediment • Dissolved Oxygen • Metals • Toxins • Temperature • Phosphorus • Nitrogen • Nitrogen:Phosphorus ratio	• Urgency • Restored Length • Connected Length • Restored Floodplain Area • Limited by Other Projects

The following list describes the ecology criteria used in the MCDA:

- *Hydrology* – These criteria describe changes to the flow regime (magnitude, timing, duration, frequency, and rate of change), the amount of water stored in the floodplain (wetlands, ponds, side channels, shallow groundwater), impervious area in the basin, and floodplain connectivity (surface and subsurface connections between uplands, riparian zones, and the channels).
- *Habitat/Geomorphology* – This category involves channel morphology with respect to aquatic and riparian habitat and includes changes to the width to depth ratio, hydraulic complexity (depth-velocity combinations) as affected by roughness elements, wood debris and other local geomorphic heterogeneity, substrate embeddedness/diversity/quality, bank condition, and channel stability. Rapid field measurements for assessing these characteristics are outlined in Barbour *et al*. (1999) and numerous other physical habitat protocols.
- *Riparian* – These criteria describe the width of the riparian corridor, the diversity of native riparian vegetation species, energy source and structural inputs to the channel from riparian vegetation, and shading/temperature benefits.
- *Biology* – This category involves the species and processes that make up the aquatic biotic communities. As in the Riparian category, emphasis is placed on native species and ecological integrity. Also included are criteria that support the Colorado Natural Heritage Program's (CNHP) identified conservation areas and goals.
- *Physiochemical Water Quality* – This category examines improvement or degradation resulting from changes in fine sediment loading or deposition, dissolved oxygen, temperature, metals and other toxins, phosphorus, nitrogen, and nitrogen to phosphorus ratio.
- *System Level Benefits* – This category is intended to give special consideration to projects that have positive effects on the watershed beyond the project boundary. The category includes criteria

describing the extent of the project and any high-quality habitat that the project reconnects, the urgency of the project, and limitations caused by other projects.

Of these six categories of criteria, System-level Benefits was deemed the most significant. As discussed in Chapter 2, effective watershed management involves restoring processes that create and sustain habitats and ecosystems. Restoring key processes provides much greater benefits to the watershed than simply installing a patchwork of engineered habitats with little regard for the watershed context outside of the project boundaries. Reconnecting areas of currently fragmented high quality habitats provides disproportionately greater ecological benefits both upstream and downstream of the project area.

5.4 WATERSHED STRATEGY

The Watershed Strategy component contains one category of criteria that describes how the project leverages other restoration activities in the watershed, the potential for community and volunteer involvement, the potential for fundraising, and the visibility of the project on a local, state, and/or national scale. This list of criteria was developed in large part based on input from watershed stakeholders. The individual criteria are presented in Table 5.3.

Table 5.3: Watershed Strategy criteria.

Watershed Strategy
• Leverages Other Activities • Community/Volunteer Involvement • Fundraising Potential • Project Visibility

5.5 PRACTICALITY

This component of the MCDA accounts for influences on decision-making involving the practicality of a project with respect to risk and technical uncertainty. Table 5.4 presents the practicality criteria as used in the MCDA. These criteria, similar to those in *Watershed Strategy*, were developed based on input from watershed stakeholders and includes the following two categories:

- *Complexity* – This category involves the complexity of the project with respect to the legal/permitting procedure, landowner cooperation, and design/implementation.
- *Risk to Public Health and Safety* – This category deals with how and if the project will improve public health and safety.

Table 5.4: Practicality categories and criteria.

Complexity	***Safety***
• Legal/Permitting Complexity • Landowner/Access Complexity • Technical Complexity	• Safety Improvement

5.6 SOCIOECONOMICS

Because many people living in or visiting the Eagle River watershed use the river and tributaries for recreational purposes, recreational benefits and linkages were also represented in the MCDA. The biodiversity and rich history of the Eagle River watershed provide great potential to educate a variety of individuals about the nature and value of river ecosystems. These potential benefits are included in the Social section of the MCDA (Table 5.5). The following list outlines the specifics of these criteria:

- *Economic Base* – This category involves long-term support for the economic base in the watershed. For example, should a project support sustainable public fishing access, it will score high in this category because it supports long-term recreation and tourism revenues in the watershed.
- *Education* – This category rates the potential for the project to be used as a context for educational activities and outreach. Projects score high in this component if they have a high potential for eco-interpretive signs, field trips, youth education, demonstration projects, and adult natural history seminars.
- *Recreation* – Fishing, rafting, and kayaking bring significant tourism revenues into Eagle County as well as provide recreational benefits for residents. This category includes criteria addressing additional public access to the river, additional parking available at a site, enhanced boating on the river, and enhanced trout habitat for anglers.
- *History* – Some projects, Camp Hale in particular, have significant historical components and values. This category addresses the potential for conducting restoration while maintaining or enhancing the historical significance of a site.

Table 5.5: Socioeconomic criteria.

Economic Base	***Education***	***Recreation***	***History***
• Sustains Local Economic Base	• Environmental Education Potential	• Public Access • Vehicles • Whitewater Value • Game Fish Habitat	• Historical Value

5.7 COST

Separate from the MCDA is a cost analysis of projects under consideration. Clearly, the cost of design, implementation, and maintenance plays an important role in project selection. However, detailed engineering analysis is required to generate reasonably accurate cost estimates for each project. Several cost-benefit analysis techniques are available to analyze economic aspects of project alternatives. Cost-benefit analysis was kept separate from the MCDA because the MCDA is intended to provide a rapid assessment of the watershed benefits and feasibility of each project. Because specific alternatives have not been fully identified and selected, costs for individual projects require further refinement. As a starting point, we have identified 'tiers' as described below. In accordance with the objectives of the ERIA, more detailed cost estimates are provided for selected high priority projects highlighted in Chapter 6 'Recommendations' and in Appendix A.

5.8 SPECIAL CASES

Several projects in the watershed have spatial or other overarching multi-project connections that needed to be addressed in the development of the framework and criteria. Furthermore, the distinction between conservation and restoration projects and the variability in the degree of urgency among projects were also important aspects for consideration. These factors are described below.

5.8.1 Limitations Caused by Other Projects

The "Limited by Other Projects" criterion (*Ecology, System Level Benefits*) was added to address a situations like that occurring at the U.S. Forest Service access point just upstream of the Gore Creek – Eagle River confluence. One project considered in the MCDA involves combining improved access with channel habitat improvements at this access point. However, ongoing metals loading from the upstream Eagle Mine suggest that water quality at this project site is currently an overarching limiting factor in restoring the aquatic biologic community. In other words, habitat improvement will have diminished benefits if metals concentrations remain at toxic levels for at least some biota.

5.8.2 Conservation Versus Restoration Projects

Projects in the watershed can be classified in a general sense as either restoration projects or conservation projects, although some involve both elements. A restoration project assists the recovery of the watershed system or implements a policy that reverses degradation in the watershed. Restoration of Camp Hale is an example of this type of project. Alternatively, a conservation project involves maintaining the natural values of an existing high quality area of the watershed. This type of project typically involves a fee simple or conservation easement purchase of a property containing high quality habitat at risk. The MCDA is designed to evaluate either type of project. To evaluate a conservation project, the user may analyze the project by forecasting the future state of the project site that has the greatest likelihood of occurring under ongoing management scenarios, and comparing this state to the current healthy state as the post-project state.

5.8.3 Opportunity Cost

The MCDA includes a criterion that rates the ecological urgency of a project (*Ecology, System Level Benefits*). This criterion provides a means of evaluating the magnitude of degradation that could occur if the project is not implemented. For example, should failure of Eagle Mine waste rock cribbings occur and result in deposition of mine tailings into the river, there is the potential for catastrophic loss of aquatic life. This criterion allows the user to assign additional weight to such projects.

5.8.4 Criteria/Category Weightings

Category and Total scores are calculated using a weighted arithmetic average. Table 5.6 contains the weights used for each category and criterion in the MCDA. Initially, all weights were set to an equal value of 1. Some of these weights were adjusted to reflect the importance of certain issues in the Eagle River watershed, based on knowledge gained from stakeholder input throughout our study and two public meetings/presentations, interpretation of the scientific literature, and expert judgment. The greatest weights were given to criteria and categories that involve basin-wide impacts. This section explains the justification behind the increased weights.

Table 5.6: Category and criteria weights used in MCDA.

ECOLOGY					
Hydrology	**1**	**Habitat/Geomorphology**	**1**	**Riparian**	**1**
Magnitude	1	Width:Depth	1	Width	1
Timing	1	Flow Complex.	1	Energy Input	1
Duration	1	Substrate	1	Species Diversity	1
Frequency	1	Stability	1		
Rate of Change	1				
Floodplain Storage	2				
Impervious Area	1				
Floodplain Connectivity	2				
Biology	**1**	**Water Quality**	**1**	**System Level**	**5**
Communities	1	Fine Sediment	1	Limitations	5
Natives	1	Dissolved Oxygen	1	Length	1
Food Web	1	Metals	1	Connected Length	3
CNHP Biota	1	Toxins	1	Improved Floodplain	2
CNHP Areas	1	Temperature	1	Urgency	10
		Phosphorus	1		
		Nitrogen	1		
		Nitrogen:Phosphorus ratio	1		

WATERSHED STRATEGY		*PRACTICALITY*			
Strategy	**1**	**Complexity**	**3**	**Safety**	**1**
Leverage	2	Legal	1	Safety Improvement	1
Volunteer	1	Landowner	1		
Fundraising	1	Technical	1		
Visibility	1				

SOCIOECONOMICS							
Economic Base	**3**	**Education**	**1**	**Recreation**	**2**	**History**	**1**
Economic Base Support	1	Environmental Education Potential	1	Access	2	Historical Value	1
				Vehicles	1		
				Whitewater	1		
				Game Fish	1		

5.8.4.1 Ecology

Particular weight was given to System Level Benefits under the *Ecology* component. We endeavored to use process-based approach to emphasize the importance of ecosystem-wide ecological functions. The System Level Benefits category contains the criteria used to quantify large-scale valley segment or basinwide benefits. Under this category, Urgency was heavily weighted to reflect the importance of implementing some projects in a timely manner due to an elevated risk of ecological degradation. Key processes required to be in place for restoration success include adequate water quality and streamflows. The ‘limitations’ criterion reflects the concept that if a candidate project area is likely to experience ongoing water quality and/or low flows, the ecological effectiveness and sustainability of the project are constrained. The ‘limitations’ criterion was also given considerable weight. The extra weight for the Connected Length criterion is intended to consider projects that not only improve habitat along the project reach, but also reconnect areas of high quality habitat. Multiple projects in the basin offer this type of habitat reconnection. Because floodplain connections and functions have been lost at a number of locations in the watershed, criteria that involve restoring floodplain area are given extra weight throughout the *Ecology* component. Improved Floodplain area is given extra weight under System Level Benefits to reflect the importance of the processes of a properly functioning floodplain. To further emphasize this, weight was given to the Storage and Connectivity criteria under Hydrology.

5.8.4.2 Watershed Strategy

The Leverage criterion in this component was given extra weight to reflect the potential for certain projects to be implemented synergistically.

5.8.4.3 Practicality

All of the criteria in this component are weighted equally. However, the Complexity category is weighted heavily over the Safety category. For the candidate projects selected in the watershed, legal, landowner, and technical complexity collectively play a greater role in the feasibility of a project than safety.

5.8.4.4 Socioeconomics

Economic Base is the most heavily weighted category in the *Socioeconomics* component. A variety of stakeholders have consistently expressed a desire that particular consideration be given to projects that support the long-term economic base in the watershed through sustainable tourism and recreation. Accordingly, additional weight was given to the Recreation category because of the economic and social significance of river recreation in the basin. Under this category, extra weight was given to the Access criterion due to the social importance of long-term sustainable public access.

5.8.4.5 Project Tiers

To facilitate comparison, candidate restoration projects in the watershed were divided into three tiers based on the magnitude of design and implementation costs, time requirements, and legal/access complexity. The first tier consists of short-term, lower cost projects (< approximately $300,000) that may be implemented partially or largely through volunteer activities. Tier 2 contains projects of moderate cost (approximately $300,000 to $2,000,000) and time requirements (< 3 years). The top tier, Tier 3, is a collection of relatively high cost (> approximately $2,000,000) and/or long-term "visionary" projects that necessitate a relatively high degree of planning, long-term and/or widespread interventions, and complicated legal and/or landowner issues. Table 5.7 presents notable projects for each tier and descriptions of these projects follow.

Table 5.7: Example projects classified into the three tiers.

Tier 1	*Tier 2*	*Tier 3*
• Avon Restoration – Local Areas • Eagle Canyon Litter Cleanup • Remove Piling in Avon • Riparian Planting – Lower Eagle • Riparian Tamarisk Removal • Riparian Work – Wolcott	• Belden Cribbings • Edwards/Lake Creek Segment • Enhance Gypsum SWA • Long-term Rec. Access Plan • Minturn Confluence Segment • Non-Native Species – Camp Hale	• Basinwide Nutrient Strategy • Camp Hale Restoration • Eagle Mine/Belden • Milk/Alkali/Ute Creeks • Flow Management/Decision Tools

5.9 RESULTS OF THE MCDA

The MCDA framework was used to analyze the 18 candidate projects listed in Table 5.8. The projects were ranked using the resulting Total Score for each of the four decision-making components and a summary of these rankings is presented in Table 5.8. A detailed breakdown of the criteria ratings is provided in Appendix L. For spatial orientation and comparison, the results were superimposed on maps of the watershed. Figures 5.2, 5.4, 5.6, and 5.8 illustrate the rankings for all of the projects for each component; the rankings are displayed with green indicating higher priority projects and red indicating lower priority projects. Figures 5.3, 5.5, 5.7, and 5.9 depict the top projects for each component.

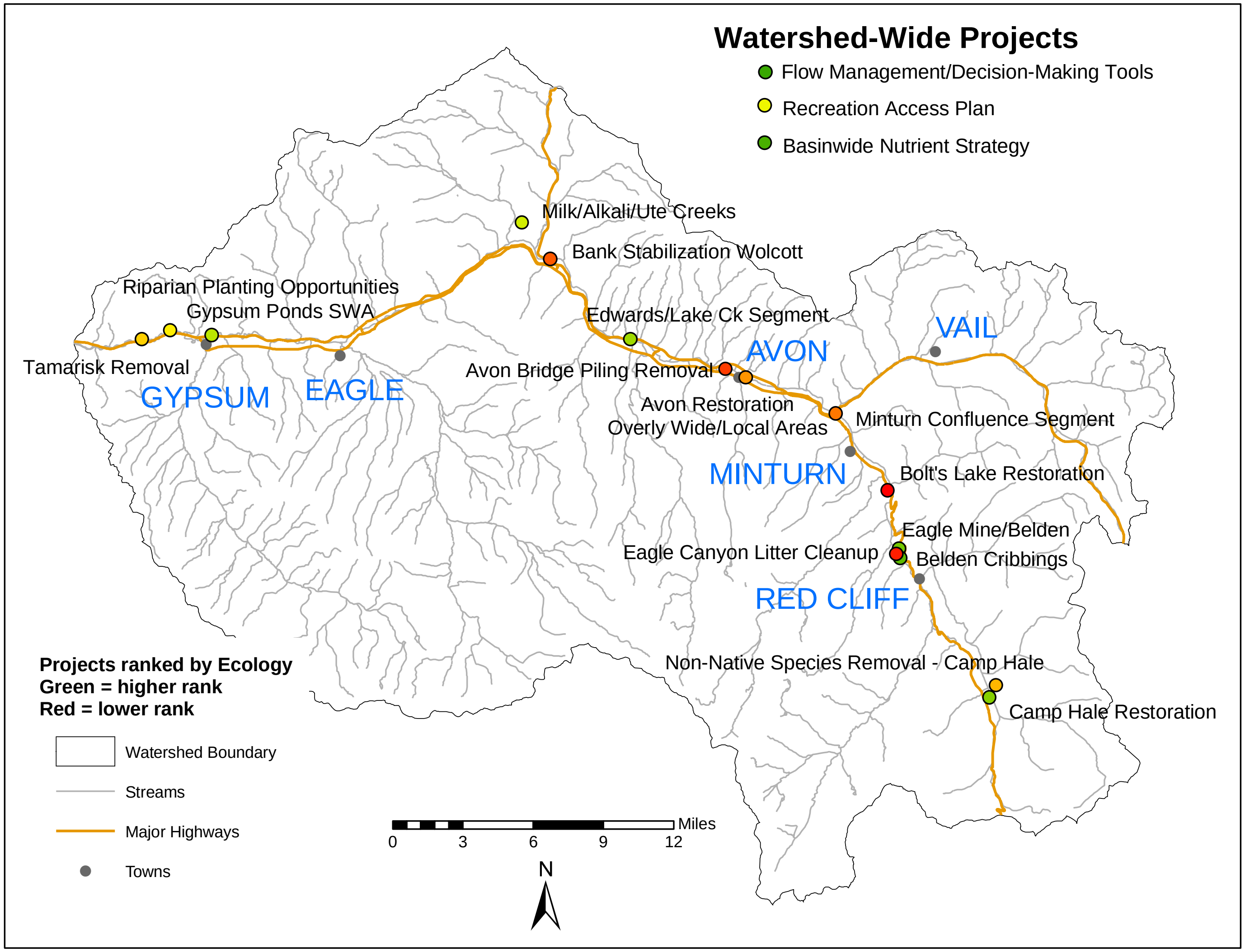
The project rankings and weights presented in this chapter are estimates based on currently available information. The rankings provide a general overview of what projects are likely to provide the most significant benefits in the watershed. It must be reiterated, however, that the MCDA technique clusters projects of similar benefits and character in a relative sense and that attaching significance to slight differences in scoring among closely ranked projects is not warranted given the precision of the scores. Socioeconomics, Practicality, and Watershed Strategy rankings will undoubtedly require additional refinement as more detailed information becomes available and stakeholders provide additional input. Specific benefits for the top-ranked projects are provided below.

For the three components besides *Practicality*, Camp Hale Restoration, Eagle Mine/Belden Cleanup, Gypsum Ponds SWA Restoration, Edwards/Lake Creek Restoration, Basinwide Nutrient Strategy, and Flow Management Tools consistently are among the top-ranked projects. The Belden Cribbings and the Recreation Access Plan are among the top-ranked in two of these three components. Taking *Practicality* into account and averaging the ranks for all of the projects, the aforementioned projects are at the top of the list, with the Recreation Access Plan ranked highest among all projects. The common thread among these projects is their potential to connect high-quality habitats and/or their watershed-wide benefits; several of these projects were also identified as high priorities during preliminary watershed stakeholder meetings.

Among the smaller projects, Eagle Canyon Litter Cleanup, Minturn Confluence Segment (restoration at the U.S. Forest Service access site), and Riparian Planting / Tamarisk Removal are ranked highly. These projects generally do not offer the wide-ranging benefits of the larger projects, but are practical to implement should resources become available and have a high potential for volunteer support.

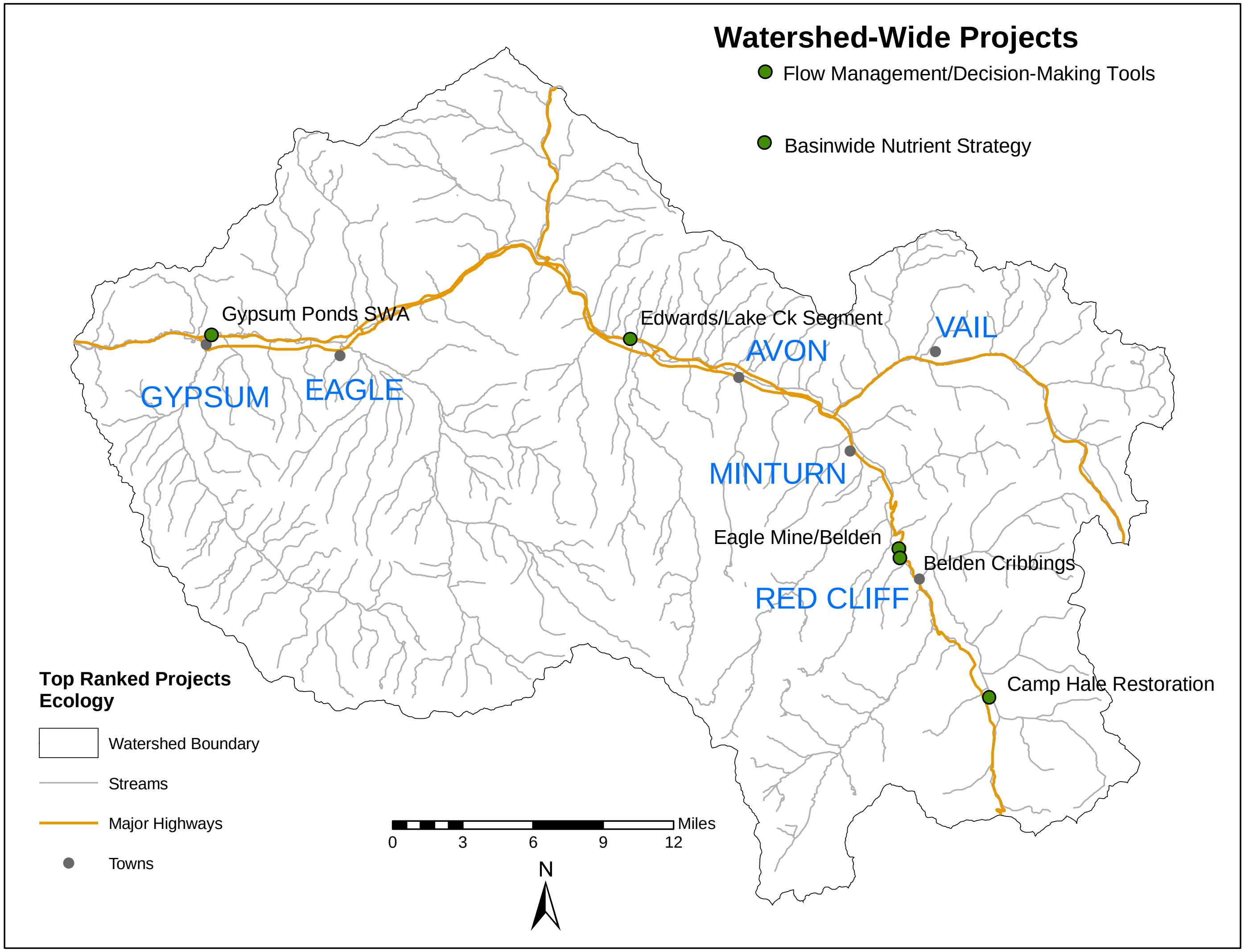
Table 5.8: Summary of MCDA preliminary rankings.

Project	Tier	*Rankings*			
		Ecology	Watershed Strategy	Practicality	Socio-economics
Avon Restoration - Overly wide, Localized Areas	1	13	12	6	15
Basinwide Nutrient Strategy	3	2	2	17	5
Belden Cribbings	2	3	4	8	8
Bolt's Lake Restoration	2	18	17	16	13
Camp Hale Restoration	3	5	1	14	1
Eagle Canyon Litter Cleanup	1	17	10	2	11
Eagle Mine/Belden	2	4	4	13	7
Edwards/Lake Creek Segment	2	6	7	12	4
Enhance River Habitat in Gypsum Wildlife Area	2	7	7	9	3
Flow Management/Decision-Making Tools	3	1	3	17	6
Long Term Access Plan for Low Impact Recreation	2	9	6	3	2
Milk/Alkali/Ute Creeks	3	8	15	15	10
Minturn Confluence Segment	2	14	14	7	9
Non-native Species Removal – Camp Hale	2	12	10	11	11
Remove Piling in Avon	1	16	18	1	18
Riparian Planting Opportunities - Lower Eagle & Eagle Valley Tribs	1	10	9	10	14
Riparian Tamarisk Removal - Lower River and Tribs	1	11	16	5	17
Riparian Work/Bank Stabilization Upstream of Wolcott	1	15	12	4	16



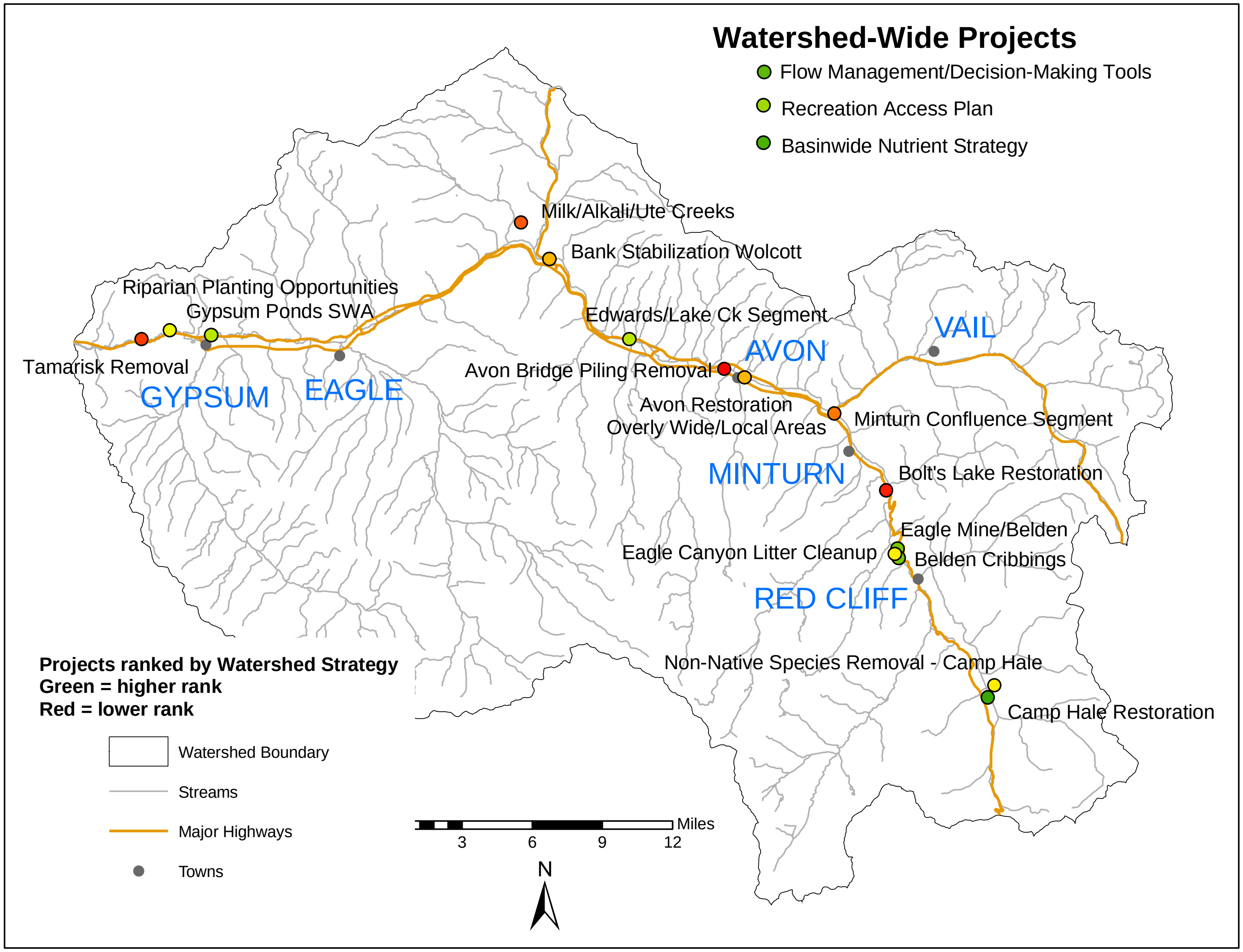
Color shades ranging from red to yellow to green correspond to lower, moderately, and higher ranked projects, respectively. Watershed-wide projects are not given a location on the map but are listed at the upper right.

Figure 5.2: Watershed projects ranked by Ecology criteria.



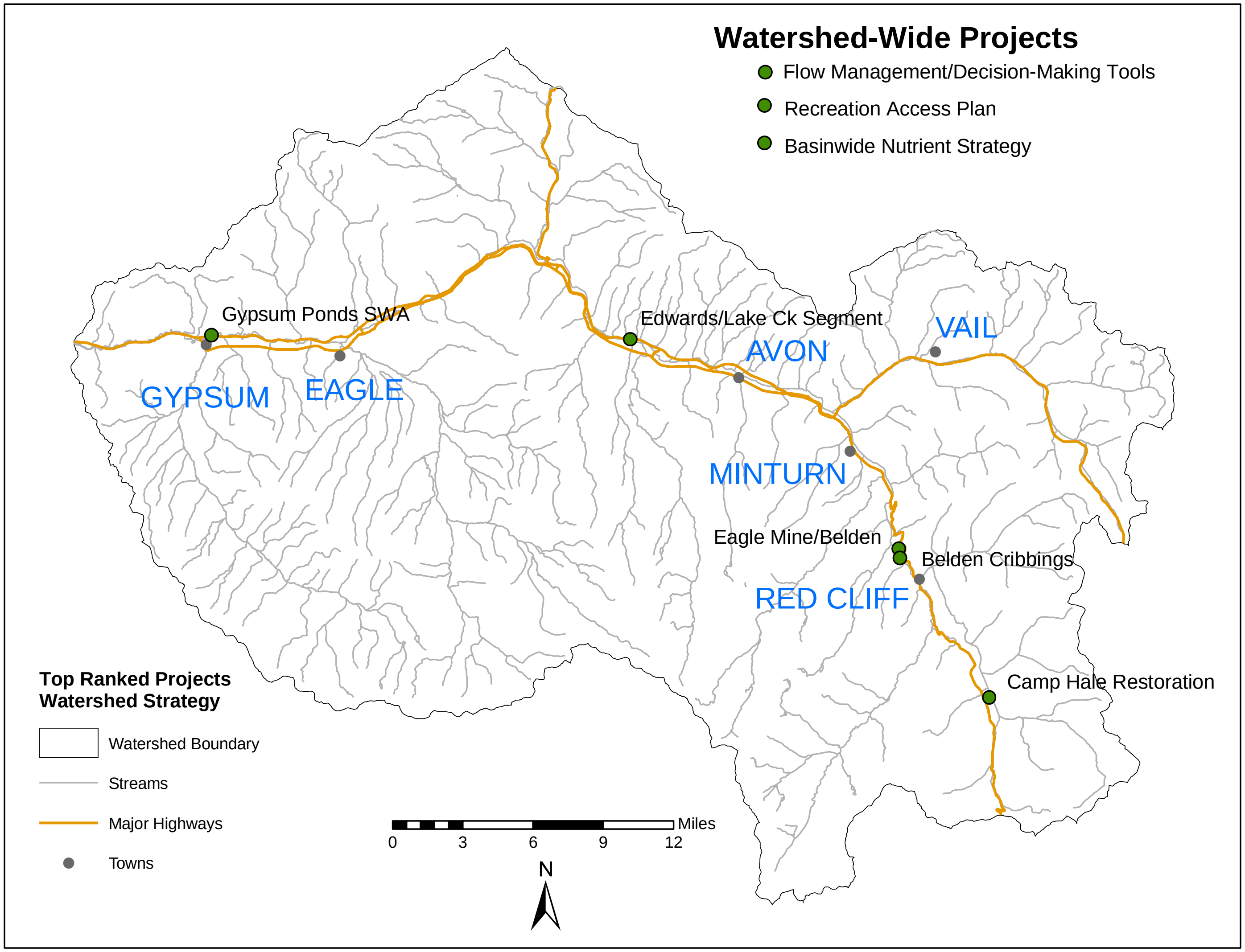
Color shades ranging from red to yellow to green correspond to lower, moderately, and higher ranked projects, respectively. Watershed-wide projects are not given a location on the map but are listed at the upper right.

Figure 5.3: Top-ranked watershed projects based on Ecology criteria.



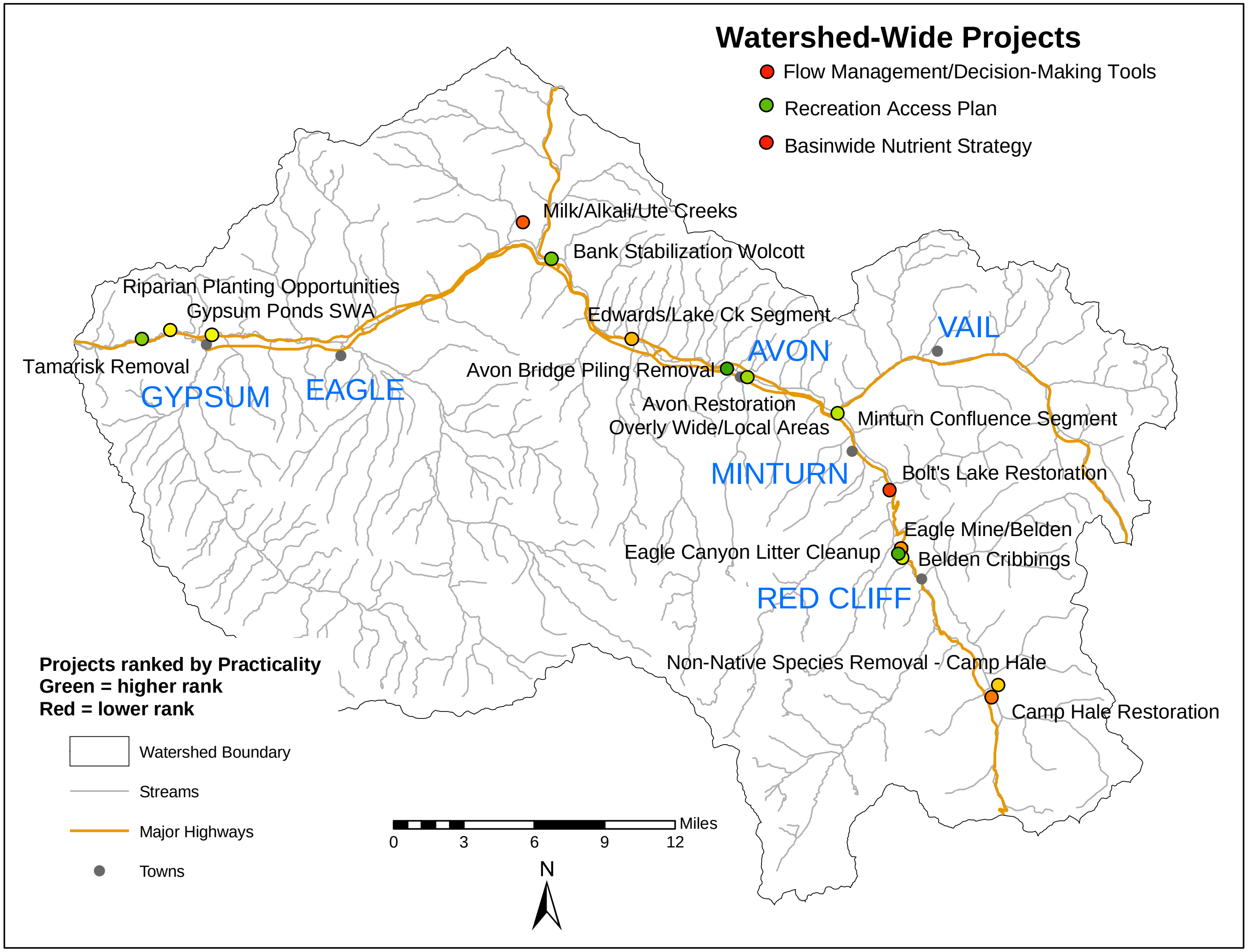
Color shades ranging from red to yellow to green correspond to lower, moderately, and higher ranked projects, respectively. Watershed-wide projects are not given a location on the map but are listed at the upper right.

Figure 5.4: Watershed projects ranked by Watershed Strategy criteria.



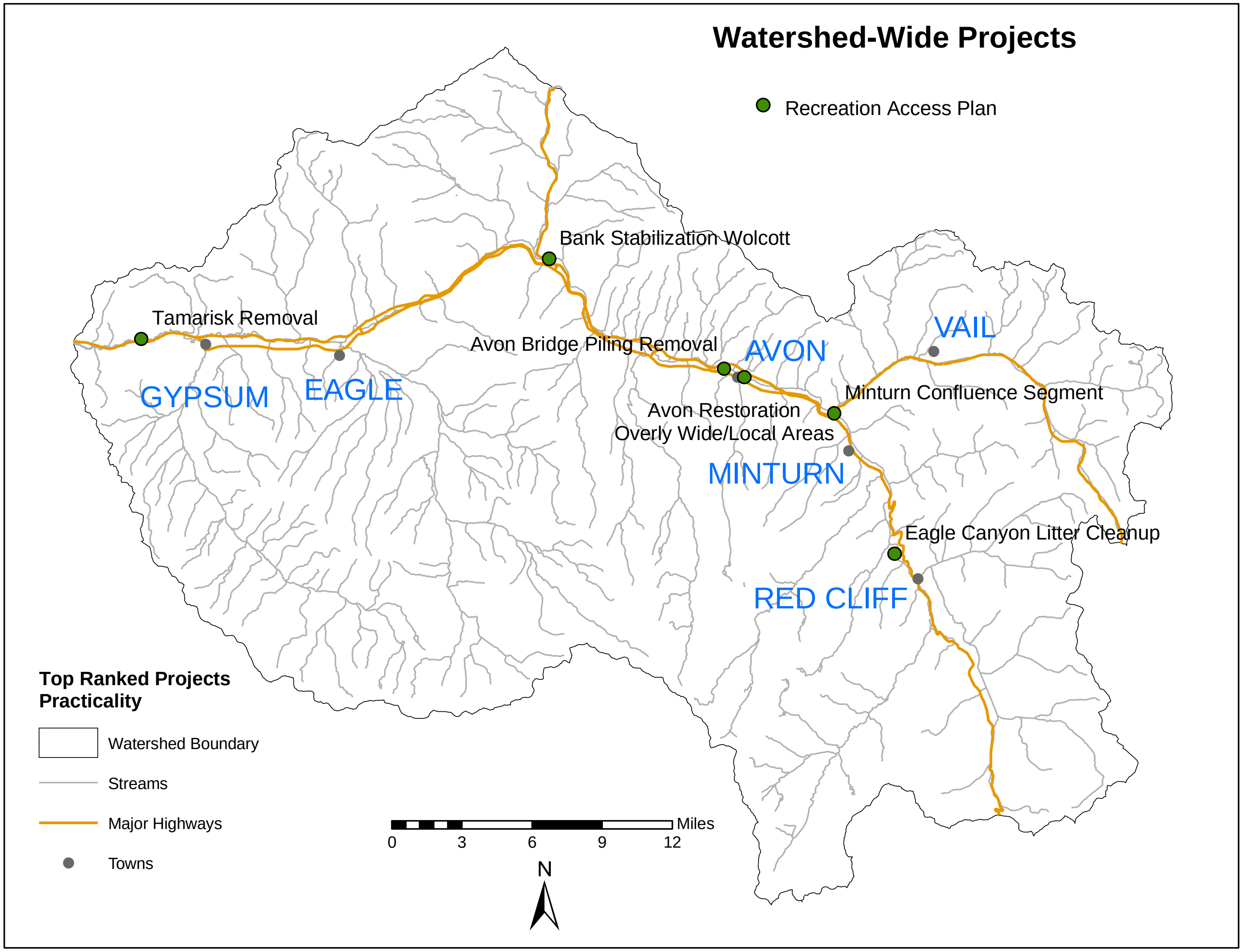
Color shades ranging from red to yellow to green correspond to lower, moderately, and higher ranked projects, respectively. Watershed-wide projects are not given a location on the map but are listed at the upper right.

Figure 5.5: Top-ranked watershed projects based on Watershed Strategy criteria.



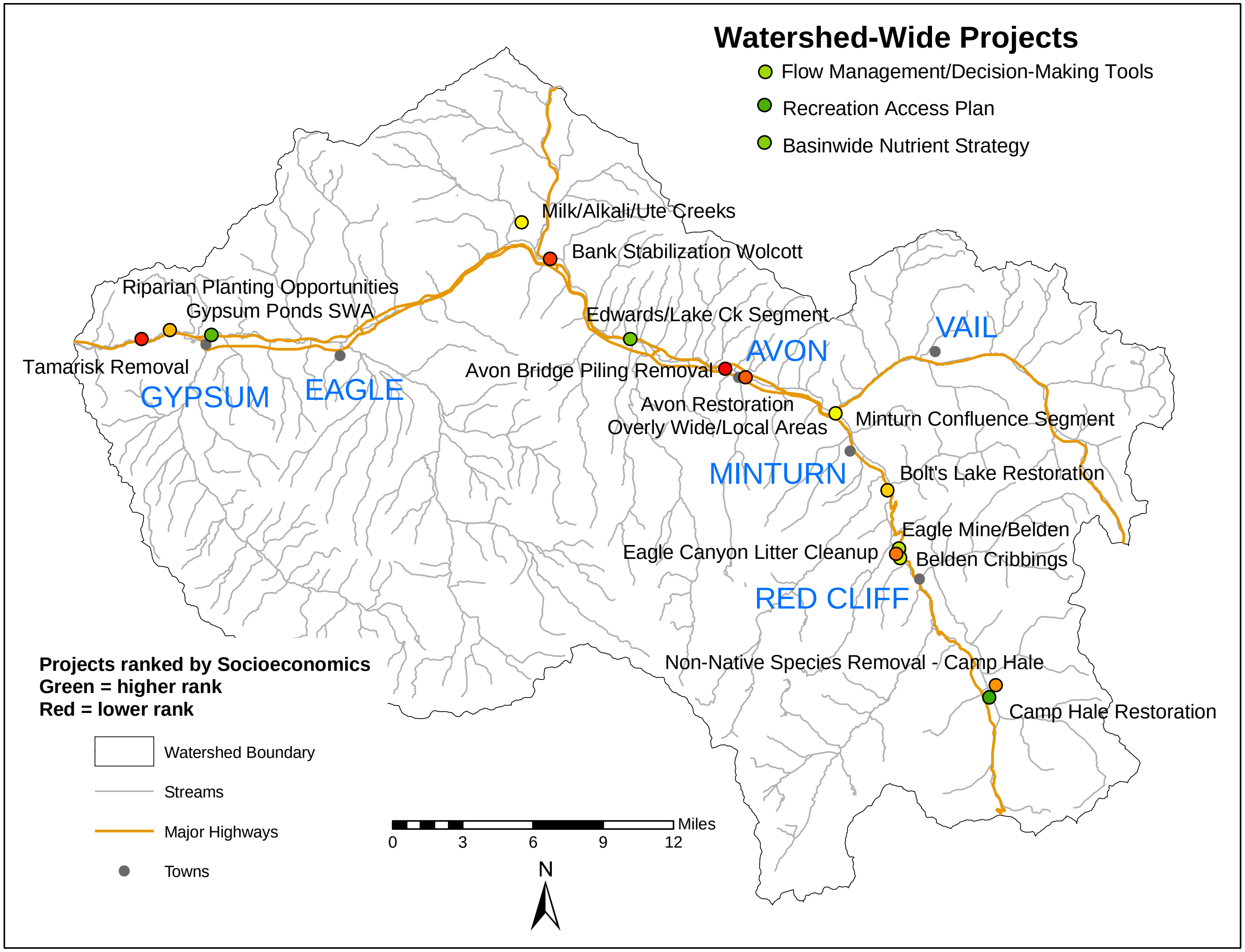
Color shades ranging from red to yellow to green correspond to lower, moderately, and higher ranked projects, respectively. Watershed-wide projects are not given a location on the map but are listed at the upper right.

Figure 5.6: Watershed projects ranked by Practicality criteria.



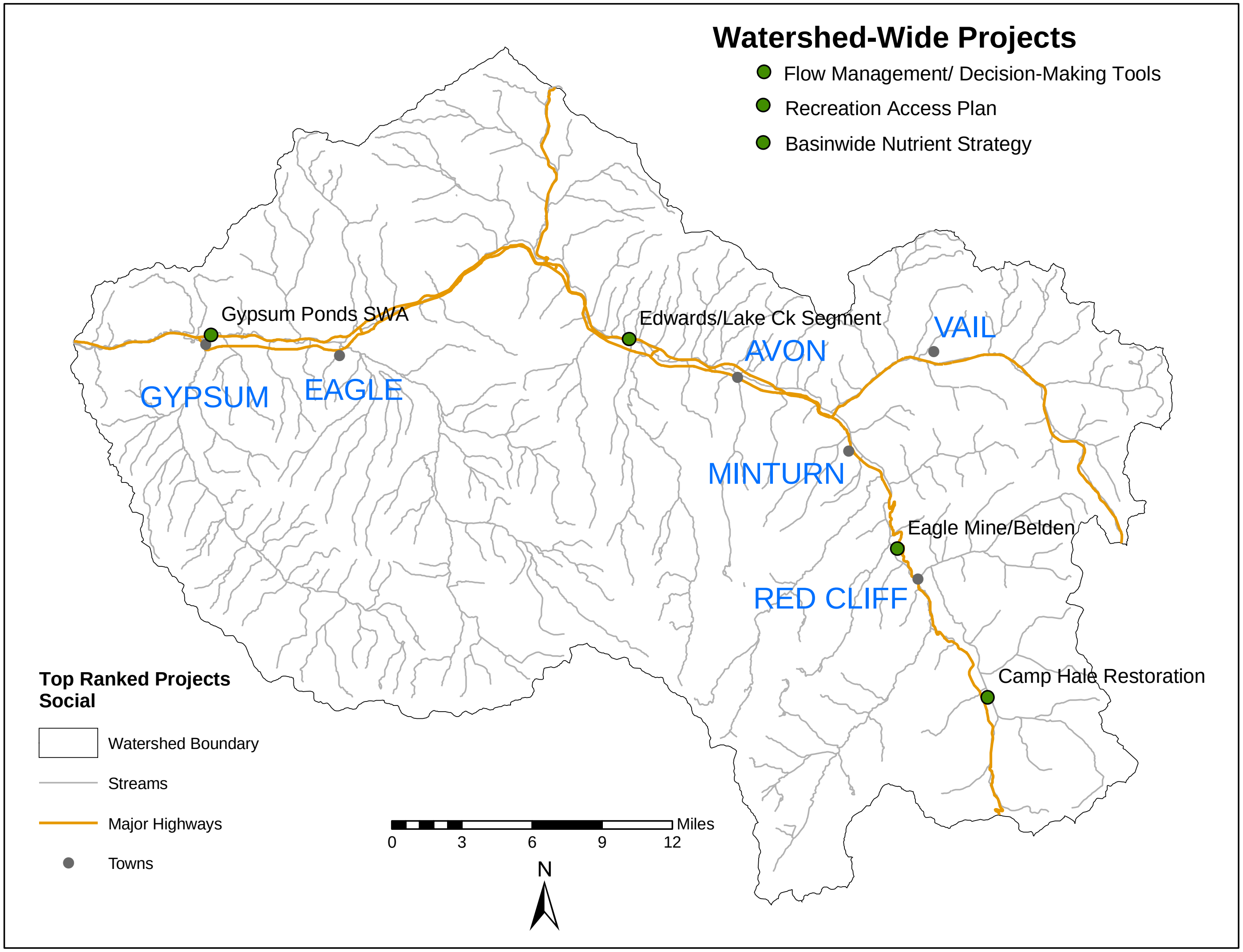
Color shades ranging from red to yellow to green correspond to lower, moderately, and higher ranked projects, respectively. Watershed-wide projects are not given a location on the map but are listed at the upper right.

Figure 5.7: Top-ranked watershed projects based on Practicality criteria.



Color shades ranging from red to yellow to green correspond to lower, moderately, and higher ranked projects, respectively. Watershed-wide projects are not given a location on the map but are listed at the upper right.

Figure 5.8: Watershed projects ranked by Socioeconomics criteria.



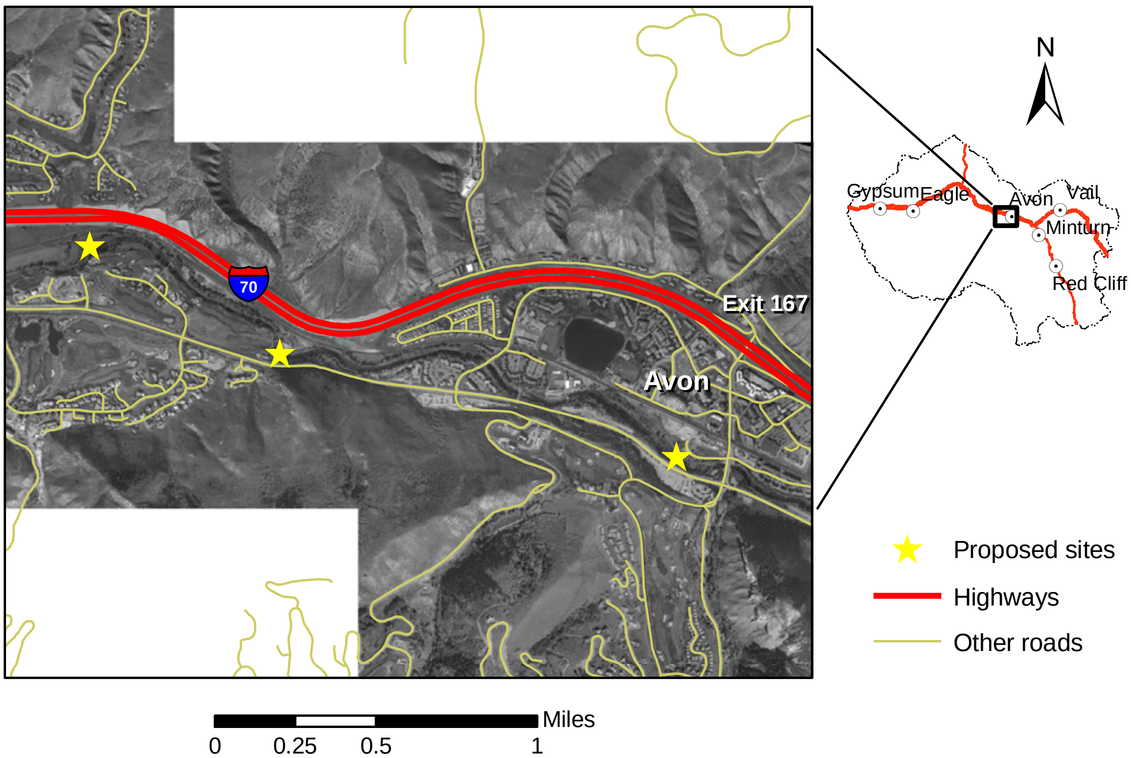
Color shades ranging from red to yellow to green correspond to lower, moderately, and higher ranked projects, respectively. Watershed-wide projects are not given a location on the map but are listed at the upper right.

Figure 5.9: Top-ranked watershed projects based on Socioeconomics criteria.

5.9.1 Candidate Projects Summaries

This section provides brief descriptions of candidate projects in the watershed. The list of potential projects was created from extensive stakeholder input and based on findings of the ERIA. Each project is presented with the location, project site ownership (public versus private), a bulleted list summarizing key project benefits, a description of the project, and a summary of how the project ranked in the MCDA framework.

5.9.1.1 Avon Restoration – Overly Wide, Localized Areas



Location

N 39°32’42” E 107°01’18”; N 39°38’59” E 107°00’33”; N 39°39’05” E 106°56’10”

Ownership

These projects are located on 2-3 parcels of private land.

Benefits

- Small-scale rehabilitation to reduce channel width, increase depth of flow, and enhance fish habitat
- Establish and protect riparian vegetation to provide shade and bank stability
- Opportunity for volunteer involvement

Project Description

Several segments of the Eagle through Avon, including the access point just downstream of “Bob” the bridge and two bends along the Arrowhead golf course, have been identified as being overly wide based on a hydraulic geometry analysis of the Eagle River. This proposed project involves grouping these sites into habitat improvement project that simultaneously addresses areas throughout the Avon segment of the main stem Eagle. These would be small-scale rehabilitation efforts to reduce channel width, increase depth of flow, and enhance fish habitat. Measures to ensure that riparian vegetation is established and protected would be included as part of the package with some aspects of these projects being accomplished through volunteer activities.

Ranking Summary

This project ranked low in Ecology and Socioeconomics. Within the Ecology component, most of the score reflects habitat and riparian improvements. Because of the small size of the three project sites, the scores were low compared to larger habitat improvement projects. The project ranked moderate for Watershed Strategy. In this component, the project provides an avenue for volunteer involvement, but the project would do little to leverage other projects or fulfill the broader goals of the watershed council. Points were awarded in Socioeconomics for the potential small-scale recreation and education benefits. Because the project would be relatively simple and inexpensive to implement and could involve volunteer support, it ranked high in the Practicality component. The design of these projects would be based on providing the elements of physical habitat outlined in Chapter 4. The main goals of restoration at these sites would be reducing channel width, increasing depth of flow, providing a variety of physical habitat types, stabilizing the banks, and protecting the riparian corridor.

5.9.1.2 Basinwide Nutrient Strategy

Location

Watershed-wide

Benefits

- Manage nutrient enrichment from point and non-point sources
- Prevent impacts to aquatic insect communities and accumulations of algae
- Link nutrient loading and streamflow to predict ecological responses
- Set nutrient loading targets
- Assess NPDES discharge permits in a watershed-wide collective analysis
- Implement nutrient loading monitoring

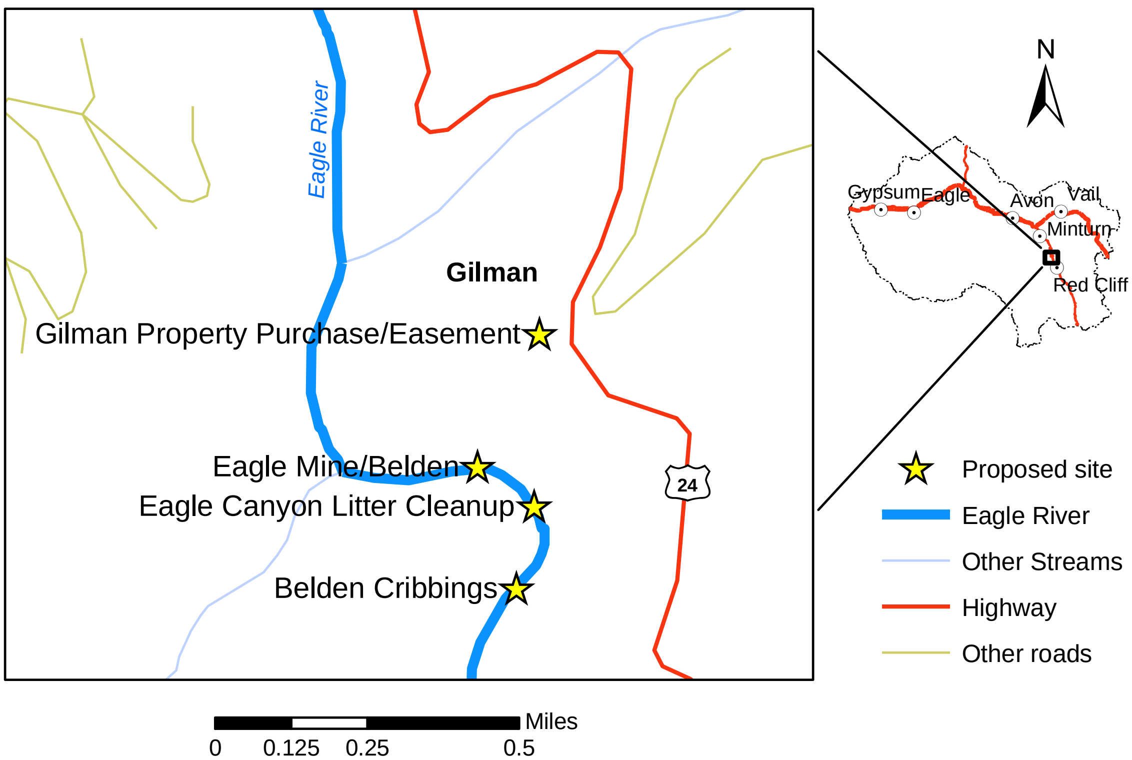
Project Description

Nutrient concentrations in the Eagle River and Gore Creek are now substantially higher than levels observed in less disturbed streams and rivers of the Colorado Rockies, as well as values recommended to prevent impacts to aquatic insect communities and nuisance accumulations of algae. Nutrient loading is expected to continue increasing under current point source discharge permits and from polluted runoff. This project involves developing a watershed wide strategy for managing nutrient enrichment based on the best available scientific information. Steps in implementing such a strategy would include: (1) linking current and expected future total nitrogen and phosphorus loading, and streamflows with probable ecological responses of algae (periphyton), aquatic insects, and trout, (2) setting nutrient loading targets that are likely to result in desired ecological states based on current science and monitoring data, (3) simultaneously assessing NPDES discharge permits in a watershed-wide, collective analysis to achieve loading targets in the most cost-effective manner and to facilitate collaboration among all dischargers and nonpoint sources, and (4) implementing a monitoring program specifically designed to assess whether target nutrient loads are achieving the desired ecological endpoints identified by stakeholders.

Ranking Summary

This project ranked high in all components except Practicality. The project ranks high in Ecology because managing nutrient loading to the Eagle and its tributaries directly supports the health of the aquatic ecosystem. The project would provide synergistic benefits throughout the watershed. The high Watershed Strategy rank reflects the change in approach to dealing with nutrient loading. This project would involve a watershed-wide approach to permitting that takes into account projected nutrient input combined with streamflow. Because better nutrient management would improve/protect aquatic ecosystems, including native species and game fish, the project scored high in Socioeconomics. Due to the complexity of the project, it scored low in Practicality. This project corresponds to Recommendation 4 of Chapter 6. Successful implementation would result in a nutrient strategy that is flexible with future development in the watershed and provide long-term benefits to the Eagle watershed with improved water quality.

5.9.1.3 Belden Cribbings



Location

N 39°31'29" E 106°23'41

Ownership

This project is on private land.

Benefits

- Eliminate the potential for waste rock material entering the river from existing waste rock piles behind cribbings
- Reduce the risk of extensive fish kills/water quality problems downstream
- Improve public safety

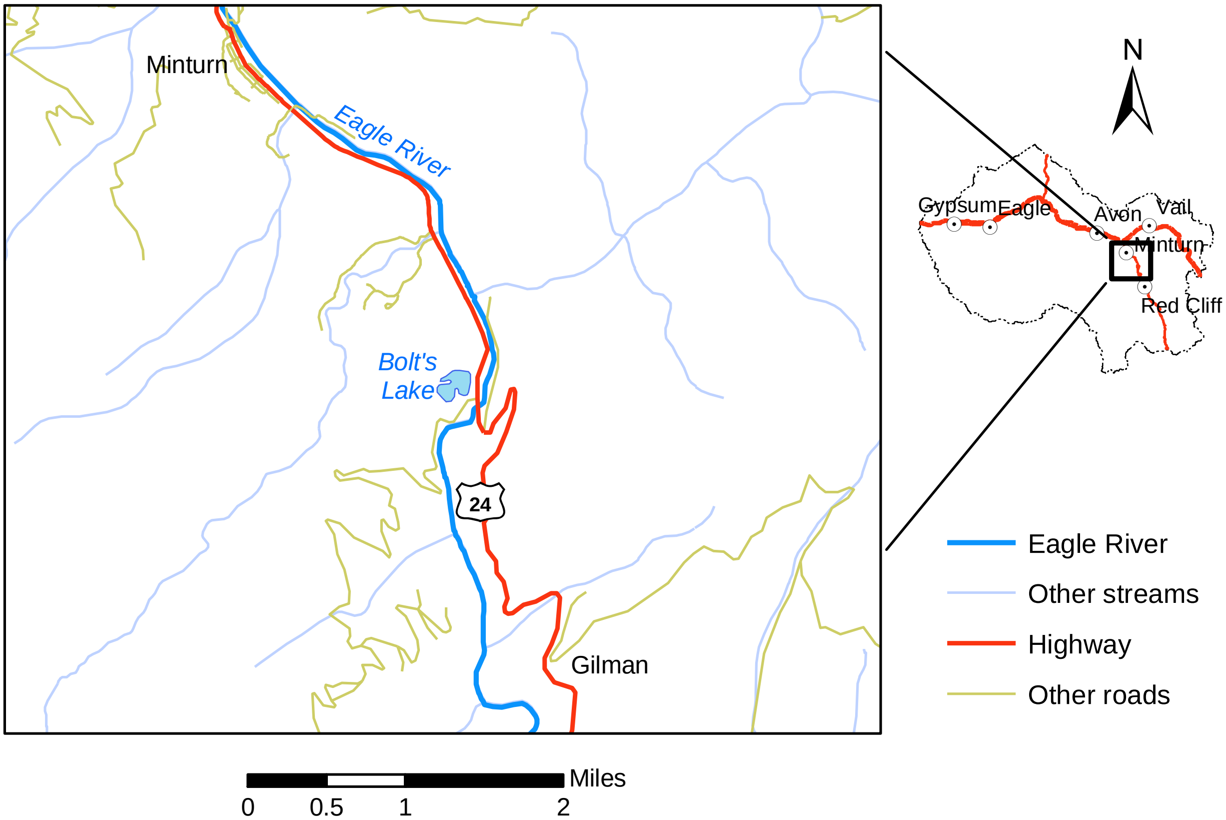
Project Description

Several historical wooden structures or 'cribbings' that were used to stabilize mining waste rock piles are located outside the Eagle Mine Superfund site, especially in the Belden area. These structures are decaying and collapsing. A series of cribbings that is readily observable from U.S. Highway 24 is of particular concern given hillslope angles, proximity to the river, and relatively large amounts of fine, low pH waste rock material that could be delivered directly into the Eagle River in the event of a catastrophic failure. The potential exists for these cribbings to fail. The ongoing degradation and potential failure of these structures represent a risk to the biological improvements that have been achieved in the Eagle Mine site. Some uncertainty exists regarding the ownership of these various sites. This project would involve surveying the cribbings and associated waste rock piles, a determination of ownership and property boundaries, and stabilization of piles posing the greatest threat to the Eagle River. Buttresses placed at the slope toe to stabilize waste rock piles could be backfilled with acid neutralizing materials such as limestone if warranted by the acid production potential and texture of the waste rock.

Ranking Summary

This project ranked high in Ecology and Watershed Strategy. In the Ecology component, points were awarded primarily for water quality and system level benefits. This project is one of the most urgent in the watershed. One or several failed cribbings could result in acute water quality problems, including fish kills. Because water quality issues from this site would affect downstream reaches of the Eagle, this project scored well in Watershed Strategy for the leverage criteria. The project would also raise public awareness for watershed issues in the Eagle basin. The cribbings project ranked moderate for Practicality and Socioeconomics. The project did not score high in Practicality due to legal, landowner, and technical complexity. The bulk of the points awarded in the Socioeconomics component reflect the risk to game fish, should the project not be implemented. The Belden Cribbings project is identified in Chapter 6 as part of Recommendation 3. The cribbings in their current state can be described as a toxic 'time bomb.'

5.9.1.4 Bolt's Lake Restoration



Location

N 39°33'26" E 106°24'11"

Ownership

This project is on private land.

Benefits

- Provide a popular recreation area near Minturn
- Additional water storage

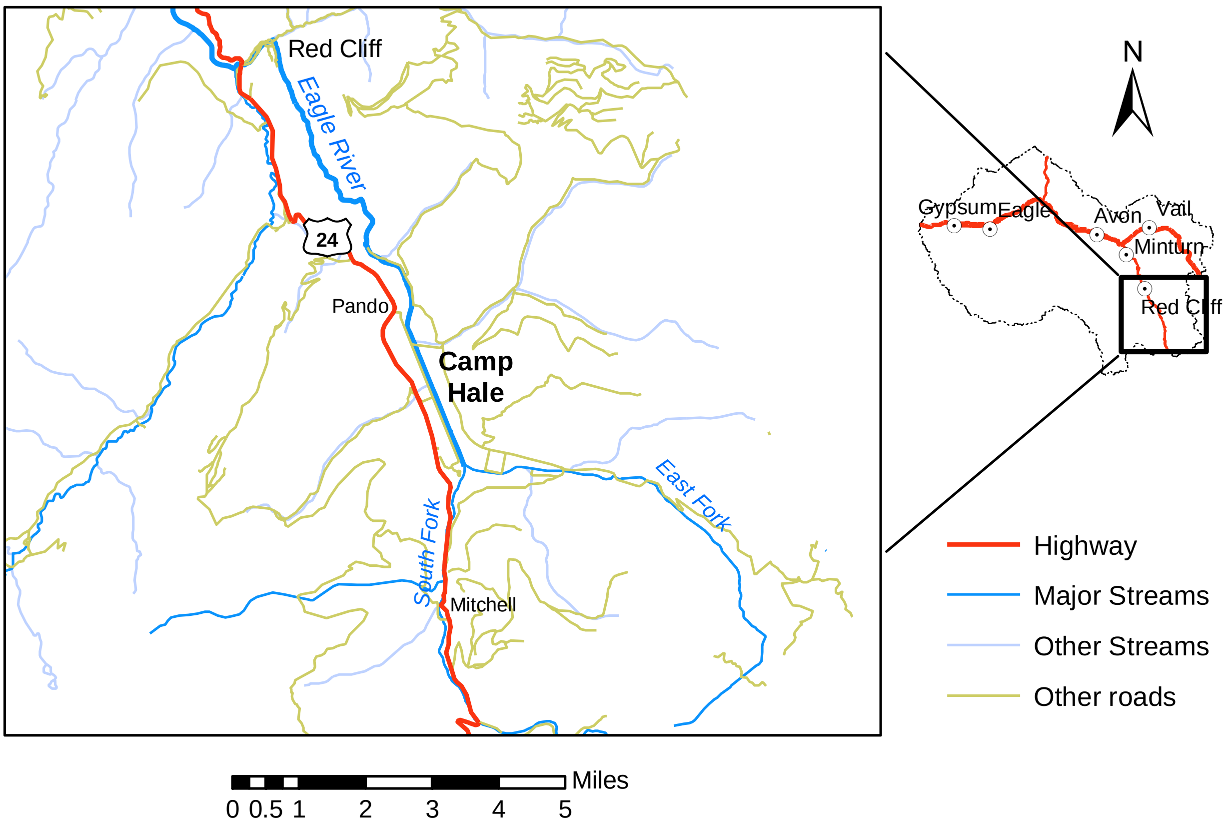
Project Description

Bolt's Lake is a small defunct reservoir with a breached dam located between Eagle Canyon and Minturn. The restoration of this recreation area for local residents has strong support. The idea proposed by stakeholders involves purchasing the lake property, refilling the lake, and creating a small park. The lake could also serve as a water storage site for the Town of Minturn. The site has not been subjected to detailed hydrogeological analysis. Depending on currently unknown subsurface processes and connections, refilling the reservoir without a liner could potentially affect groundwater dynamics in nearby remediation sites and metals loading to the Eagle River.

Ranking Summary

This project was ranked low across all components except Socioeconomics. The project does little to support the ecological processes and functions in the watershed. The score for Practicality is somewhat uncertain because the project site is located near the Old Tailings Pile/Rex Flats area. Implementation of the project could be difficult if groundwater interactions between Bolt's Lake and these contaminated areas proves to be unfavorable. Within the Socioeconomic component, the project would serve as a recreation area for Minturn.

5.9.1.5 Camp Hale Restoration



Location

N 39°26'11" E 106°19'17"

Ownership

This project is on public US Forest Service land.

Benefits

- Restore a meandering channel while preserving the straight channel as backwater
- Restore extensive wetland areas with hydrologic, water quality, and habitat functions
- Improve habitat with a greater variety of habitat types
- Streambank stabilization using a bioengineering approach
- Restore floodplain connections to support riparian vegetation and energy transfer between the floodplain and channel
- Reestablish native riparian vegetation
- Enhance the historical value and educational potential of the site

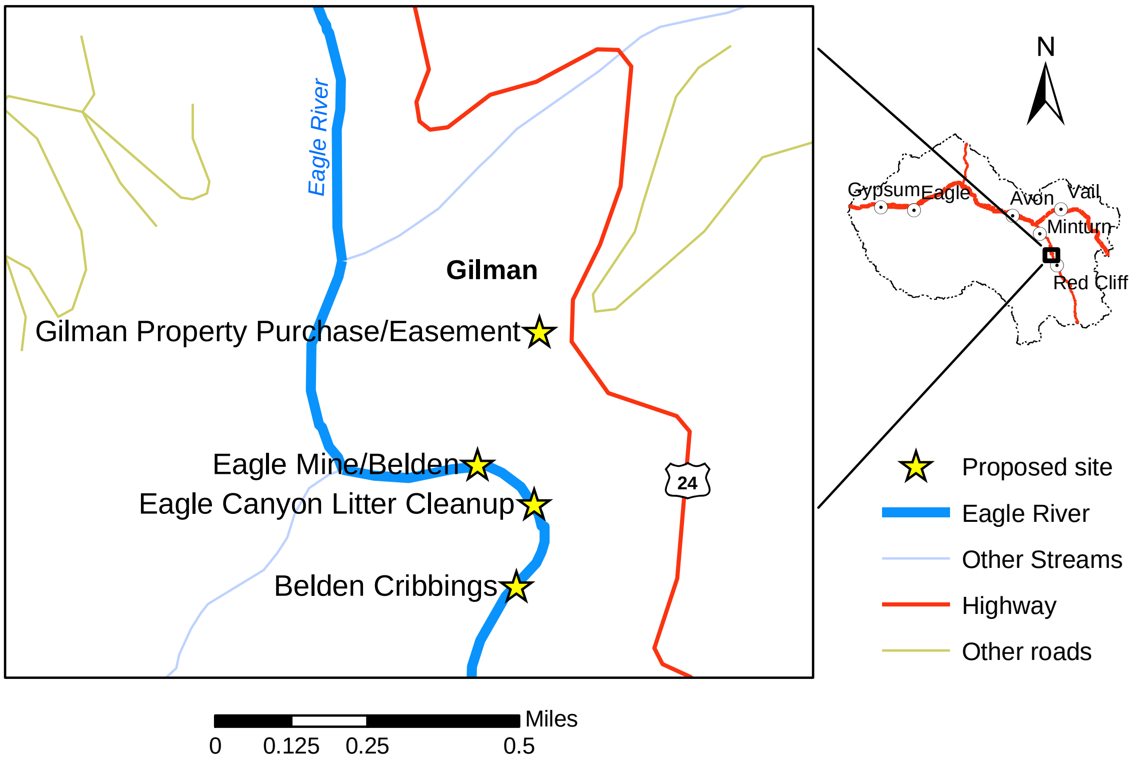
Project Description

A very popular project among stakeholders in the Eagle River watershed is the restoration of Camp Hale, the former military base of the legendary 10th Mountain Division. In 1942, the U.S. Army began constructing Camp Hale in the glacial valley known as Eagle Park. To construct the base, the Eagle River was channelized and centered in the valley. Wetlands in the valley bottom were drained and covered with at least 200,000 cubic yards of fill material. Today, the river is incised throughout much of the segment, leaving the channel hydrologically disconnected from the valley floor and lacking a functional riparian corridor. Native riparian vegetation has not re-colonized the fill terraces and the valley is covered in upland and invasive plant species. The instream habitat is generally poor and homogeneous. Historical and aerial photos taken prior to construction are being used with site surveys, geomorphic analysis, and a variety of other information to examine the feasibility of restoring the river channel to some semblance of its pre-channelized state. Restoration alternatives under consideration include re-creating a sinuous planform, instream habitat enhancements, streambank bioengineering and riparian plantings, as well as educational and historical improvements. Because Camp Hale is on the National Register of Historic Places, any changes must be sensitive to the historical value of the site. At the time of this writing, the most plausible project seems to involve restoring a meandering form and riparian connectivity to approximately four to five miles of channel by removing part of the fill material along a floodplain swath, leaving the straight channel as historical floodplain remnant, relocating willow / alder bank vegetation from channelized reaches and using bioengineering to establish additional riparian vegetation. Several preliminary alternatives / site concepts that simultaneously enhance historical aspects of the site have been developed. There was significant momentum for this project several years ago, prior to the designation of all of Camp Hale as a National Historic site; and it was easily the most popular project suggested by stakeholders involved in creating a preliminary project list. The site is located on the White River National Forest.

Ranking Summary

Camp Hale scores high in all components except Practicality. The project ranks high in Ecology because it has the potential to restore a significant area of wetlands and stream habitat. The site is fairly uninhibited by infrastructure; therefore, restoration would involve valley-scale processes as opposed to the more patchwork channel restoration projects elsewhere in the watershed. Camp Hale is the top-ranked Watershed Strategy and Socioeconomic project in the list. The high ranking in these two components is due to the high profile nature of the site. Restoration would yield a significant ecological improvement for the money spent. Because of the historical significance and high recreational value of the site, restoration would be highly publicized. The project is ranked low in Practicality due to the large size and expense of the project and the complexity involved with Camp Hale's designation as a National Historic Site. The channel form must be correctly designed for the diversion-altered flow regime so that the proper connections between channel and floodplain can be restored. Restoration at Camp Hale represents the 'flagship' project of Recommendation 2 in Chapter 6.

5.9.1.6 Eagle Canyon Litter Cleanup



Location

N 39°31'36" E 106°23"40"

Ownership

This project is on private land.

Benefits

- Potential to improve water quality by removing "unaccounted" sources of metals and other toxics
- Improve the aesthetics of the canyon
- Potential for volunteer involvement

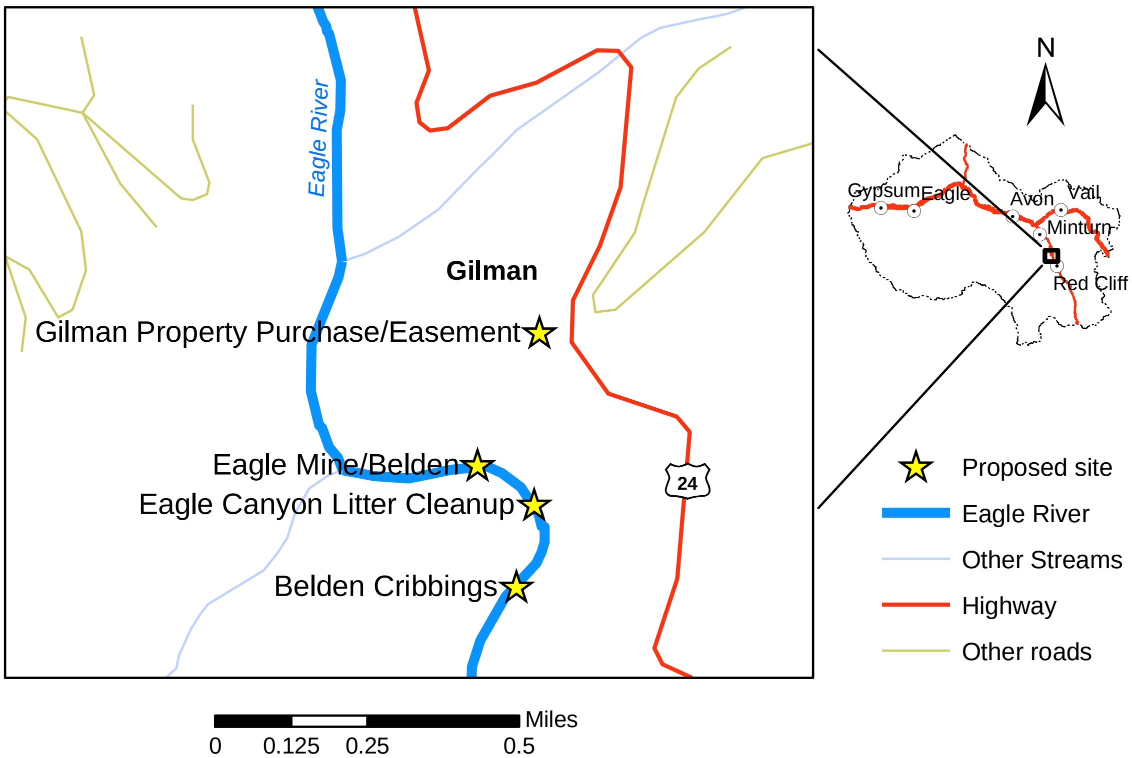
Project Description

Between Redcliff and Minturn, several areas of the Eagle River and its banks contain large pieces of rusting metal and junk materials left over from the mine. Much of this area is heavily altered private land, and is lightly used for recreation. The project would involve removing accumulated junk from the river. Because some of the junk likely contains petroleum products and possibly other toxins, this project could have both aesthetic and water quality benefits.

Ranking Summary

Litter cleanup through Eagle Canyon near Gilman and Belden ranked low in Ecology and Socioeconomics, moderate in Watershed Strategy, and high in Practicality. Although removing this litter could potentially improve water quality, the other 'unaccounted' sources through this reach likely contribute a much greater amount of metals to the Eagle River. The project scored points in Watershed Strategy with the potential for volunteer involvement. The project does little to support the socioeconomic base in the watershed. The project scored well in Practicality because the cleanup could likely by accomplished with an all-volunteer crew in a relatively short amount of time. Some heavy equipment would be needed to move litter out of the canyon, but the bulk of the labor could be performed by volunteers.

5.9.1.7 Eagle Mine/Belden



Location

N 39°31’40” E 106°23’46”

Ownership

This project is on private land.

Benefits

- Further understand/bracket areas where metals loading continues to be high
- Address metals loading from the Rock Creek drainage and the Belden area
- Improve downstream water quality and reduce toxicity to biologic communities (sustainable brown trout fishery, aquatic insects, downstream benefits for biodiversity, reduce cumulative impact of urban stormwater loading)

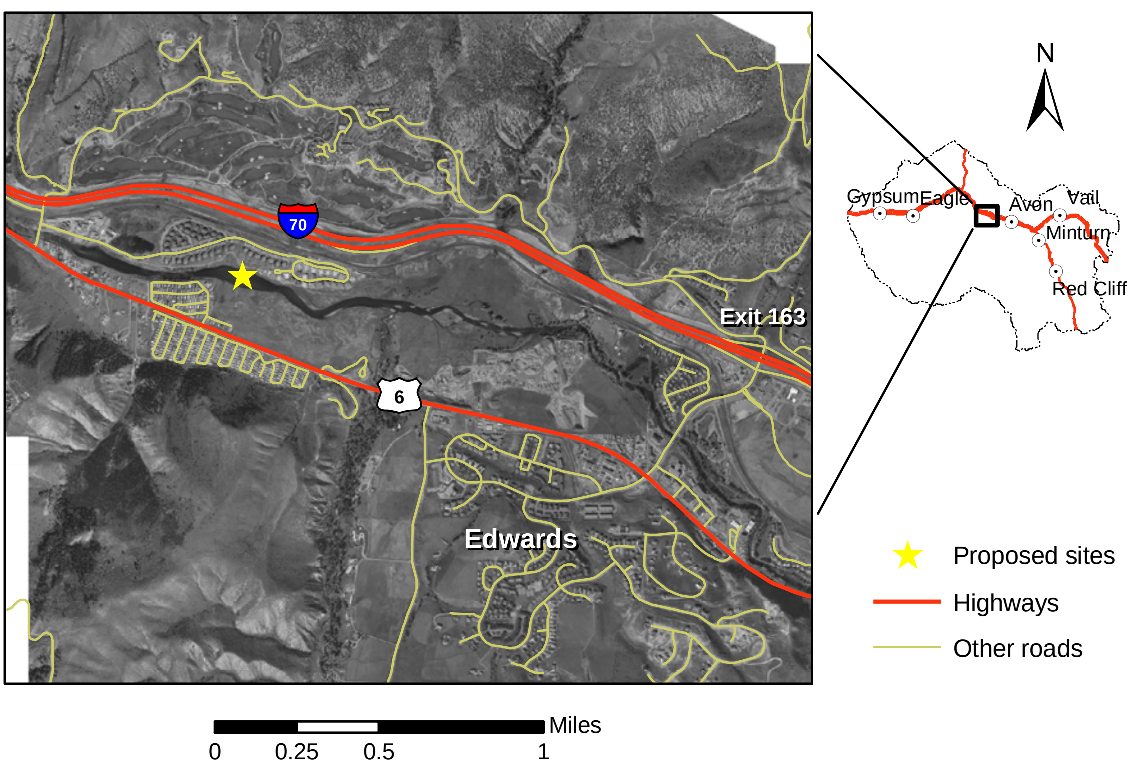
Project Description

Reductions in metals loading have resulted in significant ecological improvements within and downstream of the Eagle Mine segment. The Eagle Mine however continues to constrain water quality both within the Superfund site and further downstream. Biological impacts associated with current zinc concentrations include reduced weights in brown trout and suppression or elimination of sensitive organisms such as the native mottled sculpin and certain aquatic insects. As a result of reductions in other sources, the majority of current zinc loading to the Eagle River occurs in the Belden segment from 'unaccounted' sources. Monitoring data point to the Belden Tramway area as a bracketed primary source of the remaining zinc load. Implementation of capture/treatment or passive remediation technologies and addressing waste rock at this location could result in additional reductions in zinc concentrations and improvements in biological water quality both within and below the Eagle Mine Site. This project involves: 1) further evaluation and bracketing of groundwater loading in the Belden reach, 2) conducting cost benefit analyses to link specific remediation activities, expected loading reductions, and likely environmental benefits for river segments in the mine site and downstream, and 3) implementation of cost-effective remediation projects.

Ranking Summary

This project scored high in the Ecology and Watershed Strategy components. The Ecology score is based on the potential for water quality improvements (including benefits for native species) resulting from addressing sources of metals through the canyon. In turn, improving water quality yields a high score in Watershed Strategy because this enhances the viability of other projects (e.g., restoration of the Eagle River in the vicinity of the USFS office) and would have high visibility. The moderate score in Socioeconomics is due primarily to the points gained by supporting game fish in the Eagle. The Practicality rank for the project is low. The project is complex with respect to legal, landowner, and technical issues. Further reducing metals loading from historical mining impacts would support on-site and downstream biotic communities. Similar to the Belden Cribbings, this project is part of Recommendation 3 in Chapter 6.

5.9.1.8 Edwards/Lake Creek Segment



Location

N 39°39'10" E 106°37'02"

Ownership

This project site involves multiple private landowners.

Benefits

- Improve habitat quality by increasing the complexity of habitat features, reducing channel width, flushing fine sediment, and increasing flow depth
- Reconnect areas of high-quality habitat downstream and upstream of the site
- Reduce water temperature increases through the reach
- Protect and enhance riparian vegetation
- Establish/enhance wetlands and ponds
- Work with landowners and developers to enhance public access and stormwater management

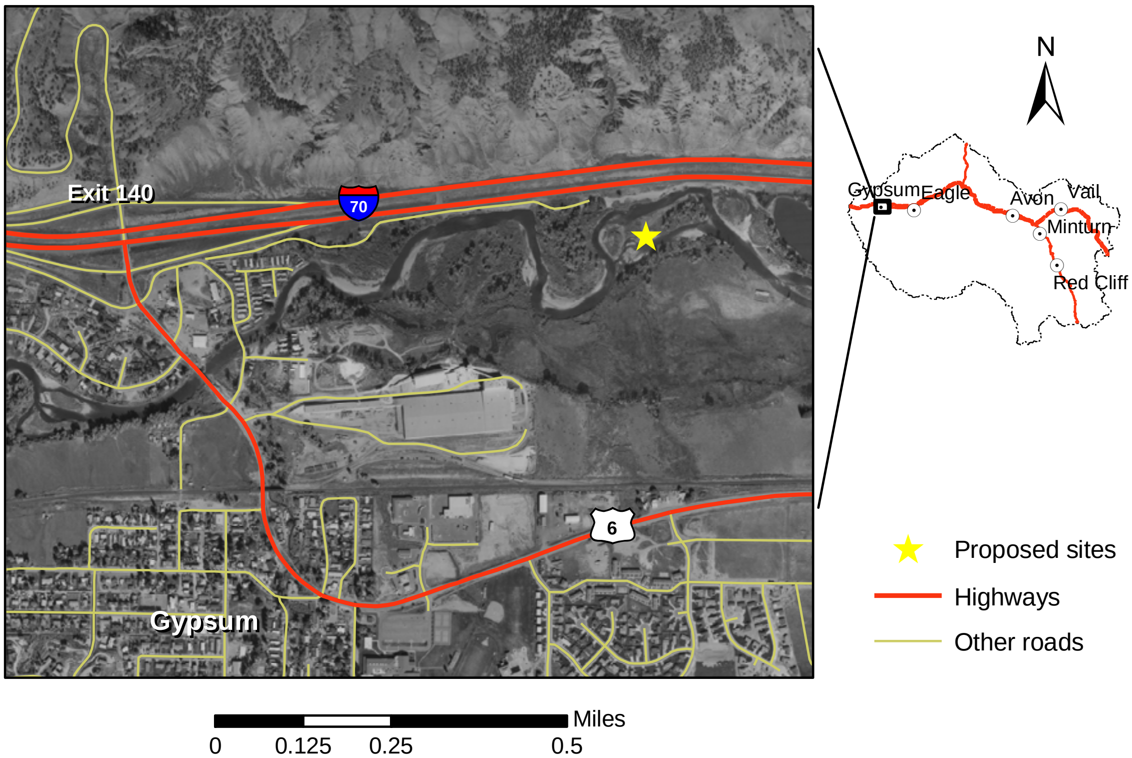
Project Description

Downstream of Edwards near the confluence of Lake Creek and the Eagle River, the river valley abruptly widens and flattens. Through this reach, the Eagle has an extremely high width to depth ratio and an insufficient capacity to transport sediment. The river has a substrate embedded with fine sediment and high temperatures during low flow periods. The segment disconnects high quality habitats upstream and downstream. The abrupt valley changes, a steep knickzone in the lower part of the segment, and uncertain land use near the upstream end of the segment constrain potential design alternatives for the site. This project would involve reducing width and increasing depth to improve sediment continuity and substrate conditions, restoring mild sinuosity, bank bioengineering, restoring native riparian plant communities that are matched to site conditions, wetland / oxbow lake restoration/creation on floodplain, improving recreational access, and educational/interpretive enhancements.

Ranking Summary

This project ranked high in Ecology and Socioeconomics and moderate in Watershed Strategy and Practicality. The high Ecology ranking is a result of potential habitat improvements through the site. Reducing channel width and increasing depth of flow would also reduce low flow temperatures. High quality habitats that exist immediately upstream and downstream of the site would be reconnected by the project. Much of the site has not been developed yet; therefore, riparian and stormwater management could be incorporated into future development. The project ranks well in Socioeconomics because it educates the public about river-friendly development, ensures public access to the site, improves boating through the site, and supports game fish. The project ranks well in Watershed Strategy because it can serve as an example for other development in the watershed. The lower ranking in Practicality is primarily a result of the complexity of working with landowners to achieve an acceptable design. A successful design, from an ecological standpoint, must reduce channel width, increase depth of flow, provide a variety of physical habitat types, stabilize the banks, and protect the riparian corridor (see Chapter 4). This project is included in Recommendation 2 of Chapter 6 for its potential to reconnect reaches of high quality habitat while addressing temperature concerns in the Eagle River.

5.9.1.9 Enhance River Habitat in Gypsum Ponds State Wildlife Area



Location

N 39°39’09” E 106°56’30”

Ownership

This project is on public State land and private land.

Benefits

- Protect existing riparian forest and enhance native riparian vegetation
- Conserve land to preserve site and ensure public access in the future
- Improve habitat quality by reducing channel width, increasing depth, and stabilizing banks
- Reconnect the channel to the floodplain to support riparian vegetation and energy transfer between the floodplain and channel

Project Description

The Gypsum Ponds State Wildlife Area near the town of Gypsum offers excellent public recreation access along the lower Eagle River. The current channel through this reach is wide and braided, but offers opportunities for physical habitat improvements. Channel restoration would involve two miles of realignment and narrowing of the channel. The narrower channel would have a greater probability of overbank flows, which would establish a better connection to the floodplain. The project would also involve protection of the outstanding remnant riparian forest community. Full implementation of the project would rely on land acquisition/protection from landowners along the south bank of the reach. Although the Division has leased access from the north, CDOW does not own any of the riverbed. The land on the south bank, also privately owned, has been rumored for development for years, although no plans have materialized. The project would purchase the small strip of land on the north bank, ensuring future public access, as well as the relatively undamaged riparian parcels on the south bank. This land is probably the best remaining riparian habitat from Eagle to the confluence with the Colorado River.

Ranking Summary

Restoring habitat in the Gypsum State Wildlife Area ranked high in Socioeconomics and received a moderate rank in all of the other components. The socioeconomic benefits lie in the enhancement of game fish habitat and the conservation of public recreation access. Points were awarded to this project in Ecology mostly for the potential habitat improvement and riparian protection/restoration. The project would reduce the channel width and stabilize the banks. The SWA contains one of the best riparian forest communities along the lower Eagle, which would be conserved in this project. In Watershed Strategy, the project could be implemented with the aid of volunteer labor and would be well-publicized. The project received a moderate rank in Practicality for the complexity of cooperating with landowners to work on the site. This Gypsum SWA is also identified in Recommendation 2 of Chapter 6 for the extensive riparian and habitat benefits.

5.9.1.10 Flow Management/Decision-Making Tools

Location

Watershed-wide

Benefits

- Analyze instream flows using a science-based approach that examines the spatial variation in the interaction between water quantity and water quality
- Suggest minimum flows that provide the water quality and physical habitat required by aquatic species
- Create decision-oriented tools to assess the potential ecological effects of flow regime modification

Project Description

Making informed decisions about potential changes in flow regime necessitates the development of decision-support tools for assessing the potential ecological consequences of flow alteration schemes. The method used to quantify instream flows on the Eagle River mainstem does not address several key factors linked to low flows such as recreation, water quality, land use changes, wastewater dilution, and temperatures. Given that current instream flow quantities do not meet recommended CDOW hydraulic criteria in several segments, and that the past application of a single-transect quantification approach to the mainstem Eagle River is questionable under current conditions, it is not recommended that existing instream flow rights be used as a standard by which the potential ecological ramifications of flow modifications are evaluated. Tools supporting decision-making for flow management are most effective if underpinned by sound science and designed to account for interactions between water quantity and water *quality* factors (current and future) in a spatially explicit manner. This means, for example, that the likely effects of flow extraction and augmentation can be evaluated within the specific river and stream segments that may be affected in different ways. Given ongoing metals loading and expected increases in nutrient loading in the Eagle mainstem, risk-based tools allowing incorporation of future water demand, pollutant loading and climate/streamflow scenarios could provide critical information for assessing probable future conditions based on the best available scientific information. This project would develop decision-oriented tools based on the Instream Flow Incremental Methodology (IFIM) for more rigorously assessing the potential effects of flow alterations on instream fish habitat and water quality in the Eagle River mainstem from at least Homestake Creek to the confluence with the Colorado River.

Ranking Summary

This project ranked high in all components except Practicality. The project ranked high in Ecology because it would involve a science-based approach to determine the flow required to meet water quality standards and provide suitable physical habitat. The project would provide system-level benefits along much of the Eagle River. The project strongly supports the economic base in the watershed, resulting in a high rank in Socioeconomics. Flow management ranks low in Practicality due to the complex nature of quantifying and implementing minimum flow requirements. The project is included in Chapter 6 as Recommendation 1. The flow regime of the Eagle River and its tributaries is a master variable that influences many ecological processes active in the watershed and improved management provide long-term and widespread benefits.

5.9.1.11 Long-term Access Plan for Low Impact Recreation

Location

Watershed-wide

Benefits

- Ensure public access to the river that does not degrade the resource
- Create access points along the river for fishing and boating
- Create a long-term and flexible strategy for improving existing access and enhancing access throughout the watershed in a sustainable manner
- Support the economic base associated with recreation and tourism

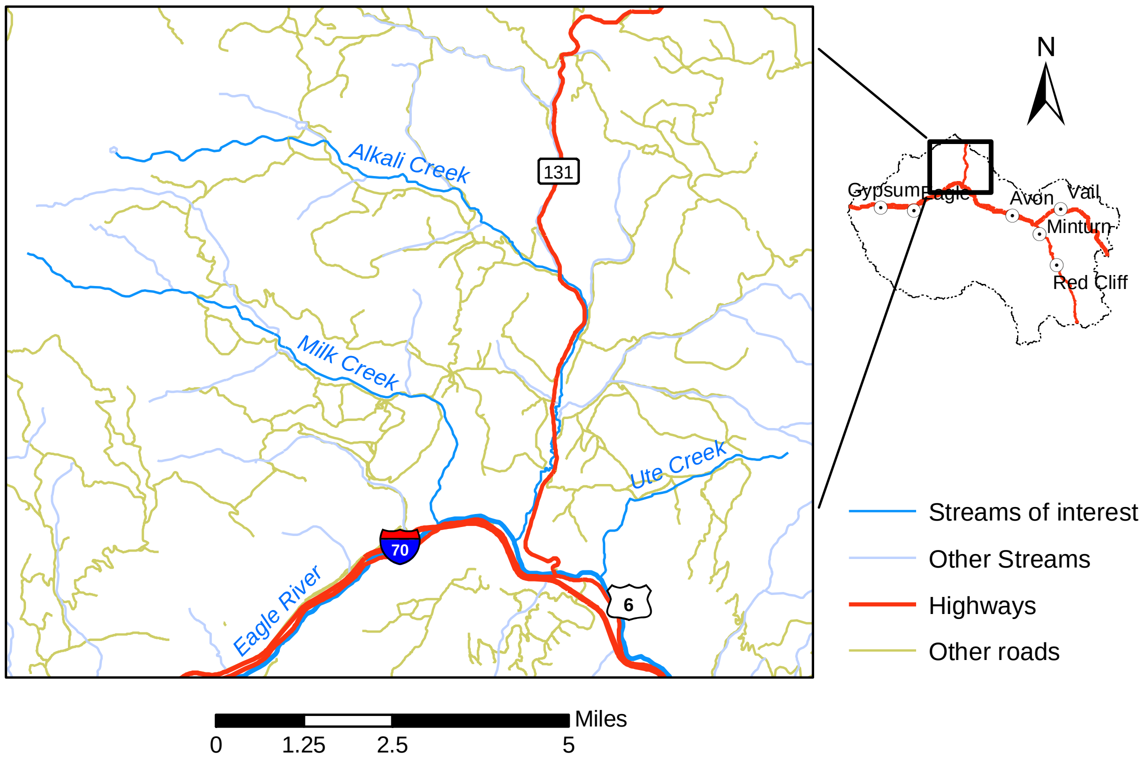
Project Description

Eagle County will soon have over 50,000 residents. This will create increasing pressure on the few existing public access points for boating and fishing, and there are few developed recreation/access areas along the Eagle River below Edwards. As the local population continues to grow, the river system will depend more heavily on the goodwill of residents to maintain water quality, a self-sustaining fishery, and trash free environs. In order to ensure that these attributes are maintained, it is important that the entire community be "connected" to the river. One way to achieve this is to create small, accessible parks along the river near population centers. Two possible sites include the area between the Edwards Bridge and the mouth of Lake Creek, and the area near the fairgrounds in Eagle. Several other locations are possible. Currently there is no plan or program that ensures access along the river, manages the parking along Highway 6 and the existing access sites, or provides for future access to accommodate rising recreational demand. This project would create such a plan based on extensive stakeholder input and analyses of carrying capacity. It would identify future access sites and methods to enhance poorly designed access points, such as the boater take-out above the fairgrounds. It would also redesign existing access points to ensure that ecological values are safeguarded.

Ranking Summary

This project ranked high in all components except Ecology, in which it ranked Moderate. In Watershed Strategy, the project ranked high primarily because of its visibility. The complexity of the project is relatively low, resulting in a high rank in Practicality. Much of the project would deal with existing public, both formal and informal, access sites. The project ranks high in Socioeconomics because it heavily supports the recreation economic base in the watershed. The project benefits Ecology by reducing future pressures on the fishing and riparian zone, resulting in a moderate rank. However, the recreation strategy would help maintain access that does not degrade the resource. This project is included in Chapter 6 as Recommendation 6. Due to the rapid growth in the watershed, the capacity for recreation should be analyzed to ensure sustainable recreation opportunities are available in the future.

5.9.1.12 Milk/Alkali/Ute Creeks



Location

N 39°44'32" E 106°41'51"

Ownership

This project is located on BLM and White River National Forest public land as well as private ranch land.

Benefits

- Decrease fine sediment loads to the Eagle River
- Protect habitat and enhance the trout fishery in the Eagle River

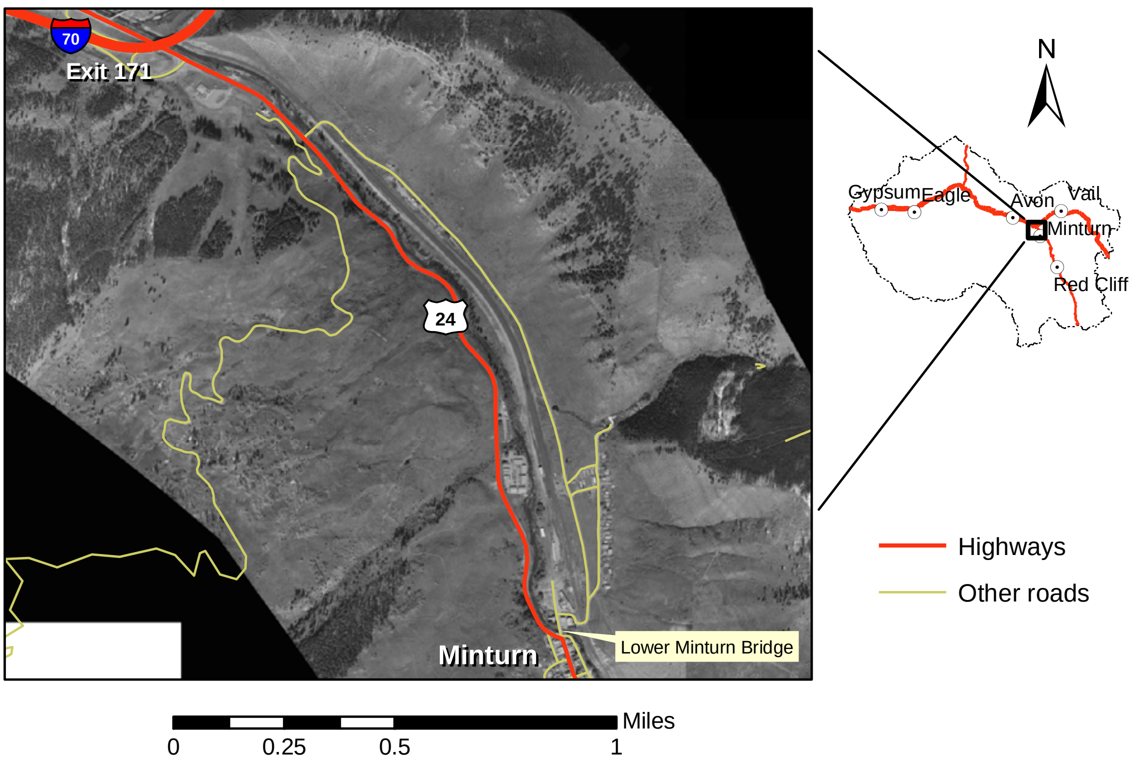
Project Description

Milk, Alkali, and Ute Creek are notorious for sending loads of fine sediment into the lower Eagle River. The huge amount of sediment yielded from these drainages is primarily due to inherent soil properties, grazing, and unstable drainage networks of the BLM (and some private) land north of the river. Controlling the output of these small creeks has been on the local angler's 'wish list' for years. However, strong disagreement exists over the ability to enact such measures, and if any action would be effective at all. Based on field reconnaissance conducted by CSU, this project would necessarily require a comprehensive strategy that includes detailed geomorphic assessment of channel evolution and stability and necessitate an integrated, long-term program of implementing best management practices. These practices include grazing management, grade control, bank stabilization, drop pipes to check headward migration of drainage networks, sedimentation basins, and brush-beating/re-vegetation.

Ranking Summary

This project ranked moderate to high in Ecology and Socioeconomics and low in Watershed Strategy and Practicality. Successful implementation of the project would reduce sediment input to the Eagle River, which would reduce suspended sediment, turbidity, and improve substrate quality in downstream reaches for habitat and spawning. This reduction in sediment supports Socioeconomics, as it would likely improve the brown trout fishery and aesthetics in the lower Eagle River. The project scored low in Watershed Strategy because it does not leverage multiple projects and a low potential for adequate fundraising. The project scored low in Practicality due to the complexity of the project and large extent of sediment sources in the three basins that would need to be addressed for project success. The future of the Milk, Alkali, and Ute Creek basins is somewhat uncertain with Front Range water interests in the area.

5.9.1.13 Minturn Confluence Segment



Location

N 39°36’27” E 106°26’44”

Ownership

This project is located on State land.

Benefits

- Improve habitat quality by increasing the complexity of habitat features
- Stabilize banks and establish riparian vegetation using a bioengineering approach
- Improve the public access to the site by making it more aesthetically pleasing and adding a restroom facility

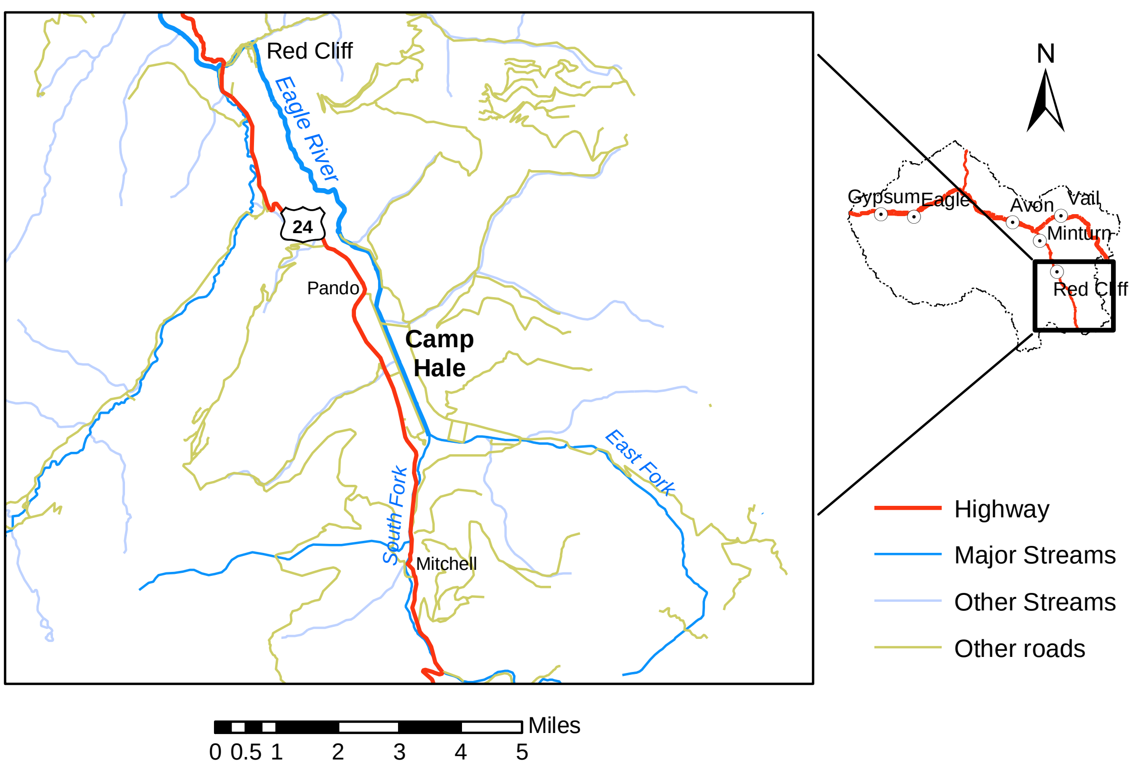
Project Description

The Eagle River between the lower Minturn bridge and I-70 is laterally confined and channelized between Highway 24 and the railroad and has homogenous instream habitat consisting of a long continuous run with little or no cover and few holding places for fish. Restoration work to improve habitat quality at this site could be combined with improvements in aesthetics and facilities at the public access point across from the US Forest Service office near the Gore Creek confluence. Specific activities could include fish habitat improvements, bank stabilization and bioengineering, and tapping into ERWSD sewer infrastructure available at the site for a restroom facility. Because the project is located upstream of the diluting effect of Gore Creek, water quality impacts from metals are a limiting factor and could partially negate the benefits of improved physical habitat.

Ranking Summary

This project ranked moderate in all components except Practicality, where it ranked high. In Ecology, the project received points primarily for habitat and riparian improvements. However, the project is *limited by poor water quality from upstream metals sources*. For Watershed Strategy, the project provides an avenue for volunteer involvement, but the project would do little to leverage other projects or fulfill the broader goals of the watershed council. Restoration would include an improved access site for boaters and anglers, yielding points for the Socioeconomics component. Because the project would be relatively simple to implement and could involve volunteer support, it ranked high in the Practicality component. Restoration design for the channel would involve adding complex habitat features that provide various velocity/depth combinations. The riparian area would also be enhanced and protected, which would help stabilize banks and provide shade for the channel. This project fits with Recommendation 6 of Chapter 6. Implementation would ensure that the site remained a public access point for the river and that access does not further degrade the site.

5.9.1.14 Non-native Species Removal – Camp Hale



Location

N 39°26’03” E 106°19’13”

Ownership

This project is on public USFS land.

Benefits

- Remove non-native species and reestablish natives
- Could be done in conjunction with channel restoration

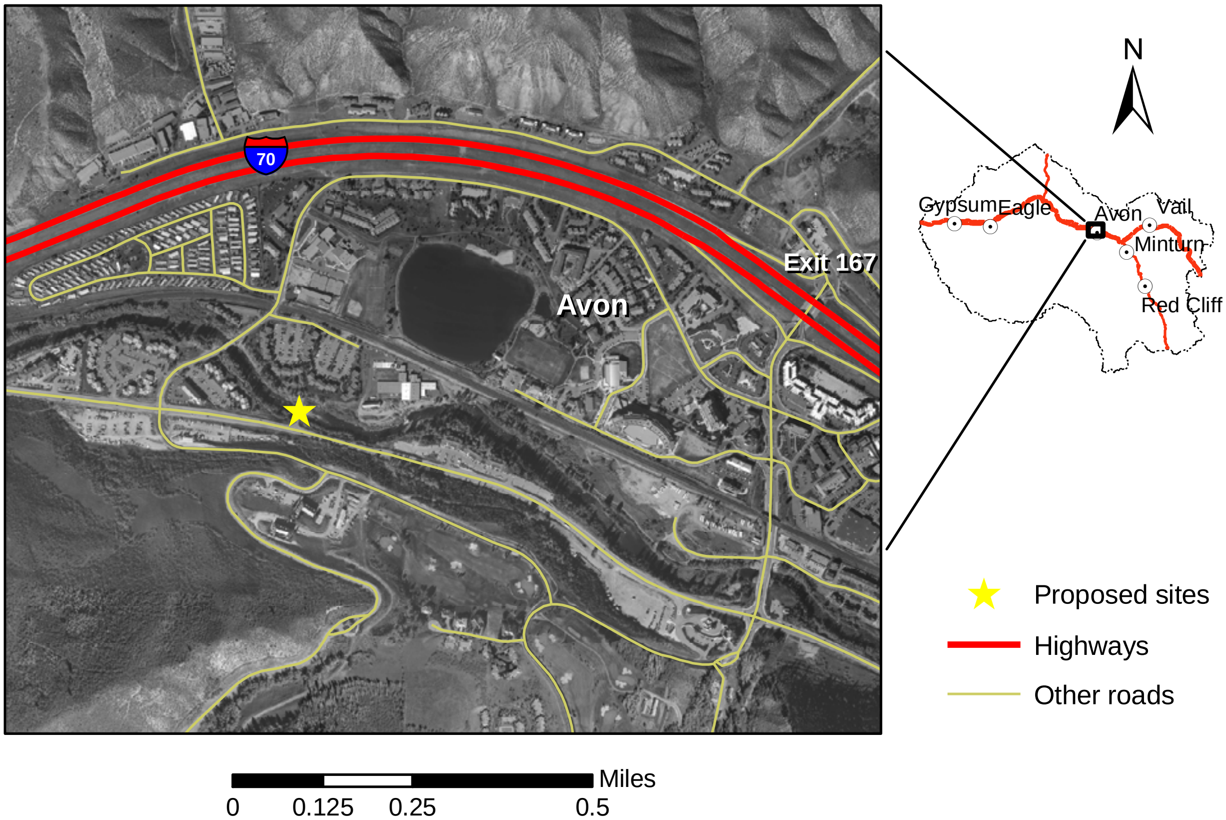
Project Description

The Camp Hale / Eagle Park area is infested with toadflax, whitetop, thistles, and other noxious weeds. This site was identified by Eagle County Weed & Pest as the heaviest concentration of non-native species in the upper river basin and the best candidate for large-scale rehabilitation. The area sees heavy recreational use in the summer. This project would involve an aggressive program of weed removal and reestablishment of native species.

Ranking Summary

This project ranked moderate in all components except Socioeconomics, in which it received a low ranking. This project would likely be implemented in conjunction with restoration of Camp Hale. Native vegetation better supports the important interactions between riparian and in-stream biologic communities (see Chapter 4). The valley is the largest infestation of non-native species in the watershed. Replacing this vegetation with native species would support the functions of restored wetlands and support energy transfer between riparian areas and the channel. The size and location of the project would garner public attention to Camp Hale and noxious weeds in the watershed, possibly leveraging weed removal elsewhere in the basin.

5.9.1.15 Remove Piling in Avon



Location

N 39°38'07" E 106°32'04"

Ownership

This project is located on 2-4 parcels of private land.

Benefits

- Eliminate constriction of the channel at the bridge
- Reduce flow impingement on the banks
- Mitigate flooding caused by backwater from the current channel constriction
- Improve boat passage
- Opportunity for volunteer involvement

Project Description

Upstream of the Westgate Shopping Complex in Avon, an old bridge has been partially removed. The remaining abutments and piling constrict the channel causing the formation of a mid-channel bar immediately upstream. Removal of the pier is a relatively low cost and volunteer-friendly project. Potential benefits of the project include reduced flow impingement on the banks and improved boat passage.

Ranking Summary

This project ranked low in all components except Practicality, where it ranked high. Other than minor geomorphic and habitat improvements, the project offers very little ecology benefit. The project is not highly visible and does not improve access to the river. It would make for better boat passage through the site, but otherwise not support socioeconomics in the watershed. The high Practicality rank is due to its simplicity. Removing the piling would be inexpensive and simple to do and would improve safety at the site. Reducing the constriction at this point could potentially reduce the risk of flooding.

5.9.1.16 Riparian Planting Opportunities – Lower Eagle and Eagle Valley Tributaries

Location

Lower watershed

Benefits

- Increase bank stability in the lower watershed
- Provide shade and cover for fish and riparian species
- Enhance food inputs to the channel
- Buffer pollutant inputs
- Potentially benefit high temperatures along lower Eagle

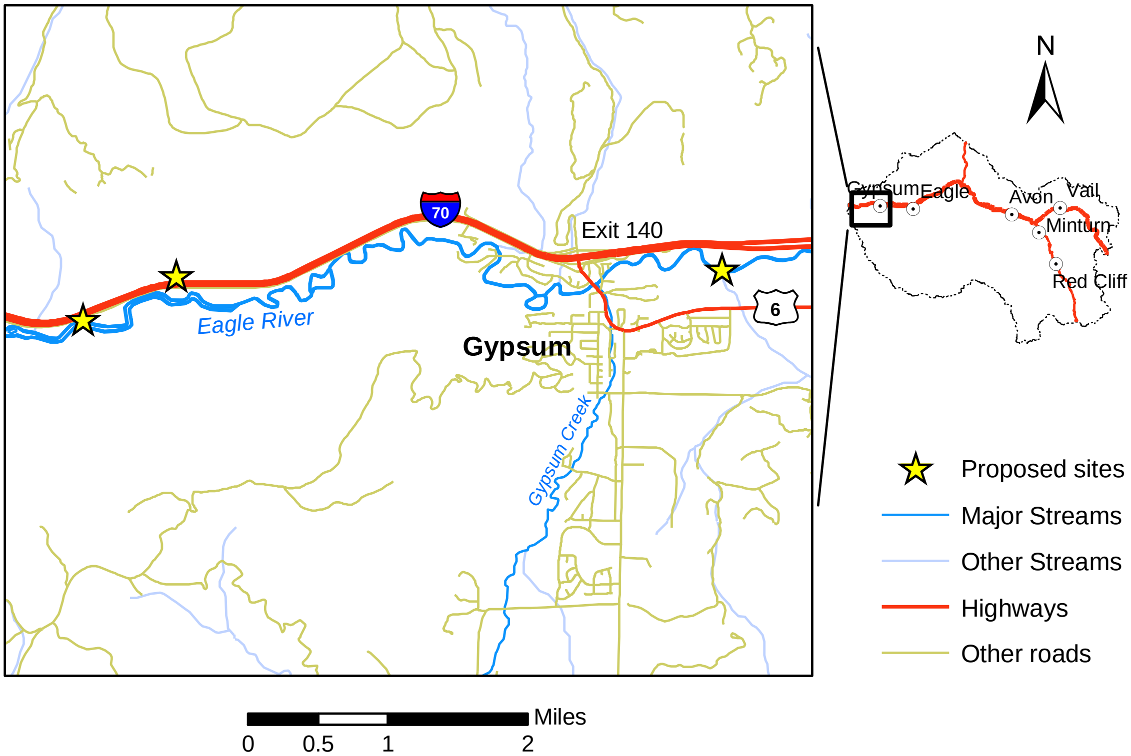
Project Description

Riparian corridors of the lower Eagle River and tributaries entering the main stem valley are characterized by sparse or no woody vegetation in many locations. Based on field reconnaissance and aerial photo analysis, several sites have been identified where native vegetation could be established along the riparian corridor to increase streambank stability, provide shade for fish and cover for riparian species, buffer pollutant inputs, and enhance food inputs into the channel. Specific attention was given to locations along the south bank with a single landowner. Riparian planting opportunities are in the lower cost project tier with high potential for volunteer assistance. Approximately half the sites are currently grazed and would require alternative management to allow revegetation.

Ranking Summary

This project ranked moderate in all components. Most of the Ecology benefits relate to riparian zone and bank stability improvements. The project would not be as high profile as some of the larger candidate sites, but would be an excellent opportunity for volunteer involvement. The complexity of the project lies principally in working cooperatively with a number of different landowners. Finally, the socioeconomic benefits would lie primarily in the education and fisheries aspects of the project.

5.9.1.17 Riparian Tamarisk Removal – Lower River and Tributaries



Location

N 39°38’30” E 106°33’34”; N 39°38’13” E 106°32’54”; N 39°37’57” E 106°31’31”

Ownership

These projects are located on State and BLM public land and private land.

Benefits

- Identify and inventory areas of infestation
- Eradicate non-native tamarisk in the lower watershed and reduce the risk of future infestation
- Restore native vegetation

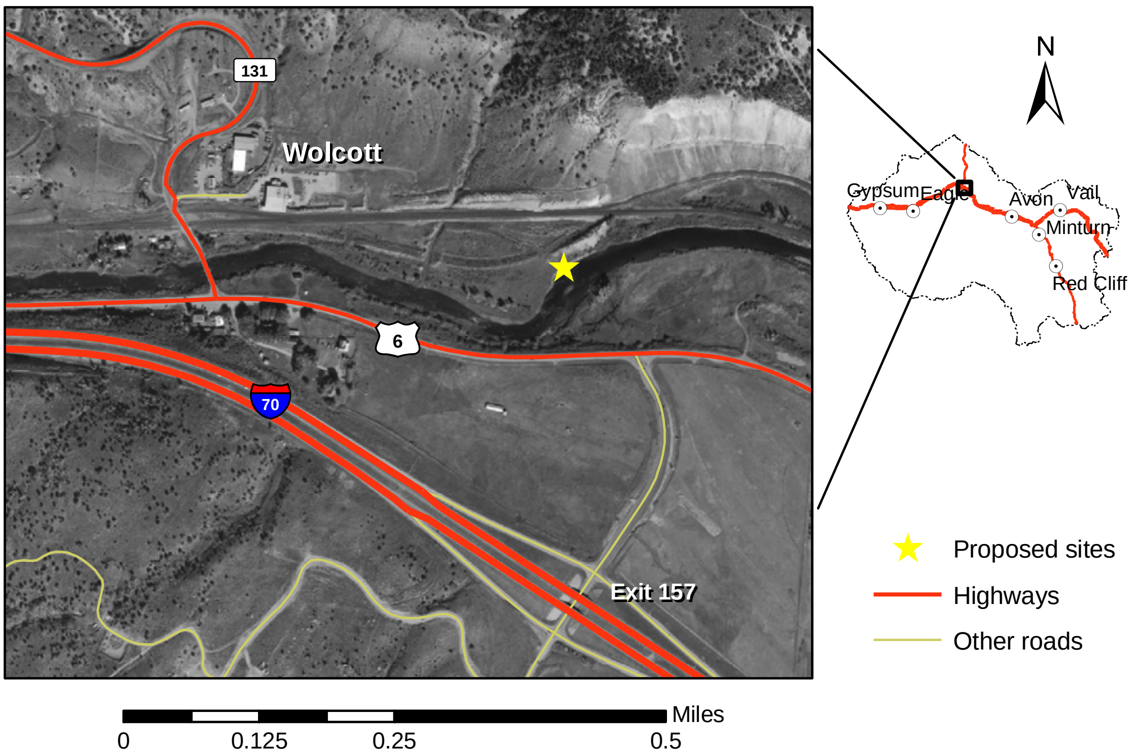
Project Description

Patches of the invasive tree tamarisk are present along the Eagle River below Brush Creek. Most of the stands are located on private lands, although there are infestations on BLM land as well. This project would create an inventory of tamarisk sites (with permission from private landowners), contact those landowners along the river to offer tamarisk removal services and identification training, and eradicate tamarisk in the lower Eagle River. The return of native vegetation would also be pursued to increase native flora.

Ranking Summary

This project ranked moderate in Ecology. The project would eradicate tamarisk in the watershed to prevent its spread and support the return of native vegetation. The project ranked low in Watershed Strategy and Socioeconomics. Weed removal does not have the public support associated with high-ranking Watershed Strategy projects. The project would not leverage other projects and does not have a relatively high fundraising potential but does provide educational opportunities. Tamarisk removal does not directly support socioeconomics in the watershed. The project ranked high in Practicality because of the small extent of the current infestation; therefore, removal would be a straightforward proactive process. The most challenging part of the project would be obtaining permission from private landowners.

5.9.1.18 Riparian Work/Bank Stabilization Upstream of Wolcott



Location

N 39°42'06" E 106°40'18"

Ownership

This project is located on one private parcel.

Benefits

- Stabilize the right bank using toe protection combined with vegetation
- Protect/augment existing riparian vegetation
- Opportunity for volunteer involvement

Project Description

A segment of the Eagle River just upstream of Wolcott has been identified as a location where bank stabilization could be combined with riparian vegetation establishment to increase channel stability and riparian functions. The right bank consists of an approximately 100-meter long and 3-meter high eroding cut bank. Grazing practices have altered the riparian community of the left bank but there is still some vegetation immediately adjacent to the channel and a small stand of cottonwoods. This project would consist of addressing bank erosion, most likely using a combination of toe protection and vegetation establishment, and protecting/augmenting existing riparian vegetation through best management practices. This lower-tier project would present an opportunity for volunteer assistance.

Ranking Summary

This is essentially a straightforward bank stabilization project that would improve and protect the riparian area. However, the project site is already located in an area of high quality habitat. This project ranked low in Ecology and moderate in Watershed Strategy because it is a stability project that is fairly visible and that can be accomplished primarily with volunteer support. The project ranked high in Practicality because it is a small, single-landowner site and would be relatively inexpensive to implement. Finally, the project ranked low in Socioeconomics, as the benefits of the project are principally confined to minor education potential and localized game fish habitat improvement.

5.9.1.19 Unranked Projects

Some projects (primarily non-structural, water conservation related, or acquisition/easement projects) were not ranked due to relatively high uncertainty regarding the likely future state of the project site or regarding ecological consequences and benefits. The following are the descriptions of these unranked projects:

Conduct Sediment/Erosion Control Workshops

The Eagle River Watershed Council has conducted a successful pilot program on this topic for general contractors and builders. However, the workshops have not been held recently. One of the highest conservation priorities mentioned by several interviewees is the need to control poor development practices, particularly those that send sediment and other construction runoff into nearby waterways. Creating a formal Sediment/Erosion Control workshop program (with on-site demonstrations) would be an effective tool to combat this problem. The workshops would be conducted by the Eagle River Watershed Council and qualified technical experts.

Encourage Municipal and County-based Xeriscaping Program

During the summer of 2002, xeriscaping measures enacted by the Town of Vail cut water use dramatically on Town properties (38-50%). Currently there are no county-wide xeriscaping programs in place. This project would encourage the development of xeriscaping guidelines in other municipalities and unincorporated areas of Eagle County for water conservation.

Gilman Property Purchase/Easement

The Gilman Property is comprised of 6,000 contiguous acres located between Minturn and Red Cliff. Most of the land is east of the Eagle River and is largely surrounded by the White River National Forest. The Eagle Mine EPA Superfund site is contained within its boundaries, along with other damaged lands. There is strong support within the community for the transfer of the bulk of this land to the US Forest Service. Preventing development on the undamaged portions of the property and restoring the areas in the canyon would provide long-term benefits to the river. Federal money would possibly be available for a possible purchase if ongoing litigation regarding ownership is resolved.

Implement Magnesium Chloride Testing Program

Magnesium Chloride has been in use as a de-icerin the Eagle River watershed for several years. It is unpopular with many residents, although alternative road treatments are probably more damaging to the watershed. Also, according to some figures, CDOT has increased the amount of magnesium chloride used on local roadways in recent winters. This project would examine the fate of magnesium chloride, and if the increased amount of chemical use is having an effect on water quality. No current testing program is in place. This project was not ranked in the MCDA.

Municipal Flow Meter Installation

The installation of flow meters at primary irrigation sites within the Town of Vail cut use by 10% in the summer of 2002. This project would encourage installation of flow meters at all large municipal irrigation sites within the watershed. Ideally, the project would identify and prioritize sites that would benefit from water conservation measures.

Native Colorado River Cutthroat Restoration

Colorado River Cutthroat trout is the only species of trout native to the Eagle River watershed. Protection and restoration of Colorado River cutthroat trout typically necessitates the existence or construction of barriers in smaller streams that prevent upstream movement of non-native trout, which are superior competitors. There are currently three known populations of pure "A-strain" Colorado River Cutthroats left in the Eagle River watershed. This project would seek to identify other viable populations, and determine possible restoration sites. Ultimately, the goal would be to establish more populations to reduce the chance of extirpation. This project was not rated due to extensive Colorado cutthroat restoration activities consistent with these goals that are already being implementing by CDOW and other entities in the Eagle River watershed.

5.10 TOP ECOLOGY PROJECTS – BENEFITS OF IMPLEMENTATION

Many of the projects in the MCDA ranking fall within a narrow range of scores. The intent of the MCDA is not to 'split hairs' between closely ranked projects, but instead to prioritize a group of top projects within each tier. This section outlines the major ecological benefits of each of the top-ranked projects in each tier.

5.10.1 Flow Management/Decision-Making Tools [3]

Flow regime is a master variable that profoundly influences ecological processes in stream and river systems. As described above, this project would provide (1) a more rigorous scientific basis for evaluating the incremental benefits of various instream flow scenarios, and (2) decision-making tools to examine what-if scenarios in specific river segments with regard to aquatic habitat and water quality interactions involving dilution of pollutants and temperature. As opposed to a focus on minimum survival flows, tools should be developed for examining the ecological relevance of incremental changes in low flow, flow variability (not just mean states), changes in peak flows, flow timing, and other hydrologic attributes. Given ongoing metals loading and increases in nutrient loading in the Eagle River watershed, decision-oriented tools allowing incorporation of future water demand, pollutant loading and climate/streamflow scenarios may provide critical information as to probable future conditions in the Eagle River, based on the best available science. Thus, the primary benefits of this project would be to provide a basis for making informed decisions regarding proposed flow modifications and potential future consequences for fisheries, water quality, recreation, and other values, as well as a more scientifically defensible evaluation of the adequacy of instream flows.

5.10.2 Basinwide Nutrient Strategy [3]

Benefits of this project include preventing eutrophication and aesthetic degradation due to proliferations of algae, maintenance of ecological integrity, reduced risk of impacts to the Gore Creek and Eagle River trout fisheries, reduced disinfection byproducts in drinking water supplies, and a better understanding of links between future growth, flow regime, and water quality. As part of this process, all NPDES permits in the watershed could be evaluated and issued simultaneously based on the results of a coordinated monitoring program that provides up-to-date information. This approach facilitates: (1) comprehensive analysis of the cumulative effects of NPDES discharges from an ecological standpoint, (2) integrated management of point and nonpoint source pollution, and (3) collaboration among dischargers and nonpoint sources in achieving water quality goals in a market based, cost-effective manner.

5.10.3 Camp Hale Restoration [3]

Restoration of the Eagle River and riparian wetlands at Camp Hale could bring a wealth of ecological benefits to this large, unique system. Channel restoration would reinstate complex habitat features for fish and other biota, and reconnect the channel to large areas of floodplain wetlands. The restored wetlands would increase water storage in the valley and sustain base flows, provide habitat for riparian fauna, increase food/energy input into the channel, and provide diverse habitat, shade and cover. Key advantages of this project site include its size and lack of constraint from development, providing unusual latitude in creating a functional restoration plan for the valley. Furthermore, an ecologically beneficial design could be readily integrated with features that enhance the historical significance and great educational value of the site. The restored site could simultaneously increase awareness of the 10th Mountain Division legacy and the ecological significance of the valley, wetlands, and meandering river.

5.10.4 Belden Cribbings [2]

Implementation of this project would decrease the risk of waste rock loading directly into the Eagle River and further impacts to aquatic life. This project would also improve human safety in Gilman Gorge and potentially reduce current metals loading from runoff.

5.10.5 Eagle Mine/Belden [3]

Further reductions in metals loading from historical mining impacts could potentially increase brown trout relative weights and abundance in the Belden to Gore Creek segment of the Eagle River, increase the extent of native sculpin recolonization in downstream segments as documented at Arrowhead, increase the occurrence and abundance of metal-sensitive aquatic insects, and decrease the risk of chronic and synergistic effects associated with stormwater / nonpoint source loading in urbanized segments downstream.

5.10.6 Edwards/Lake Creek Segment [2]

This project site represents an area where future development could be coupled with channel/floodplain restoration. The current, channel has little habitat value and increases water temperatures. Channel restoration could be accompanied by wetland restoration and re-established connectivity between the channel and the floodplain. Ponds could also be included in the design for recreational, floodplain water storage, and stormwater management purposes. Restoration would reduce temperatures through the site, increase dissolved oxygen, reconnect high-quality fish habitats upstream and downstream, flush fines and improve the channel substrate. By integrating restoration design with anticipated land use changes and recreational access, this project also provides educational opportunities.

5.10.7 Enhance River Habitat in Gypsum Wildlife Area [2]

Conservation and restoration efforts at the Gypsum Ponds State Wildlife Area would protect an excellent public access point to the lower Eagle. Ecological benefits include the protection of more than two miles of the best remaining riparian habitat along the lower Eagle, improvement of instream fish habitat, and reestablishment of floodplain connections and enhanced riparian functions.

5.10.8 Long-term Access Plan for Low Impact Recreation [2]

This project would ultimately result in a comprehensive strategy to improve existing access and enhancing access points throughout the watershed in a sustainable manner. In its initial stages, it would also create a process for stakeholders to provide input and develop long-term goals and a vision for the watershed. This process could be facilitated by experts and managers who have specialized knowledge regarding forecasting of future pressures and carrying capacity studies. This project could play a key role in ensuring a sustainable economic base associated with recreation and tourism, as well provide aesthetic and ecological improvements to riparian areas degraded by existing access practices.

5.10.9 Riparian Planting Opportunities – Lower Eagle and Valley Tributaries [1]

Bank material is generally more erodible along the lower Eagle River valley due to changes in geology, soils, and climate. Where vegetation is sparse along the riparian corridor due to grazing, mechanical removal, or other factors, erosion is often accelerated. Several locations exist where riparian vegetation can be established or supplemented. Beyond increasing bank stability, re-establishing woody vegetation would provide a buffer against nonpoint source pollution, shade to improve habitat and decrease temperatures, and habitat for terrestrial species. In particular, establishing trees along tributaries entering the Eagle valley that are narrower than approximately 25-ft wide could result the greatest shading and temperature reduction benefits. Riparian planting requires careful planning and evaluation but can provide excellent opportunities for volunteer involvement.

5.10.10 Riparian Tamarisk Removal – Lower River and Tributaries [1]

Tamarisk has been identified at several locations in the lower watershed, but is not expected to spread above approximately 7,000 ft in elevation. Eagle County is currently undertaking measures to control its spread, but implementing a tamarisk-specific eradication program would accelerate its removal from the watershed and decrease the risk of future problems. Removal of tamarisk could be accompanied by riparian planting to encourage the return of native vegetation. Similar to other riparian planting projects, tamarisk removal could also draw on volunteer support.

5.10.11 Avon Restoration – Overly Wide, Localized Areas [1]

Localized zones of high width to depth ratio exist in the Eagle River through Avon where channel restoration and riparian zone protection could improve physical habitat. The location identified immediately downstream of “Bob” the bridge could be combined with measures to provide low impact public access to the Eagle. Benefits of this project include improved fish habitat quality and continuity, aesthetics, and riparian functions.

5.11 PROJECT CONNECTIONS

Although the MCDA analysis can only examine multiple projects in a relative sense, many of these projects could be combined to provide additional benefits and draw on a single funding source for implementing the group of projects. The following is a preliminary list of logical project combinations.

1. Camp Hale Restoration and Non-native Species Removal.
2. Flow Management/Decision-Making Tools and Basinwide Nutrient Strategy.
3. Long-term Access Plan for Low Impact Recreation, Edwards / Lake Creek segment, Gypsum SWA Enhancement, Minturn Confluence Segment, and Riparian Planting Opportunities – Lower Eagle & Eagle Valley Tributaries.
4. Riparian Planting Opportunities – Lower Eagle & Eagle Valley Tribs, Riparian Tamarisk Removal – Lower River and Tributaries, and Riparian Work/Bank Stabilization Upstream of Wolcott.

5.12 CONCLUSIONS

The Eagle River watershed offers numerous opportunities for implementing restoration projects of varying ecological effectiveness at several spatial and financial scales. The purpose of this MCDA is to identify the important components involved in decision-making at the watershed scale and apply them to the prioritization of several key projects identified throughout the ERIA. The analysis is intended to provide a rapid, first order comparison of project functionality and feasibility. Although the MCDA described above provides a rational approach for systematically comparing the relative benefits and characteristics of candidate projects, it will undoubtedly require additional refinement as more information becomes available. By weighing the benefits projected by this analysis with more detailed cost estimates, available funding sources, and future socio-political factors, decision makers will have a clearer rationale for targeting funds to maximize the ecological effectiveness of watershed restoration efforts. In the final chapter of the ERIA, the prioritized projects described above are linked with specific strategies for restoration of the Eagle River watershed.

CHAPTER 6

Recommendations

"We don't inherit the earth from our ancestors, we borrow it from our children." – David Brower, 10th Mountain Division Veteran

"The significant problems we face cannot be solved at the same level of thinking we were at when we created them." – Albert Einstein

This final chapter describes how those projects identified in the previous chapter may be viewed as components of a larger strategy for restoration of the Eagle River watershed. Although the ecological benefits and technical feasibility of many of these projects are increasingly clear, the social and political feasibility of implementation is more uncertain. Basin-wide problems are characterized by complex linkages and interdependencies among social and ecological systems, and in the final analysis, watershed restoration is fundamentally a social process that invokes science to varying degrees. Long-term personal, institutional, and financial commitments are essential for success. These commitments must be realized as part of a coordinated framework for action; otherwise, watershed strategies will become static or unravel. Coordinated and cooperative actions are sorely needed because neither "command and control" regulatory prescriptions nor "invisible hand" market approaches are likely to solve large-scale water resources problems in a sustainable manner (Grigg, 1996).

Ten key principles of watershed restoration derived from numerous case studies, scientific literature, and experience were summarized in Chapter 2 and bear repeating:

1. Address the causes of problems and not just symptoms, i.e., focus on ecosystem processes rather than achieving a particular condition.
2. Recognize many scales and potentially limiting factors. A long-term, large-scale, multidisciplinary perspective is critical.
3. Work with rather than against natural watershed processes and reconnect severed linkages (e.g., channels and floodplains).
4. Clearly define goals and make both sustainability and enhancing ecological integrity explicit goals. Doppelt *et al.* (1993) argue that the most critical measures of sustainability are whether a riverine ecosystem (1) is free of "distress symptoms," (2) can self-repair after disturbances, and (3) supports native riverine-riparian biodiversity.

5. Utilize the best available science in predictive assessments that are risk-based and decision-oriented. For inclusive decision-making, predictive assessments should link system manipulations to probable outcomes that are of primary interest to all stakeholders: clean water, productive fisheries, other valued biota, reliable water supply, recreation, and aesthetics.
6. Honestly identify and openly debate key knowledge gaps and uncertainties but adopt an action-oriented principle that ensures that the decision-making exercise will lead to results.
7. Make decisions in a transparent, organized framework that:
   - structures the problem clearly;
   - provides a ranking of the options even though the uncertainties may not be resolved in the foreseeable future;
   - involves affected stakeholders;
   - documents and justifies the decision process to all stakeholders; and
   - provides research priorities by showing whether resolving particular uncertainties would affect the preferred option(s).
8. Watershed restoration projects are as much a social undertaking as an ecological one: understand social systems and values that support and constrain restoration while establishing long-term personal, institutional, and financial commitments.
9. Some strategies will work, some won't, and some will take many years to assess. Be patient and learn through careful long-term monitoring of key ecological processes and biotic elements. Reevaluate and update the restoration strategy.
10. The best strategy is to avoid degradation in the first place. Emphasis should be placed on preventing further degradation rather than on controlling or repairing damage after it begins.

It is clear from reviewing this list that there is much work, both technical and sociopolitical, that remains before a comprehensive watershed restoration strategy can be effectively implemented. Nonetheless, an action-oriented approach that ensures results is critical in the rapidly changing Eagle River watershed. The ERIA has filled some information gaps but numerous questions remain and many new questions have arisen. These questions necessitate ongoing multidisciplinary input and continuing efforts to include the best available scientific information and expert judgment. The decision approach described in Chapter 5 is provided as an initial prioritization framework, and is designed to be flexible and adaptable as new information is obtained and the decision-making process evolves. Furthermore, the recommendations provided below are not intended to be all-inclusive and do not supplant the many excellent recommendations made in previous 'big picture' reports described in Chapter 3, including the Eagle River Watershed Plan (1996) and the 208 Report (NWCCOG, 2002). Instead, the following recommendations reflect what we view as the most pressing stressors and threats to sustainability and ecological integrity. All the projects described in Chapter 5 have individual merits but those likely to have the greatest long-term and collective ecological benefits per expenditure are emphasized below. Key uncertainties as well as expected benefits are also described below.

6.1 SEVEN RECOMMENDED ELEMENTS OF A COMPREHENSIVE RESTORATION STRATEGY FOR THE EAGLE RIVER WATERSHED

6.1.1 Recommendation 1 – Define and Manage for Key Ecological Aspects of Flow Regime

Flow regime is a master variable that profoundly influences numerous ecological processes in stream and river systems. Although the flow regime of the Eagle main stem is less altered than some other rivers of comparable size on the western slope of Colorado, reservoirs and diversions have influenced the flow regime of several segments in the basin. Demands for water associated with anticipated growth, Front Range water rights, and snowmaking are expected to increase. Making informed decisions about potential changes in flow regime necessitates the development of decision-support tools to assess the potential ecological consequences of flow alteration schemes. The method used to quantify instream flows on the Eagle River main stem does not address several key factors linked to low flows such as recreation, water quality, land use changes, wastewater dilution, and temperatures. Given that current instream flow quantities do not meet recommended CDOW hydraulic criteria in several segments, and that the past application of a single-transect quantification approach to the main stem Eagle River is questionable under current conditions, it is not recommended that existing instream flow rights be used as a standard to evaluate the potential ecological effects of flow modifications. Decision-making tools for flow management are most effective if underpinned by sound science and designed to account for interactions between water quantity and water *quality* factors (current and future) in a spatially explicit manner. This means, for example, that the likely effects of flow extraction and augmentation can be evaluated within the specific river and stream segments that may be affected in different ways. Given ongoing metals loading and expected increases in nutrient loading in the Eagle River main stem and Gore Creek, risk-based tools allowing incorporation of future water demand, pollutant loading and climate/streamflow scenarios could provide critical information to assess probable future conditions based on the best available scientific information. We recommend the development of decision-oriented tools based on or comparable to the Instream Flow Incremental Methodology (IFIM) to more rigorously assess the potential effects of flow alterations on instream fish habitat and water quality in the Eagle River.

The benefits of such an effort would include: (1) a more rigorous scientific basis for evaluation of the incremental benefits of various instream flow scenarios, and (2) decision-making tools to examine hypothetical scenarios in specific river segments with regard to aquatic habitat, dilution of pollutants, and temperature changes. As opposed to a focus on minimum survival flows, tools could also be developed to examine the ecological relevance of incremental changes in low flow, flow variability (not just mean states), peak flows, flow timing, and other hydrologic attributes. The primary benefits of this effort would be to provide a basis for making informed decisions regarding proposed flow modifications and potential future consequences for fisheries, water quality, recreation, riparian communities and other values, as well as a more scientifically defensible evaluation of the adequacy of instream flows.

For example, instream flow recommendations for rivers are increasingly based on several of these factors. For example, a multidisciplinary group of scientists and managers known as the Instream Flow Council issued the following policy statements (IFC, 2002):

- *Instream flow prescriptions must recognize the relation between the quantity and quality of water in streams, document the effects of water quality changes on riverine resources, and implement prescriptions that maintain or improve water quality characteristics for natural riverine resources.*
- *Instream flow prescriptions must recognize the connectivity between instream flows and riparian areas, and maintain or establish riparian structure and functions.*
- *Instream flow prescriptions should maintain or reestablish connectivity between instream flows and floodplains.*
- *Instream flow prescriptions should provide intra-annually and interannually variable flow patterns that mimic the natural hydrograph (magnitude, duration, timing, rate of change) to maintain and restore processes that sustain natural riverine characteristics.*
- *Instream flow prescriptions must maintain spatially complex and diverse habitats that are available through all seasons.*
- *Channel maintenance flow is an integral component of instream flow prescriptions for alluvial channels, and the maintenance, restoration, and preservation of stream channel form should be based on geomorphic principles and geofluvial processes.*

Currently, a framework and decision tools to assess the extent to which these recommendations are being met and can be met in the future are not available for the Eagle River. A detailed analysis of flow regime characteristics was performed during the ERIA. Numerous hydrologic metrics were computed and related to ecological aspects of the system. Although making specific recommendations on 'optimal' flow regime attributes is beyond the scope of this study, it should be noted that scientific understanding of the linkages between specific hydrograph attributes and geomorphic-ecological processes is rapidly increasing. For example, techniques similar to those developed by Andrews and Nankervis (1995) and W.W. Emmett (USGS Emeritus, pers. comm.) provide a basis for quantifying the magnitude and duration of flows for channel maintenance. The 'Recruitment Box Model' of Mahoney and Rood (1998) also provides quantitative guidance on managing peak flows for maintenance of certain riparian communities. Opportunities for better flow management clearly exist, as there appears to have been no regional organized efforts to identify and quantify specific aspects of the flow regime crucial to sustaining habitat, riparian processes, water quality and channel maintenance. These linkages are a key uncertainty and undoubtedly vary with pollutant levels, geomorphic contexts, and riparian plant communities in the watershed. Specifying flow magnitudes needed to achieve ecological objectives is more straightforward than specifying the necessary *frequencies* of channel and riparian maintenance flows, as this is a scientific knowledge gap.

Linking flow regime with key ecological processes and decision support tools can provide critical information on 'how much water the river needs' to support various services and amenities valued by stakeholders. But satisfying these needs is even more complex. Clearly, the seniority of other water rights over ISF rights in the Eagle River watershed constrains options for emulating natural flow processes. Nonetheless, implementation of this recommendation will help stakeholders and policy-makers balance competing interests with a clearer vision of future ecosystem states with regard to fisheries, water quality, recreation, aesthetics and other values.

Monitoring is an important component of flow management. Because the Colorado Water Conservation Board (CWCB) holds instream flow rights and cannot consistently monitor instream flow levels, we also recommend the creation of an organized monitoring program for instream flows. A pilot program, "Adopt an Instream Flow" was initiated in 1998, with one staff gage placed at the Eagle County Fairgrounds. However, the gage was washed out by ice jams and is no longer being monitored. Currently, no strategy exists to ensure that instream flows are met prior to junior rights. Monitoring activities could rely on both USGS real time gauges and volunteer, such a program would develop stage-discharge relationships and maintain 'educational' staff gages at reaches known to be most susceptible to low flows, elevated temperatures and fish kills. Replacement of generic staff gages with easily interpretable signs directly pointing out the stage of the instream flow could also have educational value. Such signs could be mounted like staff gages but have adjustable heights that could be altered to reflect changes in measured stage-discharge relationships. Stage-discharge relationships should be established by volunteers who are knowledgeable and trained in hydrologic monitoring methods consistent with USGS protocols.

Finally, water conservation is a critical element in flow regime management. We concur with the numerous water conservation and planning activities recommended in the Eagle River Watershed Plan and 208 Report. Planning for future growth, education, xeriscaping, recycling and gray water systems, metering and numerous other actions can reduce consumptive uses and support adequate flows in the Eagle River watershed. Collaboration with the Colorado Water Trust is also recommended.

6.1.2 Recommendation 2 – Implement Restoration Projects That Have the Potential to Provide Synergistic Benefits Across Relatively Large Segments of the System

There are three relatively long segments of the river corridor with substantially degraded habitat that provide outstanding and feasible opportunities to reconnect existing high quality habitats and/or reestablish wetland and riparian functions on a disproportionately large scale:

- Eagle River at Camp Hale,
- Eagle River at Edwards / Lake Creek Segment, and
- Eagle River at Gypsum SWA.

At Camp Hale, five miles of meanders and hundreds of acres of wetlands were filled, and replaced with a straight canal. The current channel contains homogeneous and degraded habitat and is hydrologically disconnected from the adjacent valley floor.

The Edwards / Lake Creek segment is severely overwidened with degraded habitat, unstable banks, and poor substrate. The 1.7-mile segment is located between two extant segments of very good aquatic habitat in the Eagle River.

The Gypsum SWA segment of the Eagle River is a key riparian corridor in the lower Eagle valley. This two-mile segment is geomorphically unstable and has a tendency toward braiding, and multiple meanders have been truncated by I-70.

In addition, the section of the Eagle River from the Minturn railroad yard to I-70 contains several reaches of highly disturbed habitat. Although this corridor holds the potential for significant improvements in physical habitat, riparian re-vegetation, and recreational access, ongoing water quality impairment due to metals loading would limit the ecological benefits of restoration project in this segment.

6.1.2.1 Camp Hale Restoration

(Above: schematic of potential Camp Hale restoration alternative.)

The benefits of restoring portions of Camp Hale include:

- extensive high-elevation wetlands,
- improved fish habitat,
- greater food web support,
- historical enhancement, and
- education and recreation opportunities.

Possible restoration approaches are:

- restore meandering form and floodplain connectivity (~5 miles),
- leave straight channel as historical floodplain remnant,
- relocate willow / alder bank vegetation from channelized reach,
- several preliminary alternatives / site concepts have been developed, and
- enhance historical aspects.

Currently, the cost for this project is estimated between $5 and $8 million for the full site.

A very popular project among local stakeholders is the restoration of Camp Hale, the former military base of the 10th Mountain Division. In 1942, the U.S. Army Corps of Engineers began constructing Camp Hale in the glacial valley known as Eagle Park. To construct the base, the Eagle River was channelized and centered in the valley. Wetlands in the valley bottom were drained and covered with at least 200,000 cubic yards of fill material. Today the site is located on the White River National Forest. The river is incised throughout much of the segment, leaving the channel hydrologically disconnected from the valley floor and lacking a functional riparian corridor. Native riparian vegetation has not re-colonized the fill terraces and the valley is covered in upland and invasive plant species. The instream habitat is generally poor and homogeneous. Historical and aerial photos taken prior to construction were used with site surveys, geomorphic analysis, and a variety of other information to examine the feasibility of restoring the river channel to some semblance of its pre-channelized state. Restoration alternatives under consideration include re-creating a sinuous planform, instream habitat enhancements, streambank bioengineering and riparian plantings, as well as educational and historical improvements. Because Camp Hale is on the National Register of Historic Places, any changes must be sensitive to the historical values of the site. At the time of this writing, the most plausible project seems to involve restoring a meandering form and riparian connectivity to approximately four to five miles of channel by removing part of the fill material along a floodplain swath, leaving the straight channel as a historical floodplain remnant, relocating willow / alder bank vegetation from channelized reaches and using bioengineering to establish additional riparian vegetation. Several preliminary alternatives / site concepts that simultaneously enhance historical aspects of the site have been developed (Appendix A). There was significant momentum for this project several years ago, prior to the designation of Camp Hale as a National Historic Register site; and it was easily the most popular project among stakeholders involved in creating a preliminary project list.

Although not as urgent as other projects in the basin, restoration of the Eagle River and riparian wetlands at Camp Hale could bring a wealth of ecological benefits to this large, unique system. Channel restoration would reinstate complex habitat features for fish and other biota, and reconnect the channel to large areas of floodplain wetlands. The restored wetlands would increase water storage in the valley and sustain base flows, provide habitat for riparian fauna, increase food/energy input into the channel, and provide diverse habitat, shade and cover. Key advantages of this project site include its size, public ownership / sole owner development. These features provide unusual latitude when creating a functional restoration plan for the valley. Furthermore, an ecologically beneficial design could be readily integrated with features that enhance the historical significance and great educational value of the site, simultaneously increasing awareness of the 10^{th} Mountain Division legacy and the ecological significance of the valley, wetlands, and meandering river.

6.1.2.2 Edwards / Lake Creek Area

The benefits of river restoration near Edwards include:

- connectivity of high quality fish habitats,
- temperature reduction,
- increase dissolved oxygen,
- flushing fine sediments and coarser substrates,
- floodplain and wetlands creation, and
- improved recreation access.

Possible restoration approaches are:

- restore lower width/depth ratio and improve floodplain connectivity – fill material from wetland / pond complexes,
- enhanced access points, and
- integrated stormwater management.

Current estimated cost for the project is $1.7 to 3.7 million, not including land conservation measures.

(Above: Lake Creek, 1890; Below: Edwards, 2004)

Downstream of Edwards near the confluence of Lake Creek and the Eagle River, the river valley abruptly widens and flattens. Through this reach, the Eagle has an extremely high width to depth ratio and an insufficient capacity to transport sediment. The river has a substrate embedded with fine sediments that support tubifex worms (*Tubifex tubifex*), an organism associated with the occurrence of whirling disease (*Myxobolus cerebralis*) in trout. Relatively high temperatures occur in this segment during low flow periods and this site marked the upstream extent of the most recent severe fish kill in the Eagle River. The current, overly-wide channel has little habitat value, and the segment disconnects high quality habitats upstream and downstream. The abrupt valley changes, a steep knickzone in the lower part of the segment, and uncertain land use near the upstream end of the segment constrain potential design alternatives for the site.

This project would involve reducing width and increasing depth to improve sediment continuity and substrate conditions, restoring mild sinuosity, bank bioengineering, restoring native riparian plant communities that are matched to site conditions, wetland / oxbow lake restoration/creation on floodplain, improving recreational access, and educational/interpretive enhancements. This project site also represents an area where future development could be coupled with channel/floodplain restoration. Ponds could be included in the design for recreational, floodplain water storage, and stormwater management purposes. Restoration would reduce temperatures through the site, increase dissolved oxygen, reconnect high-quality fish habitats upstream and downstream, flush fine sediments, and improve the channel substrate. By integrating restoration design with anticipated land use changes and recreational access, this project also provides educational opportunities.

6.1.2.3 Gypsum Wildlife Area

(Above: Aerial view of Eagle River at Gypsum, 1998. Note encroachment of I-70 on meanders near top-center and right corner of photo.)

The benefits of restoration and conservation of the river channel near Gypsum include:

- conserve the best remaining riparian corridor in lower Eagle,
- improved instream habitat,
- enhanced floodplain connectivity, and
- stabilized riparian functions.

Possible approaches to achieve benefits are:

- voluntary conservation of south bank parcels,
- restore lower width/depth ratio and improve floodplain connectivity,
- fill material from floodplain wetland / pond complexes, and
- develop educational/recreational opportunities with Division of Wildlife and Town of Gypsum.

Current estimated cost for the project is $0.7 to $1.1 million for channel work, not including land conservation.

The Gypsum Ponds State Wildlife Area near the town of Gypsum offers excellent public recreation access along the lower Eagle River. The river channel through this reach is wide and braided, with a remnant cotton-willow forest. Two meander bends were truncated and re-aligned for construction of I-70. These alterations have led to further channel adjustments and the formation of chute cutoffs. Channel restoration would involve 1.6 to 2 miles of realignment and narrowing of the channel. The narrower channel would have a greater probability of overbank flows, which would establish a better connection to the floodplain. The project would also involve protection of the outstanding remnant riparian forest community. Full implementation of the project would rely on land conservation along the south bank of the reach. This land is privately owned and has been rumored for development for years, although no plans have materialized. The project would conserve the relatively undamaged riparian parcels on the south bank and enhance future public access as the area sees more use. Ecological benefits include the protection of more than two miles of the best remaining riparian corridor along the lower Eagle, improvement of instream fish habitat, reestablishment of floodplain connectivity, and enhanced riparian functions.

6.1.3 Recommendation 3 – Further Reduce Metals Loading From Historic Mining Impacts and Stormwater and Defuse Toxic 'Time Bombs'

6.1.3.1 Reduce Metals Loading from the Belden Area and Rock Creek

(Above: Waste rock pile 14 and the Tramway tributary area in Belden: a key source of zinc loading to the Eagle River.)

The benefits of additional reductions of zinc may include:

- enhanced brown trout fishery (abundance, relative weight, fish health),
- greater diversity of aquatic insects, and
- decreased cumulative impact of urban stormwater loading downstream.

Possible approaches to achieve additional reductions are:

- capture and treatment at Belden,
- implementation of passive treatment – permeable reactive barrier,
- combination of strategies to yield best result, and
- some room left in consolidated tailings pile.

The estimated cost to further reduce zinc loading in the Eagle River from the Belden area is unknown.

Reductions in metals loading have resulted in significant ecological improvements within and downstream of the Eagle Mine site. The Eagle Mine however continues to constrain water quality both within the Superfund boundary and further downstream. Biological impacts associated with current zinc concentrations include reduced weights in brown trout, and suppression or elimination of sensitive organisms such as the native mottled sculpin and certain aquatic insects. As a result of reductions in other sources, the majority of current zinc loading to the Eagle River occurs in the Belden segment from 'unaccounted' sources. The Rock Creek drainage at Gilman is the second largest contributor. Monitoring data point to the Belden Tramway area as a primary source of the remaining zinc load. Implementation of capture/treatment or passive remediation technologies and addressing waste rock at this location could result in additional reductions in zinc concentrations and further improvements in biological water quality both within and below the Eagle Mine site. This recommendation involves: (1) further evaluation and bracketing of groundwater loading sources in the Belden reach, (2) conducting cost-benefit analyses to link specific remediation activities, expected loading reductions, and likely environmental benefits for river segments in the mine site and downstream, and (3) implementation of cost-effective remediation projects.

Further reductions in metals loading from historical mining impacts could potentially increase brown trout relative weights and abundance in the Belden to Gore Creek segment of the Eagle River, increase the extent of native sculpin recolonization in downstream segments as documented at Arrowhead, increase the occurrence and abundance of metal-sensitive aquatic insects, and decrease the risk of chronic and synergistic effects associated with stormwater / nonpoint source loading in urbanized segments downstream.

Key uncertainties include:

- Groundwater dynamics in the Belden segment;
- The efficacy and design life of passive treatment technologies at temperatures and iron levels occurring at Belden;
- Connectivity of waste rock piles #13 and #14 to surface and subsurface delivery pathways;

- The relationship between mine pool elevation and groundwater loading patterns; and
- Costs relative to incremental ecological benefits.

6.1.3.2 Belden Cribbings Stabilization

The cribbings upstream from Belden are an ecological "Time Bomb." The potential for catastrophic failure exists.

Possible methods for stabilizing the cribbings area include:

- buttressing the 'toe' of slope,
- backfilling with limestone material, and
- address multiple cribbings.

Projected cost for this project is between \$500,000 and \$2 million. The most likely estimate is approximately \$1.2 million.

(Left: Aging cribbings holding waste rock / tailings precariously over the Eagle River.)

Several historic wooden structures or 'cribbings' used to stabilize mining waste rock piles are located outside the Eagle Mine Superfund boundary, especially in the Belden area. Many of these structures are decaying and collapsing. A series of cribbings readily observable from U.S. Highway 24 is of particular concern given hillslope angles, proximity to the river, and relatively large amounts of fine, low pH waste rock material that could be directly delivered into the Eagle River in the event of structural failure. The potential exists for these cribbings to fail catastrophically. The ongoing degradation and potential failure of these structures represent a substantial risk to the biological improvements that have been achieved in the Eagle Mine site. Chronic and acute impact estimates based on failure/direct loading scenarios and measured leachable zinc concentrations suggest stream pulses with elevated zinc concentrations ranging from 13,000 μg/l to 350,000 μg/L over current conditions. For comparison, the generic water quality Table Value Standard suggested by the USEPA for zinc is 106 μg/L for background conditions in the Eagle River.

This effort would involve surveying the cribbings and associated waste rock piles, a final determination of ownership and property boundaries, and stabilization of piles posing the greatest threat to the Eagle River. Buttresses placed at the slope toe to stabilize waste rock piles could be backfilled with acid neutralizing materials such as limestone if warranted by the acid production potential and texture of the waste rock. We also strongly recommend addressing the leaking adit located just upstream of the site (Figure 4.77) as part of a cribbings stabilization project.

Implementation of this project would decrease the risk of waste rock loading directly into the Eagle River, as well as potentially reduce current metals loading from runoff and further impacts to aquatic life.

Key uncertainties include:

- The probability of occurrence of different failure and delivery modes;
- The extent of downstream impacts from estimated pulse inputs have not been quantified using an advection-diffusion model; and
- Landowner constraints.

Finally, it must be noted that increases in metals loading from diffuse stormwater sources are expected to increase with sub/urban development over time. Improved stormwater management for new development and retrofitting existing stormwater 'hotspots' have the potential to reduce the cumulative impacts of metals loading to the Eagle River and its tributaries. Specific stormwater recommendations are described under Recommendation 5 below.

6.1.4 Recommendation 4 – Develop and Implement a Watershed Strategy for Addressing Nutrient Enrichment

Nutrient concentrations in the Eagle River and Gore Creek are now substantially higher than levels observed in less disturbed streams and rivers of the Colorado Rockies, as well as values recommended to prevent impacts to aquatic insect communities and nuisance accumulations of algae. Ecological impacts from nutrient enrichment can occur abruptly, with little indication prior to threshold responses in biological processes. No general nutrient criteria that set targets for total nitrogen (TN) and total phosphorus (TP) loading are currently in place for streams and rivers in the Eagle River watershed. Point source discharge permits are currently evaluated and issued on an individual basis. Nutrient loading is expected to increase under current point source discharge permits and from polluted runoff. This recommendation involves developing a watershed wide strategy to manage nutrient enrichment based on the best available scientific information. Steps in implementing such a strategy would include:

- Linking current and expected future total nitrogen and phosphorus loadings, and streamflows, with probable ecological responses of algae (periphyton), aquatic insects, and trout;
- Setting nutrient loading targets that are likely to result in desired ecological states based on current science and monitoring data;
- Simultaneously assessing NPDES discharge permits in a watershed-wide, collective analysis to achieve loading targets in the most cost-effective manner and to facilitate collaboration among all dischargers and nonpoint sources; and
- Implementing a monitoring program specifically designed to assess whether target nutrient loads are achieving the desired ecological endpoints identified by stakeholders.

Benefits of this initiative include preventing eutrophication and aesthetic degradation due to proliferations of algae, maintenance of ecological integrity, reduced risk of impacts to the Gore Creek and Eagle River trout fisheries, reduced disinfection byproducts in drinking water supplies, and a better understanding of links between future growth, flow regime, and water quality. As part of this process, all NPDES permits in the watershed could be evaluated and issued simultaneously based on the results of a coordinated monitoring program that provides up-to-date information. This approach facilitates: (1) comprehensive analysis of the cumulative effects of NPDES discharges from an ecological standpoint, (2) integrated management of point and nonpoint source pollution, and (3) collaboration among dischargers and nonpoint sources to achieve water quality goals in a market based, cost-effective manner. Basinwide permitting approaches have improved the ecological and economic effectiveness of managing point sources of nutrients in many river basins. Basinwide permitting basically involves the simultaneous evaluation of all permits, typically on a 5-year schedule. As a result, monitoring can guide permit decisions by examining the cumulative ecological influence of all discharges. Economic benefits are derived from targeting any necessary reductions at facilities where they are most readily achieved and cost-effective. In very large urbanized basins like the South Platte, such an approach could prove intractable. However, in the Eagle River watershed, where consolidation of water resources infrastructure has already occurred to a substantial extent, such a strategy will allow financial resources to be targeted in a manner that maximizes ecological benefits. Further information on basin-wide management of point source discharges is provided in Appendix K.

Together, nutrient budgets (point and nonpoint sources) and scientific assessments linking desired ecological states and nutrient concentrations provide the foundation of a unified strategy for managing point and nonpoint nutrient sources. Ecological goals can be achieved by meeting target nutrient loads and concentrations. For example, stakeholders set a goal of keeping periphyton biomass below 100 mg Chl *a* /m^2 in the Clark Fork River, Montana, by maintaining mean concentrations of total nitrogen and phosphorus below 0.3 mg/L and 0.02 mg/L, respectively. In identifying nutrient loading goals, it is recommended that *decision-oriented* scientific assessments be developed. Exclusive reliance on mechanistic modeling is strongly discouraged given the complexity of processes, parameter uncertainty, and the need for decision endpoints that are valued by stakeholders. Instead, these assessments should be risk-based and would likely include a mix of small models, decision trees or probability networks, and expert judgment (e.g., NRC, 2001; Reckhow, 1999; Reckhow and Chapra, 1999). Such an approach facilitates the envisioning of future ecosystem states that matter most to stakeholders and linking those states with specific nutrient goals as exemplified in Table 4.30.

Key uncertainties include:

- The nutrient loading and flow conditions at which current diatom communities are likely to shift to filamentous algae at nuisance levels are uncertain;
- Best available technology can achieve very low TN and TP concentrations but the feasibility and costs of implementing additional advanced treatment technologies at various facilities in the Eagle River watershed are unknown;
- Eutrophication impacts on fisheries are difficult to predict given complex interactions with other factors such as flow and temperature; and
- The spatial and temporal density of biological monitoring (including periphyton) necessary to assess whether biological goals are being met and the cost of such monitoring.

6.1.5 Recommendation 5 – Develop and Implement an Integrated Strategy for Managing Stormwater and Restoring Riparian Corridors as Growth Occurs

Research conducted as part of the ERIA indicates that local stormwater and riparian zone policies are highly variable in terms of protectiveness, compliance monitoring, and enforcement mechanisms. We concur with previous studies including the Eagle River Watershed Plan (1996) and 208 Plan (NWCCOG, 2002) that recommend the development and implementation of improved strategies to manage stormwater and riparian zones in the region. Extensive resources including technical assistance and model ordinances are currently available to stakeholders (e.g., http://www.stormwatercenter.net/). A summary of existing local policies is provided in Sections 3.5 and 3.6 and additional information on ordinances for stormwater and riparian zones is provided in Appendices I and J, respectively.

In particular, the Eagle River Watershed Plan provided several specific recommendations regarding stormwater management and riparian buffers. We fully support these recommendations and suggest that local governments in the watershed:

- Strive for integration of both stormwater and riparian zone ordinances and management programs among jurisdictions.
- Proactively develop and implement stormwater programs that are consistent with the six minimum control measures required under NPDES Phase II stormwater:

    1. Public education and outreach on stormwater impacts.
    2. Public involvement/participation.
    3. Illicit discharge detection and elimination.
    4. Construction site stormwater runoff control.

5. Post-construction stormwater management in new development and redevelopment.
6. Pollution prevention/good housekeeping for municipal operations.

(The Town of Vail is currently developing such a program).

- Ensure that ordinances require implementation of water quality BMPs that capture and treat small runoff events in addition to 'peak shaving' of 2-year and larger events in new development and redevelopment.
- Establish long-term maintenance of water quality BMPs as part of permit requirements.
- Improve compliance monitoring, couple compliance monitoring with technical assistance, and require performance bonds for sediment and erosion control.
- Promote better site design concepts including 'low impact development,' especially the minimization of directly connected impervious areas.
- Consider requiring sediment and erosion control for disturbances less than 5 acres.
- Address septic tanks through inspection and maintenance, e.g., require functionality when property ownership is transferred.
- Inventory stormwater retrofit opportunities, especially those involving potential 'hotspots' like gas stations and industrial facilities.
- Ensure best management practices are implemented for snow storage and disposal to prevent direct delivery of polluted melt water.
- Develop riparian ordinances that speak directly to soil disturbance, vegetation disturbance, fertilizers and pesticides, and native riparian vegetation in streamside buffer zones.

Protection and restoration of riparian zones is a cornerstone of watershed management. Similar to the tools available for protection of riparian zones in urban areas, specific guidance is also available for agricultural lands. For example, the NRCS conservation practice standard for Riparian Forest Buffers (Code 391) on agricultural lands is discussed in Appendix J. Riparian corridors of the lower Eagle River and tributaries are characterized by sparse or no woody vegetation in many locations. Where vegetation is sparse along the riparian corridor due to grazing, mechanical removal, or other factors, erosion is often accelerated. Based on field reconnaissance and aerial photo analysis, several sites have been identified where native vegetation could potentially be established along the riparian corridor. Many of these sites are grazed and would require alternative management to allow re-vegetation. Beyond increasing geomorphic stability, re-establishing woody vegetation would provide a buffer against nonpoint source pollution, shade to decrease temperatures, cover and organic inputs to improve instream habitat, and habitat for terrestrial species. Establishing trees along tributaries entering the Eagle River below Edwards could result in the greatest shading and temperature reduction benefits. Restoration of riparian zones along lower river tributaries could provide important coldwater refugia during periods of low flows and elevated temperatures. Riparian planting requires careful planning and evaluation but can provide excellent opportunities for volunteer involvement.

We recommend the following initial steps in restoring riparian corridors in the lower Eagle River watershed:

- Protect existing riparian forest buffers and restore native riparian communities in areas where vegetation and the accompanying benefits for habitat, thermal regime, and food web support have been lost. Particular emphasis should be placed on tributaries below Edwards and southerly banks in sections of the mid and lower river that are prone to relatively long durations of high temperatures during summer and fall low flow periods.
- Develop sub-basin specific plans for key tributaries to the Eagle River below Edwards including Lake Creek, Brush Creek, Eby Creek, and the Milk, Alkali, and Ute Creek area. The complex management and ownership patterns of these sub-basins necessitates extensive landowner communication and a more focused inventory of opportunities for protection of existing riparian

forest buffers, restoration, and mitigating negative effects of grazing. Such plans would also involve working closely with agencies including NRCS, BLM, and Cooperative Extension as appropriate, and potentially implementing demonstration projects in the process of developing comprehensive strategies for the sub-basins. Although preliminary strategies have been previously developed for reducing sediment yield from the Milk Creek area, these plans have lacked (1) specific goals linked to desired biological outcomes, (2) adequate quantification of expected reductions in sediment yield, and (3) the necessary detail on system-level geomorphic processes needed to target grade control, drop pipes, sedimentation basins and other measures based on specific reduction goals. For maximum effectiveness, a geomorphic strategy should be linked with estimated reductions from upland restoration activities including brush beating and improved grazing management. Specifically, we suggest mapping incised channel evolution types, headcuts, bank heights, materials, morphology, longitudinal profiles, and other characteristics needed to identify specific geomorphic design criteria. Reductions in sediment transport capacity associated with various treatment scenarios (channel and upland) can be subsequently quantified and linked to estimates of suspended sediment loading and impacts on fishes (Newcombe and Jensen, 1996; Section 4.6.6.1) in the Eagle River main stem.
- Utilize the GIS resources and riparian inventory developed during the ERIA to guide landowner contacts and better define specific restoration opportunities.

Key uncertainties include:

- Preferences of the public and policy-makers in balancing environmental protection/public trust and individual property rights;
- The functionality of the approximately 2,200 septic systems in the Eagle River watershed;
- Landowner willingness to re-establish riparian forest buffers through improved grazing practices;
- Political feasibility of coordinated stormwater and riparian buffer management programs and collaborative compliance monitoring among jurisdictions;
- Lack of understanding of existing urban drainage infrastructure and locations of best retrofit opportunities;
- Cumulative effects and interactions of metals loading from historic mining sources and increasing nonpoint source pollution;
- Flow regime interactions with riparian restoration activities; and
- Efficacy, cost, and time frame of achieving adequate reductions of sediment loading from the Milk Creek area.

6.1.6 Recommendation 6 – Enjoy the River, but Also Recognize That There are Limits to its Capacity and Resilience – Develop and Implement a Long-term Access Plan for Low-Impact Recreation.

Eagle County will soon have over 50,000 residents. This will create increasing pressure on the few existing public access points for boating and fishing, and there are few developed recreation/access areas along the Eagle River between Edwards and Eagle. Currently there is no plan or program to ensure future access along the river, manages the parking along Highway 6 and existing access sites, or provides for future access to accommodate rising recreational demand. In general, it is important that the entire community be "connected" to the river. One way to achieve this is to augment existing access points with small, accessible parks along the river near population centers.

As the watershed's population continues to grow, the river system will depend more heavily on the goodwill of residents to maintain water quality, a self-sustaining fishery, and trash-free environments. Implementation of this recommendation would:

- Inventory the ecological condition and legal status of existing access points;
- Identify future access sites and methods to enhance poorly designed access points;
- Redesign existing access points to ensure that ecological values are safeguarded; and
- Yield a comprehensive strategy to improve existing access and enhance access throughout the watershed in a sustainable manner.

In its initial stages, it would also create an organized process for stakeholders to provide input and develop long-term goals and a vision for the watershed. It is recommended that this process be facilitated by experts and managers who have specialized knowledge regarding forecasting of future pressures and carrying capacity studies.

This effort could play a key role in ensuring a sustainable economic base associated with recreation and tourism, as well as provide aesthetic and ecological improvements to riparian areas degraded by existing access practices. Although this initiative was not ranked highest in any individual category of the MCDA, it had the highest average score across categories of any project considered.

6.1.7 Recommendation 7 – Prevent Further Degradation – Protect the Headwaters, Existing High Quality Habitats, and Native Species

It is critical to establish an ongoing process to protect and "secure" remaining healthy biotic refuges by minimizing the possibility that past and future activities will degrade them. Protection and restoration of a well-dispersed network of habitat refuges and hot spots is necessary to sustain current populations and ensure that sources of colonists are available to seed recovered habitats. The final and perhaps most important recommendation is the comprehensive protection of remaining relatively healthy headwaters, biotic refuges, least-disturbed watersheds, riparian areas, floodplains, and network of biological hotspots (Doppelt *et al.*, 1993; Frissell, 1997). This recommendation is directly linked to recommendations for improved riparian zone management described above. Protection can be achieved through any of a number of mechanisms, including conservation easements, land purchases, water rights, local ordinance, USFS planning and the NEPA process. We offer the following recommendations to prevent further degradation:

- Protect native species and their habitats. Actively work toward the goals and implementation strategies described in the CNHP (Armstrong, 2000) and the Conservation Agreement and Strategy for Colorado River Cutthroat Trout (Oncorhynchus clarki pleuriticus) (CRCT Task Force, 2001).
- Enhance communication and collaboration between the Colorado Natural Heritage Program, Colorado Division of Wildlife, U.S. Forest Service, and the Eagle Valley Land Trust (EVLT). For example, CDOW, CNHP, and USFS are simultaneously engaged in activities supporting native cutthroat trout. USFS is conducting a culvert and fish passage study that includes monitoring of fish assemblages in the White River National Forest. This study may provide information that is highly relevant to CDOW and CNHP initiatives including utilization of existing barriers to facilitate native cutthroat trout restoration, restoring connectivity among fragmented habitats (except where it would have negative impacts on native cutthroat trout), passage of native sculpin, and minimizing risk of culvert failures, sedimentation, and mass wasting.
- Support protection of biodiversity through the Eagle Valley Land Trust and local governments. EVLT has identified several properties containing high quality aquatic and riparian habitats. Protecting threatened elements of these properties through conservation easement or purchase is a critical component of sustained ecological integrity in the Eagle River watershed.
- Utilize GIS tools, a system-level perspective, the best available science, and multidisciplinary teams of experts to prioritize conservation areas. Priority should be given to locations at greatest risk for degradation of riparian functions, water quality benefits, wildlife corridors, and connectivity among key habitats. For example, CDOW scientists can provide stakeholders with the latest scientific information and expert judgment to identify conservation properties that, if protected, could prevent

further loss of connectivity in large-scale corridors for movement and dispersal of wildlife. Prioritization frameworks such as the MCDA approach presented in Chapter 5 can be readily adapted to land conservation activities by envisioning likely future impacts, weighing urgency, and systemically identifying the functions and values to be maintained.

- Develop educational programs and incentives for private landowners to initiate their own riparian protection efforts.
- Protect native riparian plant communities and riparian functions through flow regime management.
- In support of native riparian communities, we suggest completing an existing inventory of tamarisk sites (with permission from private landowners), contacting those landowners along the river to offer tamarisk removal, and eradication of tamarisk in the lower Eagle River.

Key uncertainties include:

- Locations of instream biological hotspots (e.g., tributary confluences that support a high diversity of fishes, key refugia);
- Important biological resources on private lands that have not been inventoried;
- The rate of tamarisk colonization; and
- Specific quantification of flow regime attributes that protect riparian functions.

6.2 CONCLUSION

The seven primary recommendations described above build on numerous previous recommendations to address major ecosystem processes that are either currently altered or at greatest risk of becoming altered through anticipated land and water use changes. In summary, the greatest threats to the integrity of the Eagle River watershed are: flow regime changes, nutrient loading, metals loading, land use change (impervious surfaces, stormwater, and riparian disturbance), and cumulative impacts from future recreation intensity.

Uncertainty is a fact of life in watershed management and restoration. But given the rapid changes occurring in the Eagle River watershed, forestalling action in the hopes of having perfect information, understanding, and consensus could be the greatest threat of all. The precautionary principle is often stated as "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically." Thus, there is a critical need for a collaborative framework supporting continual action, learning, and reevaluation. It is clear from surveys conducted by Eagle County (ECCD, 2003) that water quality and quantity are at the forefront of citizens' concerns about their future quality of life. They understand that clean and ample water, healthy fisheries, biodiversity, quality recreational experiences, and economic sustainability all depend on careful stewardship of the Eagle River watershed.

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