# Technical Analysis Summary

Technical Material Produced and Compiled in Support of the Eagle River Community Water Plan



lōtic hydrological

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# 1 Introduction

The Eagle River watershed is home to a network of clear mountain streams and rivers that cover approximately 960 square miles of rugged mountain ridges and verdant river valleys. Elevations in the watershed range from 6,100 feet near Dotsero to 14,003 feet at the summit of Mount of the Holy Cross, supporting a diversity of ecological communities reflective of this dramatic elevation range. Unique among most Colorado watersheds, approximately 98% of the Eagle River basin is located in a single jurisdictional boundary - Eagle County. Nearly 75% of the watershed is on public land managed by two federal agencies, the United States Forest Service (USFS) and the Bureau of Land Management (BLM). Flowing north then west for about 77 miles, the Eagle River originates in steep headwaters catchments above tree-line near Tennessee Pass. It is fed by numerous ephemeral, intermittent and perennial streams, springs and seeps as it descends through montane forests and semi-arid valley bottoms near its confluence with the Colorado River at Dotsero. Water from the mainstem Eagle River and its many tributaries supports a high diversity of ecological and human uses as they traverse Eagle County.

Although the natural flow regime[1] of many waterways in the Eagle watershed are much more intact than other Colorado streams and rivers, human settlement and the associated consumptive use and management of water inexorably alters streamflow. Roughly 75% of the average annual flow volume of the Eagle River occurs during the months of May, June and July. The remaining 25% of flow is spread across the rest of the year, supporting aquatic and terrestrial wildlife, numerous recreational uses, and helping to meet community demands for affordable, clean and reliable water supplies (ERWP, 1996). Reservoir storage and transmountain diversions reduce streamflows during snowmelt periods on many headwaters streams, with additional flow impacts rippling downstream. Conversely, these releases augment flows in some reaches during summer and fall low flow periods when water diversions for municipal and agricultural uses would otherwise reduce flows well below natural conditions. A warming climate and increasing demand for agricultural and municipal water in Eagle County and Front Range communities is likely to significantly alter patterns of streamflow in local streams and rivers in the coming decades.

The Eagle River flows into the 21st century amidst a host of changing landscapes and climate characteristics. Increasing human populations, shifting values towards water uses, and increasing impacts to streams and rivers from climate change place new pressures on local streams and rivers to satisfy the needs of both human communities and aquatic ecosystems[2]. These changes may have corresponding impacts on environmental and recreational water uses.

## 1.1 Planning Goals

Eagle River Watershed Council (ERWC) seeks to understand environmental and recreational (E&R) water needs within the Eagle River Basin. Assessing impacts of future water development

[1] A river's flow regime is the natural pattern of flow over time and can be described by the magnitude, timing, and frequency of high and low flows. In the Rocky Mountains, the natural flow regime typically features high, fast flows in late spring and early summer, declining through summer and early fall until low winter base flows settle into place.

[2] https://dnrweblink.state.co.us/CWCB/0/edoc/217373/ColoradoWaterPlanPublicReviewDraft.pdf

and climate change on river health and socially valuable aspects of the river is central to this task. This interest led ERWC to coordinate the activities of the Eagle River Community Water Plan (ERCWP, or the "Plan"). ERWC produced the Plan collaboratively with local stakeholders and Front Range water providers to achieve the following[3]:

- ➢ Support the sustainable development of natural and physical resources and the maintenance of ecological processes and biological diversity;
- ➢ promote the equitable and sustainable use and development of water;
- ➢ encourage public involvement in resource management and planning;
- ➢ promote the sharing of responsibility for resource management and planning between the local city and county governments, out-of-basin water interests, the community and the state;
- ➢ provide timely information and forecasts that directly support environmental, social, economic, conservation and resource management policy development and decision-making by local governments, utilities and special districts;
- ➢ secure a pleasant, safe and desirable working, living, and recreational environment for all residents and visitors to Eagle County;
- ➢ conserve those areas or other places which are of scientific, aesthetic, or otherwise of special cultural or environmental value;
- ➢ recognize the significant social and economic benefits resulting from the sustainable use of water resources for the supply of drinking water and commercial activities dependent on local rivers and streams;
- ➢ maintain healthy, functioning ecosystem processes and high levels of biodiversity in aquatic ecosystems;
- ➢ provide for the fair, orderly and efficient allocation of water resources to meet the community's needs;
- ➢ increase the community's understanding of aquatic ecosystems and the need to use and manage water in a sustainable and cost-efficient manner;
- ➢ provide information supporting procedures for evaluation, implementation, enforcement, and review of water resources management activities; and
- ➢ consider the multiple uses of water and the ways that each use may be affected differently by climate change, population growth, and other stressors.

The Plan promotes sustainable resource use and development. The concept of sustainable development means managing for the use, development and protection of natural and physical resources in a way, or at a rate, which enables current-day people and communities to provide for their social, economic and cultural well-being and for their health and safety while: 1) sustaining

[3] Informed, in part, by the New South Wales Water Management Act 2000 No. 92, the Tasmania Water Management Act 1995, and the Victoria Environment Protection Act 2017.

the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations in Eagle County; 2) safeguarding the life-supporting capacity of water and aquatic ecosystems; and 3) avoiding the need to mitigate any adverse effects of human activities on the environment[4]. The two-part mission of the Eagle River Community Water Plan is to:

- ➢ consider past, present, and future human needs and river health issues to identify opportunities to correct historical degradation and prevent and mitigate against non-desirable future conditions for environmental and recreational water uses; and
- ➢ understand the independent and interactive impacts of population growth, water use, reservoir development, and climate change (air temperature and precipitation patterns) on human and ecosystem water needs.

The Plan assesses historical hydrological conditions and presents a range of potential water use and management futures to consider how well these futures continue to support the diversity of human and ecosystem needs. The primary output of this plan is a collaboratively prioritized set of management strategies that reflect the goals, needs, and values of community members and other stakeholders.

## 1.2 Use of the Plan

This plan provides a road map for community members, local governments and other organizations eager to implement projects that support diverse water needs. Specifically, the Plan provides: 1) a framework for characterizing potential impacts/changes to riverine conditions and/or identifying areas where river health may be most impacted by the interaction between proposed water management activities and other physical and biological components of the ecosystem, 2) an understanding environmental and recreational needs gaps as they are affected by hydrological variability and increasing demands for water in Eagle County and on the Front Range, and 3) a set of durable planning objectives that may help guide the distribution of endowment funds to support high-priority environmental and/or recreational needs across Eagle County. Importantly, the conformance of this plan with goals and objectives identified in the ERCWP and the CBRT BIP should facilitate the procurement of state and federal funding for local project implementation.

The ERCWP serves as a guidance document that provides insight into watershed-level values and priorities. Through the planning process, stakeholders outlined objectives and identified strategies to create a foundation for the communities of the Eagle River to mitigate potential future impacts on the values they hold associated with the River.

- Stakeholders can use the plan to better understand community values associated with the Eagle River and leverage the objectives and strategies identified in the plan to apply for grants and other funding opportunities.

[4] Tasmania Water Management Act 1999

- Land managers can use the plan to help decide where and how to allocate resources.
- Decision-makers can use the contents of the ERCWP as supporting information so that they can make informed decisions based on stakeholder and community input.
- Additionally, decision-makers can use the objectives and actions identified in the plan to evaluate tradeoffs associated with future proposed projects.

The issues, needs, projects, and processes described here articulate the community's goals and objectives for collaboratively addressing the region's water future. The Plan was supported by the engagement of community members between 2017 and 2022. The ERCWP does not supersede or serve as a substitution for any local, state, or federal permitting processes or subvert any existing water rights. Any objective or action identified in the ERCWP should be considered within the existing legal and regulatory framework. ERWC encourages local land use authorities to recognize the community voices captured here by adopting or formally recognizing the ERCWP as a strategic guidance document.

## 1.3 Planning Context

The Colorado Water Plan (CWP) seeks to understand the state's water needs, identify gaps and promote projects and processes to meet those needs. The CWP recognizes the potential for changes in water supplies necessary to sustain local communities and meet diverse water needs. Local stakeholders are encouraged by the CWP to engage in strategic planning efforts that collaboratively address their changing water futures[5]. The Colorado River Basin Roundtable (CBRT) similarly called for Stream Management Plans and Integrated Management Plans in the Basin Implementation Plan (BIP) as a means for filling important data and information gaps[6].

ERWC and other local stakeholders recognize the information necessary to understand environmental and recreational water needs, and how these needs may be impacted by climate change and/or water development activities is significantly lacking. This is reflected in ERWC's 2013 Eagle River Watershed Plan, which promotes stream management planning to aid sustainable water management:

> "where individual reaches of rivers or streams are identified as impaired or having inadequate flows, craft and implement Streamflow Management Plans that offer creative and cost effective strategies to address ecological, domestic, recreational and agricultural water needs." (ERWP, 2013)

Opportunity exists in Eagle County to meet the calls in the CWP and CBRT BIP for strategic water planning. Ongoing planning efforts by local water providers focused on meeting future demands under increasingly variable environmental conditions may be supplemented by the nuanced

[5] https://dnrweblink.state.co.us/CWCB/0/edoc/217373/ColoradoWaterPlanPublicReviewDraft.pdf
[6] https://dnrweblink.state.co.us/cwcbsearch/0/edoc/216708/Colorado_BIP_Volume2_2022.pdf

evaluation of changing environmental conditions and opportunities for recreational use of streams and rivers presented in this document.

## 1.4 Community Engagement Process

The Eagle River Community Water Plan implemented a structured stakeholder process to elicit feedback from the community regarding water use and management in the planning area. The planning process promoted sound strategic planning and coordinated action by various government and non-government entities and members by:

- providing a venue for discussing the multiple uses of water and the ways that each contributes to the vitality of local communities;
- ensuring that the impacts on E&R water uses were considered when contemplating future use and development of water; and
- establishing a structured and facilitated dialog among parties for setting objectives and identifying best practices, policies and other recommendations for the use, development and protection of water resources.

Engagement with stakeholders via surveys, webinars, and in-person workshop settings featured activities that helped stakeholders contemplate relationships between existing patterns of water use, ecosystem condition, the goods and services that streams and rivers deliver to local communities, and the potential for future impacts to the delivery of those goods and services due to climate change and/or water development activities. At the first ERCWP Stakeholder Group meeting in June 2018, stakeholders formed several groups in order to guide the development of the plan: the ERCWP Stakeholder Group, the Core/Technical Group, and the Community Engagement Committee. Each group had a distinct role in the formation of the ERCWP.

### 1.4.1 ERCWP Stakeholder Group

The ERCWP Stakeholder Group consisted of stakeholders from environmental and conservation organizations, local and Front Range water providers, community members, ERMOU partners, outfitters, conservation districts, regional governmental entities, local municipalities, Eagle County, and state agencies. The Stakeholder Group had an open membership for anyone interested in providing feedback on the ERCWP. The Stakeholder Group met regularly to conduct peer-to-peer learning about topics significant to the ERCWP, provide updates and input on parallel technical developments and community engagement efforts, and identify additional high-priority planning issues. The ERCWP Stakeholder Group was responsible for developing the ERCWP objectives, strategies, and project list in this plan. The Stakeholder Group was open to anyone interested in the future of the river and committed to regular and active participation in meetings.

### 1.4.2 Core/Technical Group

The Core/Technical Group focused solely on the technical aspects of the ERCWP. Members of this group self-selected to participate in the group. The Core/Tech Group consisted of members from state agencies, ERMOU partners, technical consultants, regional governmental entities, Eagle County, and local municipalities. The Core/Tech Group met monthly until the completion of the technical elements of the plan. The purpose of the Core/Tech Group was to ensure that those who have ideas or preferences about the technical elements of the ERCWP have the opportunity to provide meaningful feedback and direction to Lotic Hydrological (the technical consultant).

### 1.4.3 Community Engagement Committee

The Community Engagement Committee focused solely on providing ongoing advice and expertise to the technical consultant and Peak Facilitation Group to help deliver the most effective community engagement possible during the ERCWP process. The Community Engagement Committee was comprised of members from local municipalities, Eagle County, ERMOU partners, state agencies, environmental and conservation organizations, local and Front Range water providers, outfitters, and conservation districts. The Community Engagement Committee designed and provided input on several community engagement strategies, including community meetings and several surveys, and helped interpret results.

The ERCWP was created with significant input through the ERCWP Stakeholder Group, Core/Tech Group and Community Engagement Committee. From 2018 to 2022, the Stakeholder Group, Community Engagement Committee and Core/Technical Group met a total of 53 times. Below is a timeline that displays when and with what frequency the different teams of the ERCWP met over the development of the plan.

ERWC hopes that the voice of the community reflected in this Plan continues to be informative and useful to elected officials and other decision-makers as they endeavor to plan for Eagle County's water future in a manner consistent with the goals and principles set forth here.

# 2 Assessing Historical and Potential Future Conditions

## 2.1 Previous Work

ERCWP development began with a comprehensive search of scientific literature, resource studies and reports, and existing policy management actions specific to the Eagle River watershed (Appendix A). This review provided context for understanding the diversity of social and environmental objectives that influence local and regional water use and management, and the array of historical conditions and trends in natural conditions. While numerous works were completed by local parties and agency partners like USGS concerning water quantity, quality, and the condition of aquatic life, fisheries, and riparian health in the watershed, a smaller subset of publications have particular relevance to streamflows and nonconsumptive water use and needs for ecosystems and recreation. Sources critical to the development of the ERWCP include:

- **Colorado Water Plan, 2015 (updated 2023)**: serves as the foundation of the ERCWP by providing initiatives, connections, and values to meet Colorado's current and future consumptive, recreational, and environmental water needs.
- **Technical Update to the Colorado Water Plan (2019)**: communicates and makes publicly-available the state's supply and demand projection data, and the methods, analytical tools, and results used to underpin the CWP's findings and recommendations.
- **Colorado Basin Roundtable Basin Implementation Plan (2015, updated 2022)**: identifies stream management plans (SMPs) and Integrated Water Management Plans (IWMPs) as top priorities. The CBRT states that such planning is vital to providing sufficient water for environmental needs among the many competing uses and demands for water, and thereby restoring and protecting ecological processes that connect land and water while ensuring that streams also serve the needs of human populations.
- **Eagle River Memorandum of Understanding Project Alternatives Study (2016**) provides evaluations of project alternatives to develop water storage and conveyance projects in the Eagle River basin for West Slope and East Slope interests. The ERMOU was executed in 1998 by multiple signatories. Various development alternatives are currently being considered and will have a bearing on water quantity and quality in the Eagle River. For instance, transbasin diversions can reduce the intensity of spring runoff flows that are important in the maintenance of aquatic habitat. Spring flows flush fine sediments from the channel substrate and provide the high-quality gravel beds needed by aquatic insects and fish for reproduction. High flows also maintain riparian communities through flooding of the banks and riparian zones adjacent to the river. Studies have not been conducted to determine how much of a "flushing" flow is actually needed on the Eagle River to maintain optimal habitat for aquatic life and bank recharge.
- **Eagle River Watershed Plan (2013):** provides information, goals, strategies and action items related to water and land management practices in the Eagle River basin. The 2013 document updates and replaces the 1996 version and includes significant new information, community input plus the vision for watersheds in Eagle County. Several issues and recommendations are discussed which provide relevant background to the development of an IWMP. The ERWP is organized around five water related topics (Quantity, Quality, Land Use, Wildlife and Recreation) all of which provide direction and insights for the ERCWP.

- **Eagle River Inventory and Assessment (2005)** (: an inclusive, scientific baseline inventory and assessment of the Eagle River with a prioritized list of restoration and conservation projects, including brief descriptions and cost estimates. It also measures public support for various prospective projects and other recommended actions. A comprehensive list of ten watershed restoration principles from scientific literature and case studies to improve the likelihood of success was included for reference and subsequent work plans. Colorado State University - Brian Bledsoe, Ph.D., et al)
- **The Eagle River Assembly, Assembly Report (1994):** convened to find a path through the acrimonious gridlock surrounding Colorado Springs and Aurora's efforts to develop the Homestake II project. The assembly reported potential strategies that would: 1) improve the condition of the river, and 2) assure adequate water supplies for future needs. The resulting assessment concluded that flows in the Eagle River were inadequate to meet existing environmental and water supply demands in average years and dryer than average years, principally in late summer and winter months. Environmental concerns were based on identified `stream flow deficits' where the amount of water in the stream was not adequate to meet recommended instream flow rights that had been implemented years earlier (CWCB flow rights) for the protection of fish. Work by the Assembly eventually led to the 1998 Eagle River Memorandum of Understanding, which specified conditions for sharing allocated but undeveloped water in joint or individual water projects, and potential priority focus areas for projects.

This historical body of work provides a rich context for ongoing water resource planning in the Eagle River Watershed.

## 2.2 Historical Streamflow Regime Behavior and Trends

The flow regime (i.e., the annual and longer-term fluctuation in streamflow levels) strongly influences river ecosystem form and function and is a central component of water resources planning. Historical observed streamflow records were assessed to describe streamflow regime patterns in the Eagle River watershed and to identify recent changes to the streamflow characteristics.

Streamflow regimes were characterized using historical observed streamflow data collected from eight United States Geological Survey (USGS) streamflow gauges across the Eagle River watershed (Figure 2). Recent conditions and trends during the 25-year period from 1996 to 2020 captured a range of streamflow trends, including wet, average, and dry conditions. Some of the gauges provided records of daily streamflow of variable length, and streamflow data was interpolated to fill missing values across the 25-year period of record.

Streamflow regimes were characterized using 113 metrics of annual and monthly streamflow behavior. The metrics describe the magnitude and timing of different aspects of hydrologic regimes. The results of this analysis were summarized by calculating 10th, 50th (median) and 90th percentile values for each metric across the 25-year period. Changes within streamflow regimes were characterized by evaluating trends for the 113 metrics of annual streamflow behavior during the 25-year period. Trends at each location were evaluated using Mann-Kendall tests and Thiel-Sen's slope analyses. Trend results were examined using 25-year rolling windows across the full record of streamflow at four gauges with historical streamflow records extending to 1945.

The role of inter-annual climatic variability was also assessed on select streamflow characteristics for all eight USGS streamflow gauges using a multiple linear stepwise regression analysis for the period between 1996 to 2020. Stepwise regression, which included both forward and background variable selection, enabled automated selection of model variables that balances trade-offs between model simplicity and explanatory power. This approach also investigated the influence of climate on streamflow and reference gauges in watersheds with minimal water development. Data usage from gauges on Cross Creek, Lake Creek, Gore Creek, and the Eagle River incorporated streamflow data affected by water diversions and reservoirs in the upper watershed and by urban areas and agriculture in the lower watershed.

## 3 Key Findings

- Hydrologic regimes in the Eagle River watershed are characterized by a snowmelt driven hydrograph. Peak flows typically occur between late May through June with declining streamflow throughout the late summer and fall (Figure 1). Low flows are typical in the winter months. Streamflow levels vary two orders of magnitude between minimum and maximum flows, and roughly 50% of total annual flow volume occurs within the period between mid-May and mid-July.
- Streamflow total yields (the total streamflow normalized by drainage area) was highest from tributary watersheds, including Cross Creek, Lake Creek, and Gore Creek, and lowest from the Eagle River. Lower streamflow export from the Eagle River headwaters is likely due to transbasin diversions.
- Streamflow trends were primarily observed as considerable declines in late summer and/or late fall streamflow (Figure 2). The significant decline in streamflow was more evident on smaller tributaries. Notable trends in streamflow were not observed during the rising limb of the hydrographs, during peak flow periods between April through July, or in annual yield or volume metrics.
- Climate based regression models had lower explanatory power in predicting streamflow metrics at the gauges on the upper Eagle, particularly the Redcliff gauge and the Minturn gauge compared to other gauges in the watershed. This suggests water management activities, such as reservoir storage and summertime releases, dampened the impacts of inter-annual climatic variability and limited the degree of climatic driven streamflow

changes on managed rivers in the watershed. The degree that management, however, can have similar impacts in the future depends on multiple factors, including future water availability, water demand, and management priorities.

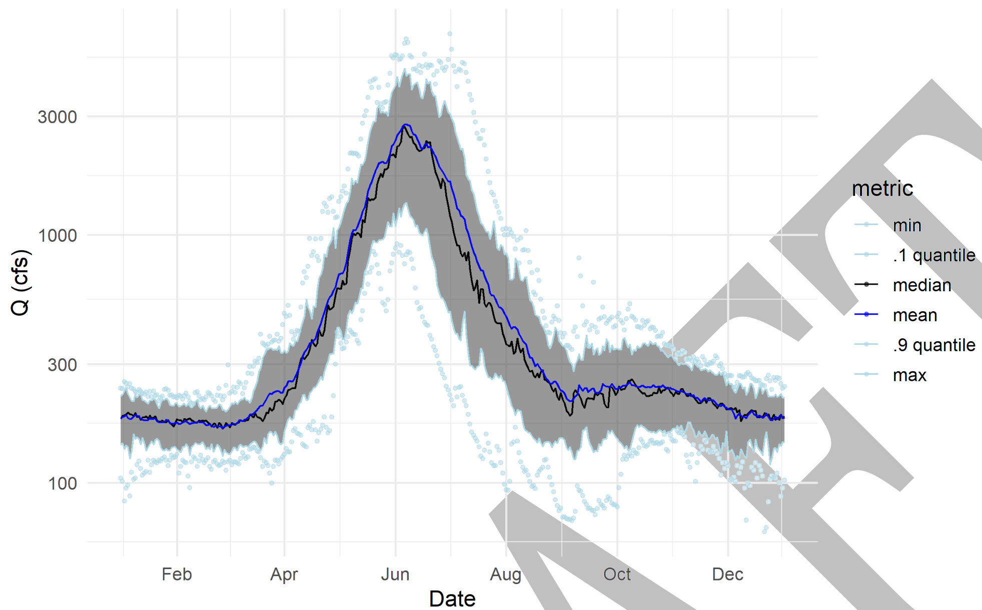


**Figure 1. Streamflow regime on the Eagle River at Gypsum indicating mean (blue line) and median (black line) and the 10th through 90th quantile (shaded area) of daily streamflow across 1996-2020. Blue dots indicate minimum and maximum daily values. Y-axis is on a log scale.**

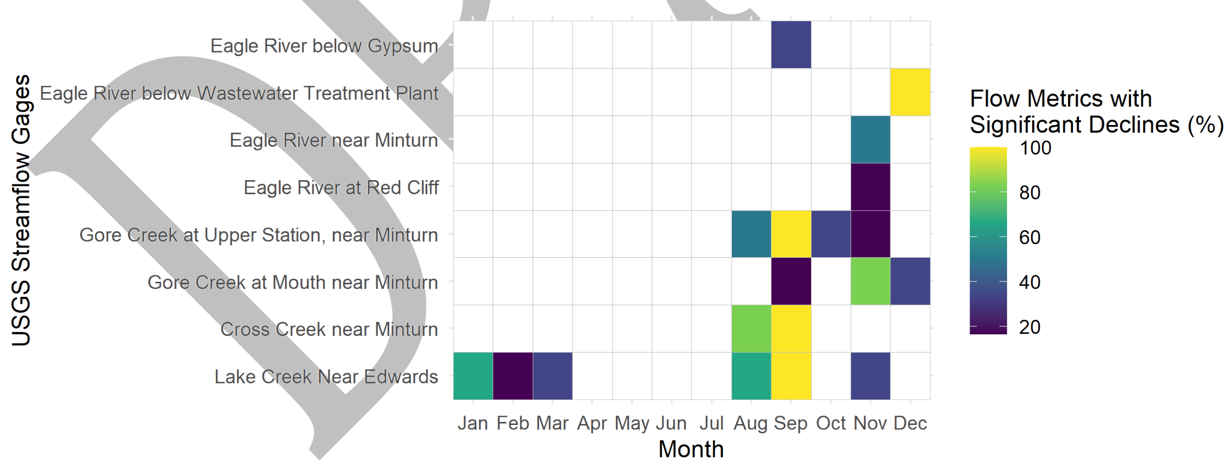


**Figure 2. Trend analysis results for monthly streamflow metrics indicate the number of significant declining trends in streamflow metrics by month. Months with no significant trends are blank.**

## 3.1 Hydrological Simulation Model Development

A key focus of the ERCWP was on characterizing risks to environmental and recreational water uses due to changing hydrology or water demands in the future. Evaluation of potential future trajectories for Eagle River streamflows requires use of a variety of scientific modeling tools. Multiple potential futures can be imagined both in terms of population growth and water use in Eagle County and in terms of potential climate change trajectories. Fortunately, the Eagle River Water and Sanitation District collaborated to provide a detailed water supply planning model (the "ER20" model) for the watershed that was tailored to describe changing streamflow conditions under a variety of potential future scenarios (Appendix C). This work roughly mirrored the approach used by Colorado Water Conservation Board to provide similar water planning models as a component of the Colorado Water Plan. The geographic scope of the model results included in the ERCWP was limited to the Eagle River mainstem below the confluence with Homestake Creek, Gore Creek below Black Gore Creek, Bush Creek, and Gypsum Creek. The use of hydrological simulation modeling results allowed for comparison of potential future streamflow trajectories with current and historical conditions and to consider how streamflow changes may affect values at risk identified by community stakeholders. The simulation scenarios used for comparison are described below.

### 3.1.1 Natural Flows (Historical)

The simulation model was used to approximate flows in local streams and rivers as they may have existed prior to human use and management.

### 3.1.2 Current Conditions (2020)

The Current Conditions scenario represents existing water supply infrastructure, decreed water rights, and current operational agreements and river administration. This scenario assumes historical patterns of streamflow will continue without change into the foreseeable future. Current demands (in-basin, out-of-basin, and transmountain) are based on recent average diversions in representative wet, dry, and average year types. This scenario assumes current demands are applied to patterns of streamflow observed over recent history creating a baseline condition for future scenarios to be compared against. Demands outside of the Eagle River Basin are set to be identical to the baseline model run for the Technical Update to the Colorado Water Plan (2019).

It is important to note that previously decreed water rights, developed infrastructure, and recently permitted water development projects within the Colorado River Basin will already cause additional changes to river administration and water availability, regardless of the implementation of additional major development projects contemplated here in other scenarios. Accordingly, river conditions observed during the last 10 years may not be the same in the next 10 years, or beyond. This scenario simply provides a comparison of recently observed streamflow conditions to several potential future scenarios.

### 3.1.3 Near Future (2030)

The Near Future scenario characterizes streamflow changes brought about by anticipated increased transmountain diversions to meet water demands of growing Front Range populations. These are changes that may occur without development of any new infrastructure or in-basin water demands. Instead, this scenario represents the full legal and physical utilization of existing decreed water rights of the Homestake Project, Columbine Ditch, Ewing Ditch, and Wurtz Ditch. The water demands driving this increase in use are consistent with projected future out-of-basin municipal, agricultural, and industrial water demands presented in the Technical Update to the Colorado Water Plan (2019). In-basin water demands are based on recent average diversions in representative wet, dry, and average year types. All demands are applied to patterns of streamflow observed over recent history.

Analysis of this scenario is important to better understand physical and legal water resources available to support existing transmountain diversion projects and identify environmental or recreational attributes that may be at greater risk in the future. The comparison of simulated stream flows between the Near Future scenario and the Current Conditions Scenario provides a better understanding of how conditions may change as alread-decreed water rights and existing infrastructure are more fully utilized in the future.

### 3.1.4 Demand Growth (2050)

The Demand Growth scenario represents existing water supply infrastructure, decreed water rights, and current operational agreements and river administration. Water demands (in-basin, out-of-basin, and transbasin), however, are set at levels forecasted to exist in 2050 or beyond depending on actual population growth rates. Year 2050 conditions were intentionally chosen to be consistent with the Technical Update to the Colorado Water Plan (2019).

In this scenario, existing in-basin diversions and storage supplies are optimally utilized to meet increased municipal and industrial water demands resulting from in-basin growth while mitigating impacts to stream flows during critical low flow periods. To the extent possible, this scenario also represents the full legal and physical utilization of existing infrastructure and decreed water rights of the Homestake Project, Columbine Ditch, Ewing Ditch, and Wurtz Ditch. Projected future out-of-basin municipal, agricultural, and industrial water demands are consistent with the Technical Update to the Colorado Water Plan (2019). This scenario represents the combined effects of growing East Slope and West Slope water demands.

Changes in water demand will be analyzed under four different potential climate futures: *Historical Hydrology*, *Warm and Wet, In-Between*, and *Hot and Dry*. These climate futures are consistent with climate science used to inform the Technical Update to the Colorado Water Plan (2019). Results reflecting each of the climate futures will be compared against one another to provide a better understanding of how adjustments in precipitation and temperature may impact the basin's beneficial use of water, environmental and recreational values, and yield to existing and future water projects.

This scenario also represents reasonably foreseeable streamflow conditions in the Eagle River Basin in 2050 without any major additional water supply infrastructure development. Analysis of this scenario is important to better understand physical and legal water resources available to new water supply development projects and identify environmental or recreational attributes that may be at greater risk in the future. The comparison of simulated stream flows between the Demand Growth scenario and the Current Conditions Scenario provides a better understanding of how conditions may change as existing water rights and infrastructure are more fully utilized in the future.

### 3.1.5 New Water Infrastructure

The New Water Infrastructure Development scenario is intended to capture the maximum extent of water infrastructure development and operations that may be expected to occur over the next 30 years. This scenario includes both the increased demands utilized in the Demand Growth scenario *and* additional water infrastructure development within the upper Eagle River basin. Water supply infrastructure development and operations represented in this scenario reflect one potential pathway for meeting the water yield objectives outlined by the Eagle River Memorandum of Understanding (MOU). These objectives include 20,000 acre-feet of average annual yield for the Cities of Colorado Springs and Aurora and 10,000 acre-feet of firm dry year yield for Western Slope MOU signatories. These entities include the Colorado River Water Conservation District, the Eagle River Water and Sanitation District, the Upper Eagle Regional Water Authority, and Vail Associates. Note that the Eagle River MOU infrastructure, operations, and yields represented by this scenario are subject to change as a result of future permitting processes and further negotiations among the participants.

This scenario also includes the redevelopment of Bolts Lake near Minturn. Bolts Lake would be utilized by the Eagle River Water and Sanitation District and Upper Eagle Regional Water Authority for augmentation of in-basin municipal depletions, mitigation of impacts to stream flows during critical low flow periods, and a strategic reserve for the mitigation of future water supply uncertainty and climate change.

The impacts of new water storage and delivery infrastructure will be analyzed under four potential climate futures: *Historical Hydrology*, *Warm and Wet, In-Between*, and *Hot and Dry,* which are all consistent with climate science used to inform the Technical Update to the Colorado Water Plan (2019). Results reflecting each of the climate futures and results will be compared against one another to provide a better understanding of how adjustments in precipitation and temperature may impact the basin's beneficial use of water, environmental and recreational values, and yield to existing and future water projects.

This scenario is intended to show Eagle River MOU-associated depletions that may occur upstream of the confluence of the Eagle River and Cross Creek. Outputs from the New Water Infrastructure Development scenario can be compared to output from the Demand Growth scenario to understand how additional in-basin water supply development will impact stream flows and identified environmental and recreational attributes.

## 3.2 Historical Hydrological Alteration

Existing streamflow conditions are altered from the 'natural' flows that existed prior to human interventions (e.g., reservoir operations, municipal uses, and agricultural water uses). Departures from natural flow conditions may impact stream ecological health and may elevate risks for changed among aquatic and riparian communities. In this way, characterizing alterations from natural flows informs an understanding of current ecosystem risks and helps stakeholders contextualize predictions of future hydrologic change.

Most stream gauges in the Eagle River watershed were installed in the mid-20th century or later when human activities were already impacting streamflow. This assessment, therefore, focuses on comparing simulation outputs from the ER20 model and includes natural and current conditions. Simulation model outputs from the Natural Flows and Current Conditions (i.e., 'baseline') simulations were used to characterize changes in 113 biologically relevant metrics of streamflow behavior at 61 study locations (model nodes) within the ERCWP study area. Metrics characterize the magnitude and timing of various aspects of hydrological regimes. Hydrological alteration was evaluated as the difference between metrics of streamflow behavior under the two scenarios. Results from the comparative analysis were summarized by calculating mean, 5$^{th}$, 25$^{th}$, 50$^{th}$ (median), 75$^{th}$, and 95$^{th}$ percentile values for the change in each metric across the simulation record (Figure 3 through Figure 10).

Flow-ecology risks imparted by hydrologic alterations were assessed using the Watershed Flow Evaluation Tool (WFET) (Appendix D). The WFET is a set of flow-ecology risk relationships that considers the health of ecosystem components, including the cold-water fishery, warm-water fishery, and riparian areas in different geomorphic settings. The WFET generates risk assessments and their relationships based on estimated flow modifications between natural and current conditions. Using the WFET approach, specific metrics of hydrologic alteration are applied to each ecosystem component, and risks are only calculated for appropriate ecosystem components, such as cold-water fishery risks are only calculated in cold-water streams. Flow-ecology risk relationships using the WFET guidelines were calculated for Trout Fish, Warm Fish, and Cottonwood Abundance and Recruitment.

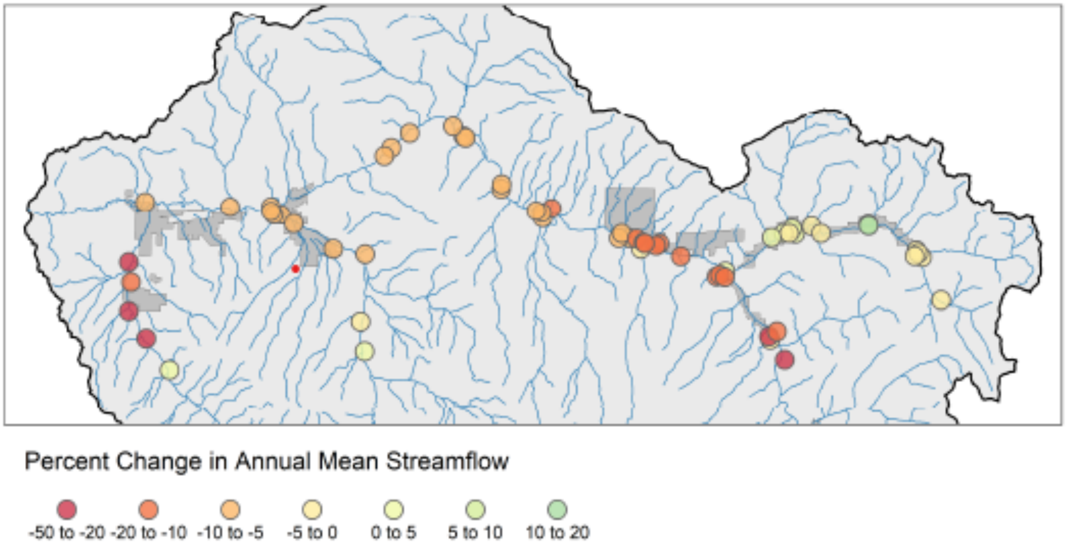


**Figure 3. Map of percent change in mean annual streamflow in the Eagle River watershed. Percent change is calculated as the mean change across all simulation years. Cooler colors indicate positive changes from natural flow conditions while warmer colors indicate negative changes.**

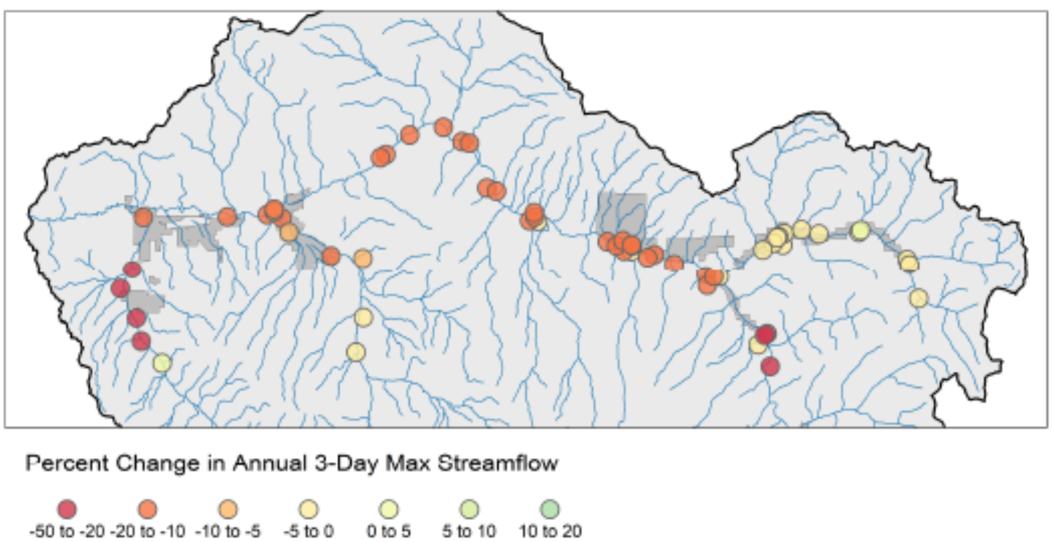


**Figure 4. Map of percent change in maximum 3-day streamflow in the Eagle River watershed. Percent change is calculated as the mean change across all simulation years. Cooler colors indicate positive changes from natural flow conditions while warmer colors indicate negative changes.**

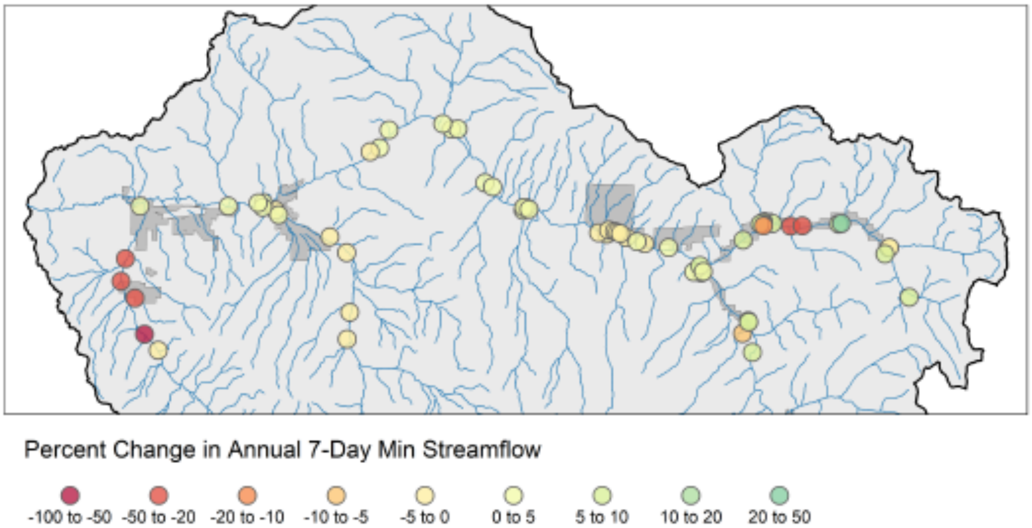


**Figure 5. Map of percent change in minimum 3-day streamflow in the Eagle River watershed. Percent change is calculated as the mean change across all simulation years. Cooler colors indicate positive changes from natural flow conditions while warmer colors indicate negative changes.**

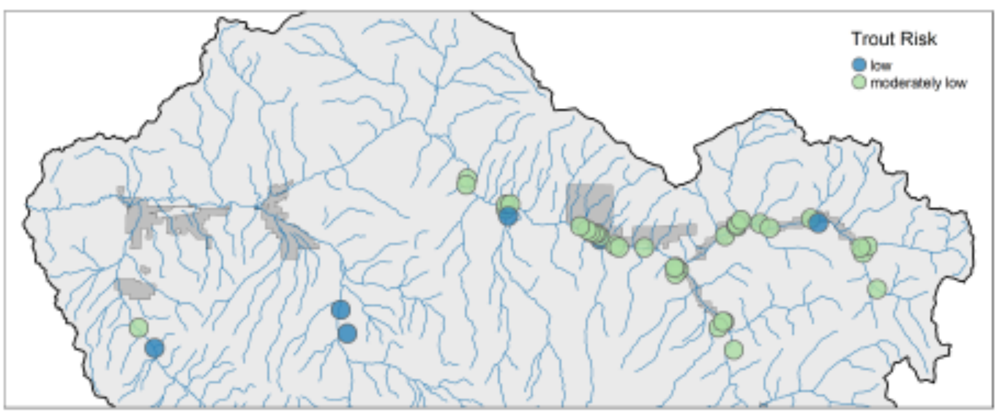


**Figure 6. Risk mapping results for trout produced by applying WFET ecosystem response models to simulated natural and baseline streamflow scenarios.**

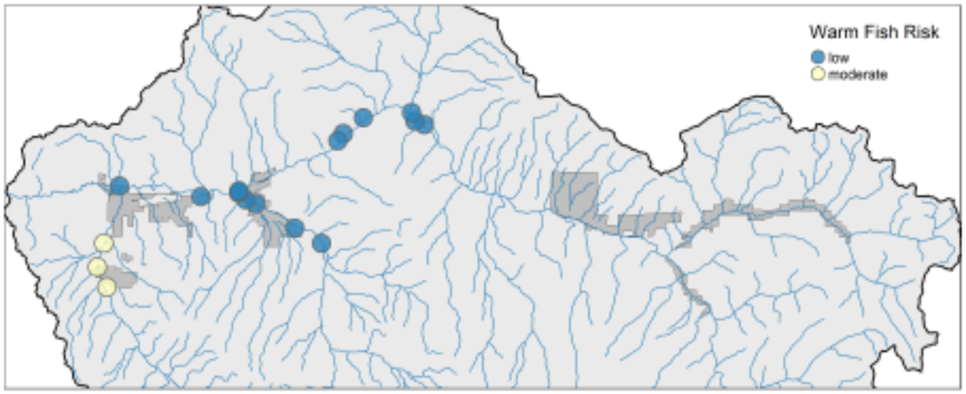


**Figure 7. Risk mapping results for warm fish produced by applying WFET ecosystem response models to simulated natural and baseline streamflow scenarios.**

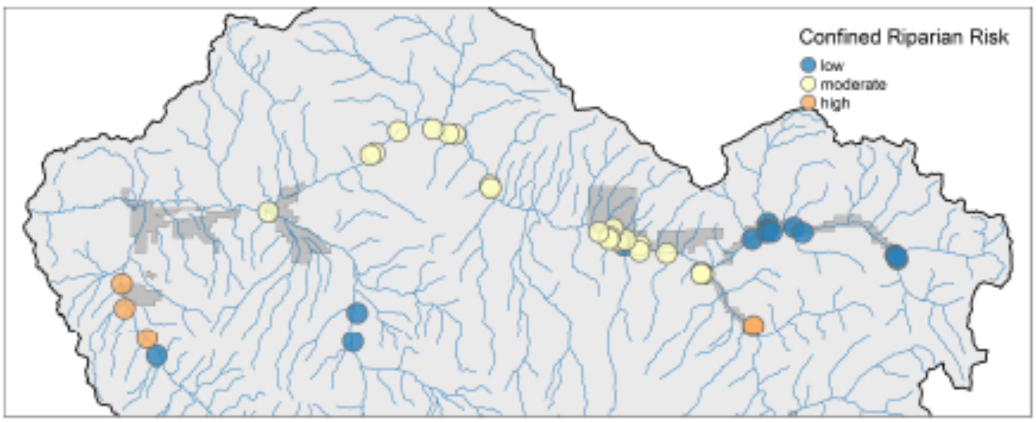


**Figure 8. Risk mapping results for confined riparian areas produced by applying WFET ecosystem response models to simulated natural and baseline streamflow scenarios.**

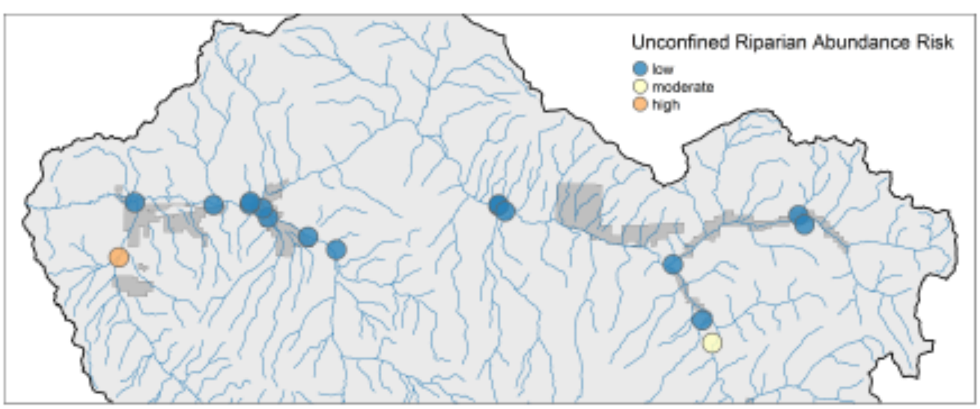


**Figure 9. Risk mapping results for abundance of unconfined riparian areas produced by applying WFET ecosystem response models to simulated natural and baseline streamflow scenarios.**

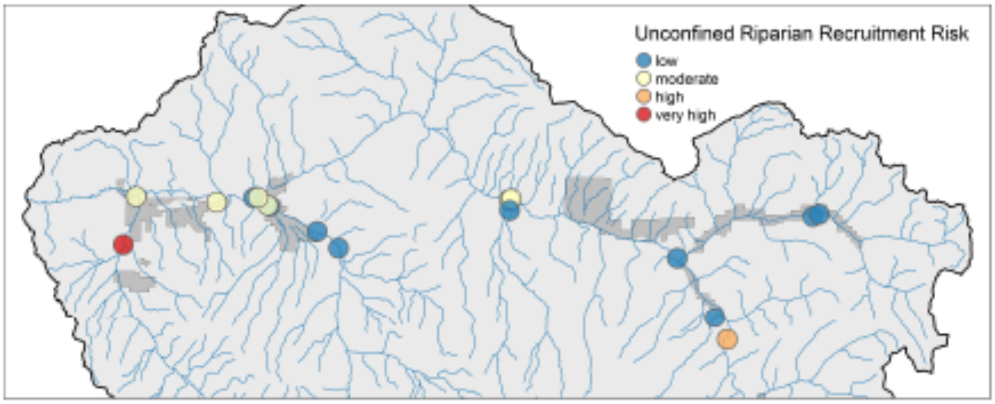


**Figure 10. Risk mapping results for the recruitment of unconfined riparian areas produced by applying WFET ecosystem response models to simulated natural and baseline streamflow scenarios.**

## 3.3 Key Findings

- Reservoir development and transbasin diversions in the Upper Eagle Watershed reduced streamflow in late spring and summer and slightly increased low flows in the winter as compared to natural conditions. The degree of alteration declines longitudinally resulting in proportionally lower hydrologic alterations on the Middle and Lower Eagle River.
- Municipal and snow-making diversions generated variable patterns of hydrologic alteration from natural conditions on Gore Creek. The largest alterations to streamflow are exhibited during low flow periods. Some segments of Gore Creek currently exhibit lower minimum streamflow than under natural conditions.
- Gypsum Creek exhibits a high degree of hydrologic alteration from natural conditions, and these conditions are likely due to agricultural and municipal diversions and associated water storage.
- Risks from hydrologic alteration of late summer flows were low to moderately low for the cold-water trout fishery. Risks in the designated warm fish reaches were low on the Eagle mainstem and on Brush Creek and moderate on Gypsum Creek.
- Risks from hydrologic alteration to riparian habitat were low on Gore Creek and Brush Creek. Risks to confined segments are moderate for most of the Eagle River and high for the upper Eagle and most of Gypsum Creek. Risks to unconfined segments are low to moderate on the Eagle River and high to very high on Gypsum Creek.

## 3.4 Hydrological Change Under Future Scenarios

The ERCWP streamflow modeling effort assessed the impacts of water use and climate change scenarios on streamflow regimes. Streamflow regimes were characterized using ER20 simulation outputs for each scenario at 61 nodes in the ERCWP study area (Appendix C). Streamflow regimes were characterized at each simulation node using 113 metrics of annual and monthly streamflow behavior. Metrics describe the magnitude and timing of various characteristics of streamflow regimes. Annual metrics were summarized for each water year (October through September). Results were summarized with the 5th, 25th, 50th (median), 75th, and 95th percentile values for each metric across the simulation record. Differences between scenarios were reported as changes from Current Conditions.

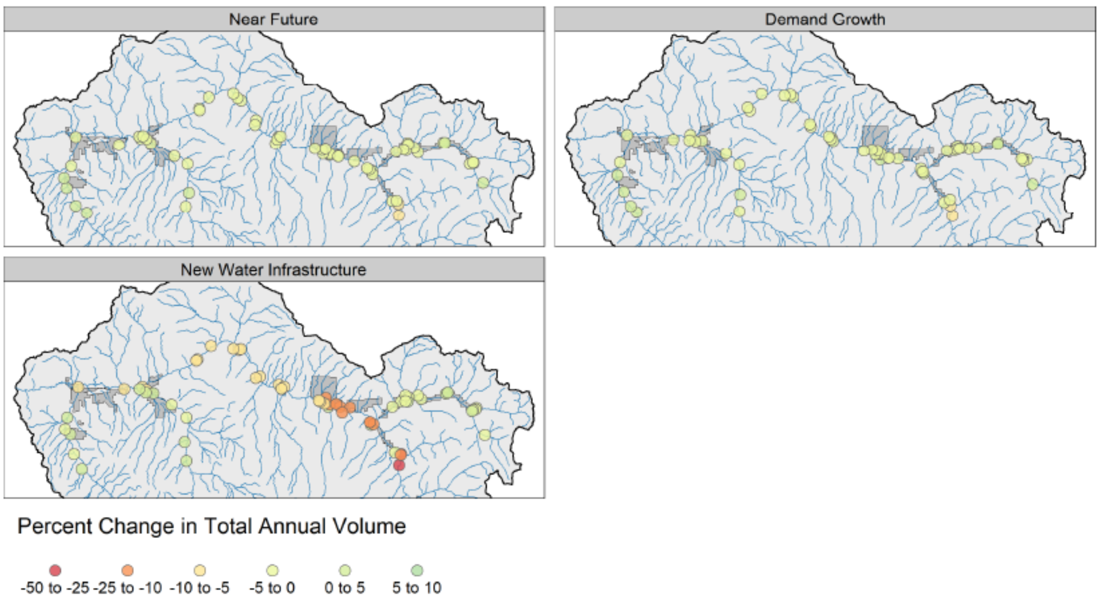


**Figure 11. Percent change from baseline in median total annual streamflow volume (acre-feet) under historical hydrology at ERCWP model nodes. Warmer colors indicate a decrease in flow while cooler colors indicate an increase in flow from baseline.**

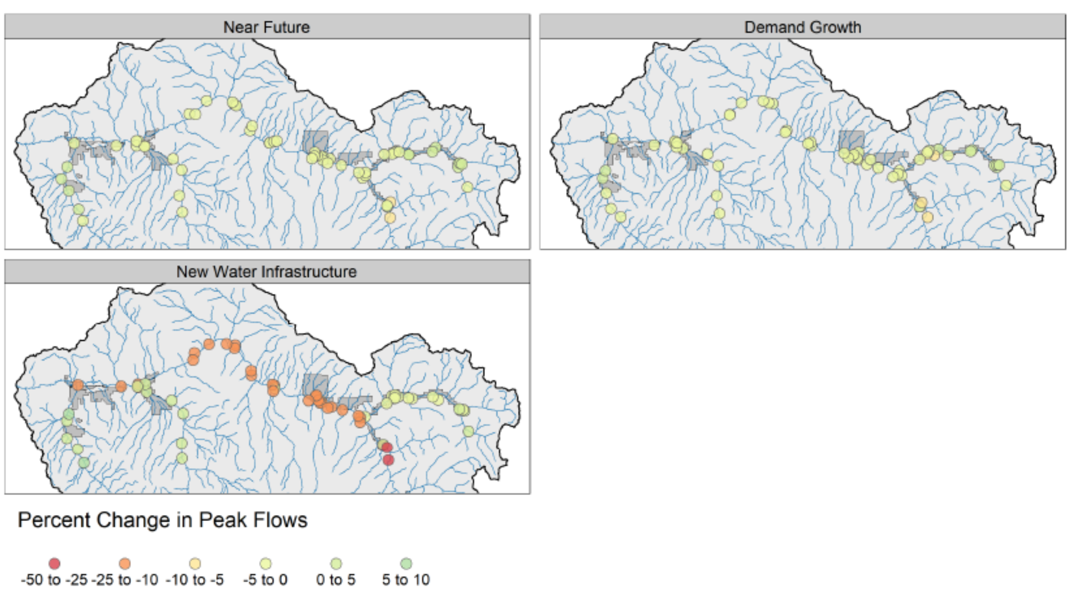

**Figure 12. Percent change from baseline in median 3-day peak flows (cfs) under historical hydrology at ERCWP model nodes. Warmer colors indicate a decrease in flow while cooler colors indicate an increase in flow from baseline.**

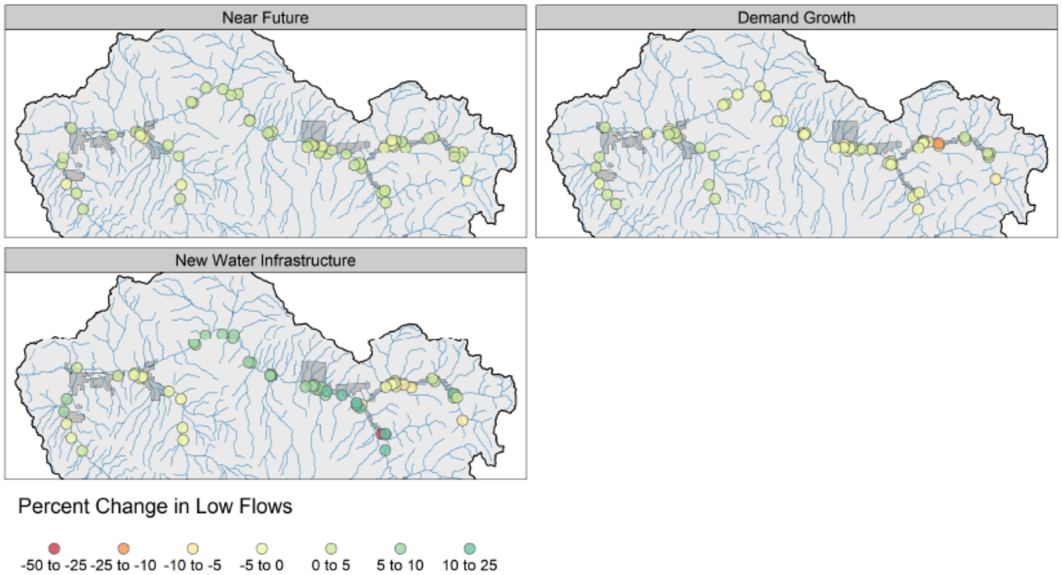


**Figure 13. Percent change from baseline in median 7-day low flows (cfs) under historical hydrology at ERCWP model nodes. Warmer colors indicate a decrease in flow while cooler colors indicate an increase in flow from baseline.**

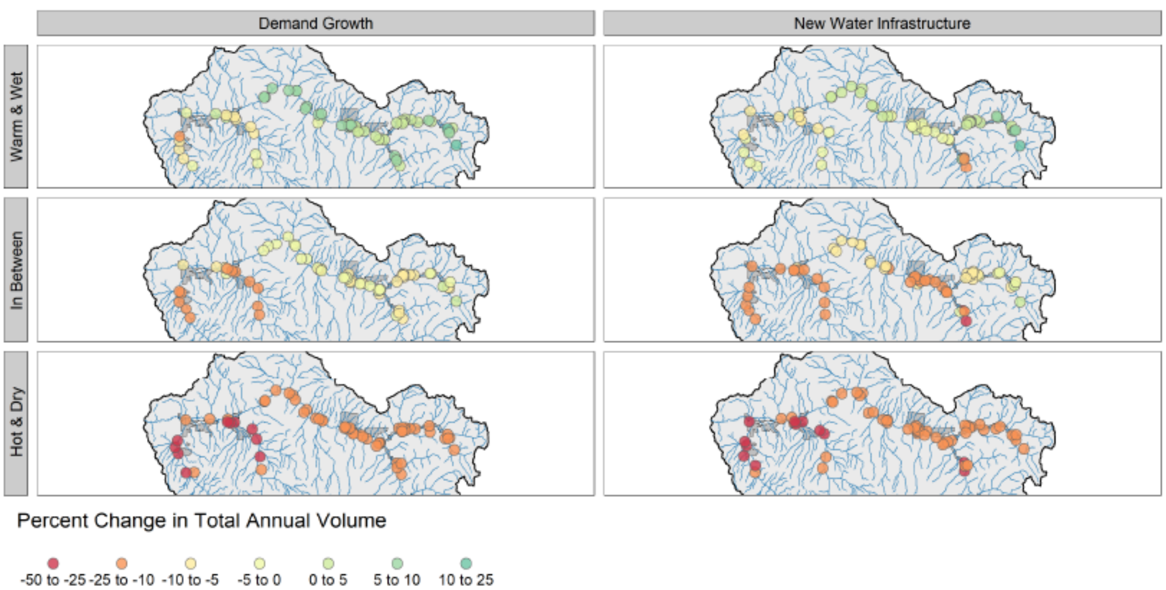


**Figure 14. Percent change from baseline in total annual flow volume (acre-feet) under climate change scenarios at ERCWP model nodes. Warmer colors indicate a decrease in flow while cooler colors indicate an increase in flow from baseline.**

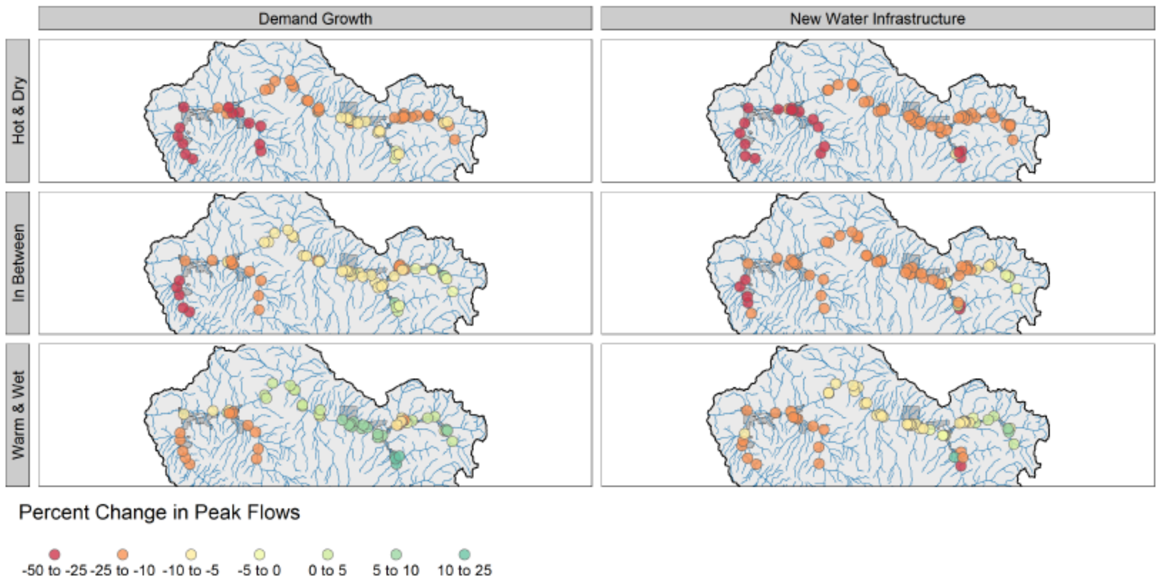


**Figure 15. Percent change from baseline in peak flow under climate change scenarios. Change in peak flow is measured as the change in median 3-day maximum flow. Warmer colors indicate a decrease in flow while cooler colors indicate an increase in flow from baseline.**

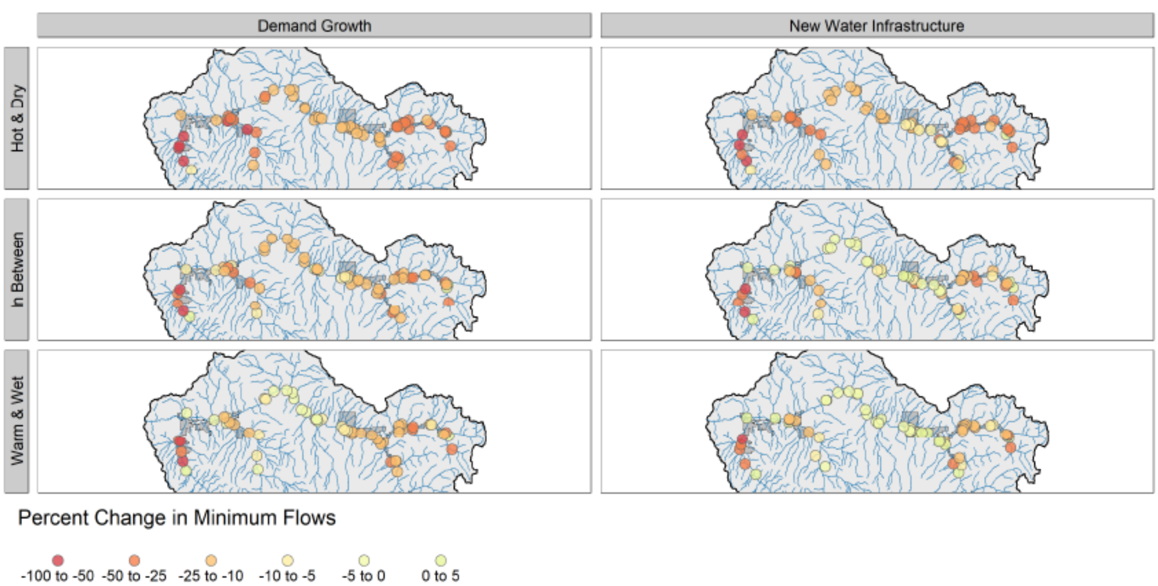


**Figure 16. Percent change from baseline in median minimum flows under climate change scenarios. Change in minimum flows is measured as the change in median 7-day minimum flow. Warmer colors indicate a decrease in flow while cooler colors indicate an increase in flow from baseline.**

### 3.4.1 Key Findings

- Predicted changes in streamflow patterns under near future and demand growth scenarios without climate change were relatively small, suggesting demand changes without the influence of climate change will not have large impacts on streamflow and riverine ecosystems.

- Reservoir development and operational changes under the New Water Infrastructure are predicted to reduce the magnitude and inter-annual variability during high flow conditions and increase low flows on the Eagle River. The largest impacts from reservoir development and operational changes are predicted to be on the Upper Eagle River. New Water Infrastructure is predicted to have minimal impacts on streamflow on the Lower Eagle River and tributaries within the watershed. Reductions in peak flows are expected to be largest in wet years and will impact average and wet years.
- Climate change is predicted to shift peak flows earlier by 10-25 days irrespective of water use scenario.
- Climate change is predicted to reduce late summer and fall flows across the watershed. The impacts of climate on low flows on the Eagle River may be reduced or eliminated under the reservoir storage and operational rules outlined in the New Water Infrastructure scenario.
- Peak flows are predicted to increase slightly under a Warm & Wet climate future without reservoir development. Peak flows are expected to be lower than baseline in a Warm & Wet future under the New Water Infrastructure scenario.
- Streamflow on Gypsum Creek is predicted to drop to zero with increasing frequency under climate change. Periods with zero streamflow are predicted to occur in most years under a Hot & Dry climate future.

## 3.5 Environmental Flow Deficits

Minimum streamflow thresholds, environmental flow targets, or preferred measures of streamflow behavior are presented by various sources, including the Colorado Water Quality Control Division, Colorado Water Conservation Board (CWCB), and Colorado Parks and Wildlife (CPW). These targets may encompass a variety of flow types, including minimum flows for habitat quality, flows supportive of fish spawning, channel maintenance flows, and flows necessary to permit aquatic organism passage through riffles. Persistent streamflow outside of recommended environmental targets can have negative outcomes for aquatic life and macroinvertebrate communities as well as riparian vegetation. Analysis of the ER20 model outputs provided a means to evaluate current and future achievement of flow targets under various water use and climate change scenarios (Appendix E). This assessment compared simulation outputs to environmental flow targets developed by the Colorado Water Conservation Board's (CWCB) instream flow (ISF) rights program.

CWCB instream flow rights were established to maintain minimum flow targets necessary for aquatic life. Periods of flow below the recommended limits are referred to as environmental flow deficits and can harm ecosystem health and integrity. CWCB ISF water right records were obtained for all reaches with simulated streamflow in the ERCWP study area. Some reaches had multiple associated ISF case numbers, which were aggregated to reflect the most recent set of flow targets. Flow targets on some reaches were distinct for up to three periods: Summer (May - Sep), Shoulder (Oct), and Winter (Nov-Apr).

Simulated streamflows at individual simulation locations (nodes) were evaluated against corresponding ISF targets. During periods when simulated streamflow was below the ISF, Environmental Flow Deficits (EFD) were calculated as the volumetric sum of flows (acre-feet) below the target, summed annually. EFD durations were calculated as the annual number of days when environmental flow deficits occurred. For the entire study period, deficits and durations were calculated at every model node for each simulation scenario. Results were aggregated to the reach scale as the mean value across all nodes within a reach. For some reaches, nodes were aggregated to sub-reaches because of increased spatial variability in model outputs at these reaches. Reach-scale results are summarized and reported as the mean and 5$^{th}$, 25$^{th}$, 50$^{th}$, 75$^{th}$ and 95$^{th}$ quantiles of all simulation years. Impacts under water use and climate change scenarios were evaluated as the EFD difference from the Current Conditions scenario.

### 3.5.1 Key Findings

- Environmental flow deficits under the baseline scenario are limited in most areas of the watershed but are more prevalent in the upper reaches of Gore Creek and on the Eagle River near Avon (Figure 17). Streamflow deficits under baseline conditions are most common in dry years with low snowpack and early snowmelt, but deficits are also influenced by spatiotemporal patterns in water use and diversions.
- The duration and magnitude of environmental flow deficits are predicted to become more severe on the mainstem Eagle River and on Gore Creek near Vail, especially during dry years, due to growing water demands and climate change.
- Environmental flow deficits are predicted to be most severe under hotter and drier climate futures, although increased environmental deficits also are predicted under wetter climate futures, likely due to earlier snowmelt (Figure 18).
- Reservoir releases under the New Water Infrastructure scenario are predicted to help reduce the frequency and duration of environmental flow deficits, even under a Hot & Dry climate future. This outcome is contingent on future reservoir operations matching the reservoir operational rules in the simulation model. Rule-making in the model was designed to use West Slope water to minimize environmental flow deficits during low flow periods.

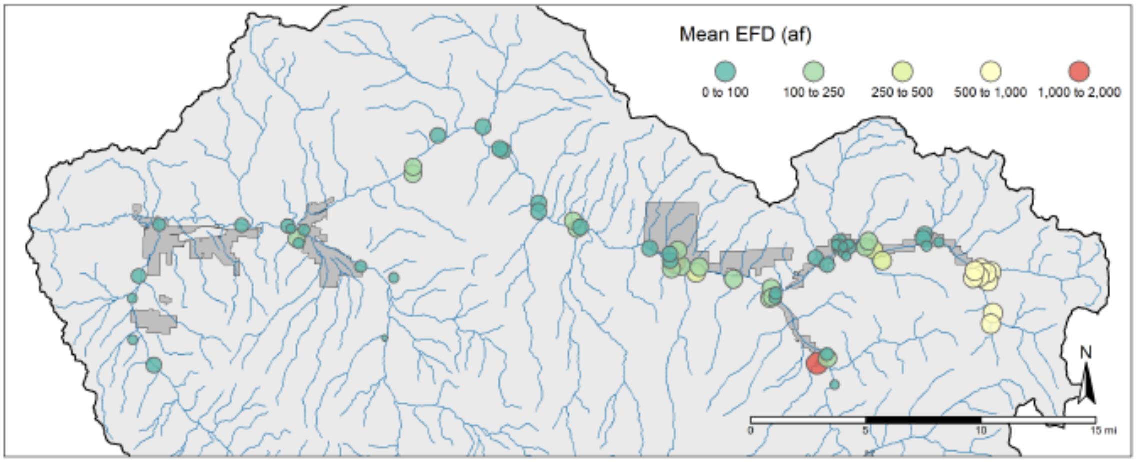


Figure 17. Mean environmental flow deficits for the Eagle River under the Baseline scenario across all simulation years. Nodes with warmer colors and larger points have higher deficits. Only nodes associated with an existing ISF minimum flow target are shown.

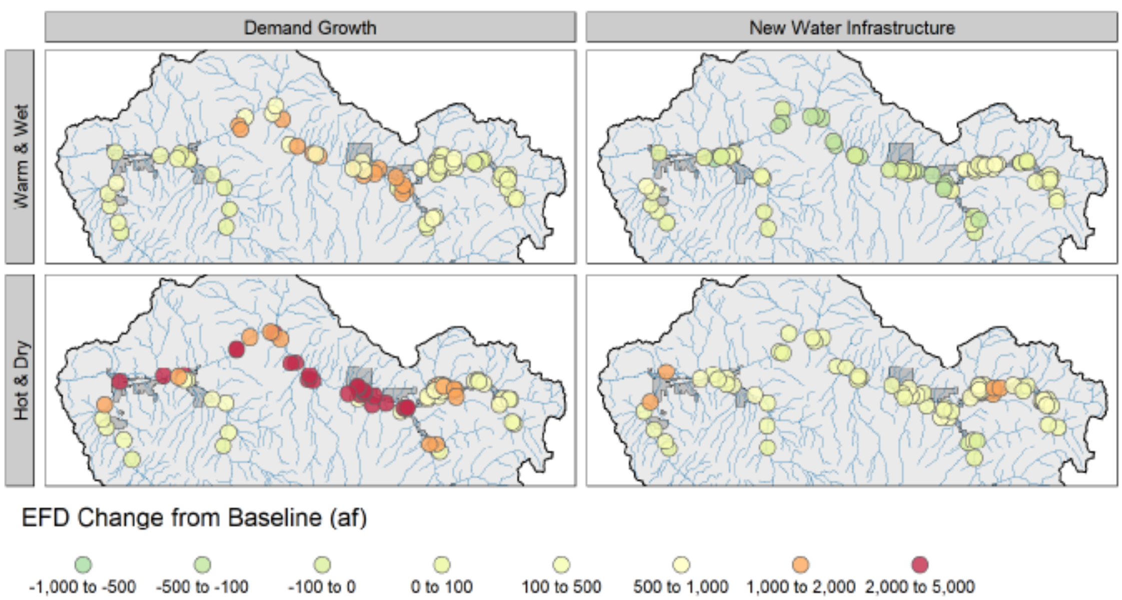


Figure 18. Changes from baseline in mean environmental flow deficits under climate change scenarios during very dry years. Values are differences in 95th percentiles across all simulation years of EFD. Nodes with warmer colors and larger points have higher increases in deficits. Only nodes associated with an existing ISF minimum flow target are shown.

## 3.6 Stream Temperature

Stream temperature is a critical determinant of aquatic ecosystem health. Stream temperature has direct impacts on fish and macroinvertebrate community structure, survival, and species abundance. Stream temperature is driven by hydro-climatic factors (i.e., air temperature, discharge), stream characteristics (i.e., channel geometry, riparian shading) and water management (i.e., reservoir releases, diversions and return flows, and point-sources such as industrial and municipal discharge). Stream temperature is of particular concern in Colorado streams for the maintenance of both cold-water trout fisheries in headwaters and warm-water species in larger downstream rivers. The analysis results presented here and in Appendix F intend to support future management decisions and inform a broader understanding of how climate and water use decisions may impact sport and native fish populations.

Modeling stream temperature under future scenarios requires identifying how stream temperature responds to various drivers within a given reach in the river system. Observed stream temperature records in the Eagle River watershed were used to calibrate and validate the semi-physical *air2stream* model. The *air2stream* model predicts daily mean stream temperature based on air temperature, discharge, and day of year. Model outputs describe the impact of net heat fluxes associated with water moving in and out of a stream reach and the impact of direct solar heating on that reach. A historical model was developed at sites with sufficient observational records. The historical model was calibrated and validated using historical stream temperature observations. Predictions of daily mean stream temperature were generated at the same sites by running a 'forward model' that used the optimal model parameters identified during calibration. The forward model was run for the suite of hydrological modeling scenarios. Model results were analyzed to understand how predicted temperatures changed across scenarios. Risks to fisheries were identified by comparing predicted stream temperatures to identified thermal thresholds known to impact specific fish species. The approach enabled assessments of relative risk under differing scenarios and distinguished risks among different fish species including cutthroat, rainbow, brook, and brown trout.

Monthly mean stream temperatures were calculated for each simulation year under each scenario. Change in monthly mean stream temperatures ($dT_w$) was calculated as the difference in mean stream temperature between a given ERCWP scenario and the baseline scenario for a given simulation year and a specific month. Species-specific sub-lethal temperature thresholds (SSLT) were identified from literature that underpin the State of Colorado stream temperature standards (Table 1). These thresholds reflect the temperature above which sub-lethal outcomes become more prevalent. Sub-lethal outcomes are not fatal but rather reflect negative outcomes if the temperatures are sustained, such as decreased reproductive success, reduced growth, and increased disease. Sub-lethal temperature thresholds have distinct values for the summer months (June through September) and for other periods of the year (October through May). Temperature thresholds that indicate lethal conditions are not considered because the modeling approach enables predictions of daily mean temperatures but not daily maximum temperatures. Observed patterns of elevated stream temperature above SSLTs correspond with higher risks of maximum temperatures above lethal thresholds.

**Table 1. Sub-lethal temperature thresholds by species.**

| Trout Species | Summer (July – Sep) | Fall (October) |
|---|---|---|
| Cutthroat | 17 °C | 9 °C |
| Rainbow (& Brook*) | 18.2 (18.3*) °C | 9 °C |
| Brown | 19.6 | 9 °C |

*Rainbow & Brook Trout have similiar thresholds and are lumped together under the Rainbow category

Periods where stream temperatures were above SSLT were evaluated using two distinct metrics, including cumulative degree days and summer hot spells. Degree days were defined as the difference between stream temperature and SSLT for a given day and are only calculated on days when stream temperature is greater than SSLT. Cumulative degree days were calculated as the sum of degree days across a given time. Cumulative degree days were calculated for each month and across the full July to October study period. Summer hot spells were identified as periods where stream temperature is greater than SSLT for 7 or more continuous days. To reduce the impact of day-to-day variability, days with stream temperature greater than SSLT was considered part of a hot spell if either four of five or five of seven neighboring days had stream temperatures greater than SSLT. The duration and the cumulative degree days were calculated for each identified summer hot spell. Summer hot spells were only calculated between July and September using summer SSLT values.

### 3.6.1 Key Findings

- Stream temperatures along the Eagle River and Gore Creek generally peak in July and August. Relatively high stream temperatures were observed on the Middle Eagle between Edwards and the confluence with Milk Creek and on the Lower Eagle at Gypsum (Figure 19 and Figure 20).
- Mean daily stream temperatures in the summer and fall were not strongly impacted by streamflow changes caused by demand growth without climate change. Reservoir releases during low-flow periods under New Water Infrastructure are predicted to reduce high stream temperatures on the Eagle River during the later summer and early fall.
- Mean daily stream temperatures under climate change are predicted to increase from 2-5°C on the Eagle River and from 1-3°C on Gore Creek.
- Mean daily stream temperatures on most reaches are predicted to stay below sub-lethal temperature thresholds for rainbow and brown trout in most years. In dry years and under hotter and drier climate futures, degree days and summer hot spells are predicted to increase for cutthroat and rainbow trout on portions of the Middle and Lower Eagle. Degree days are not predicted at any sites for brown trout. Reservoir releases during low-flow periods under the operational rules in the New Water Infrastructure scenario may

moderately reduce the magnitude and duration of degree day increases under climate change.

- There is considerable uncertainty in predictions of stream temperatures on the Lower Eagle due to limited monitoring data. Based on river characteristics and network position, it is likely that this area is at higher risk for degree days and hot spells under climate change, but additional data is needed to better characterize this risk.

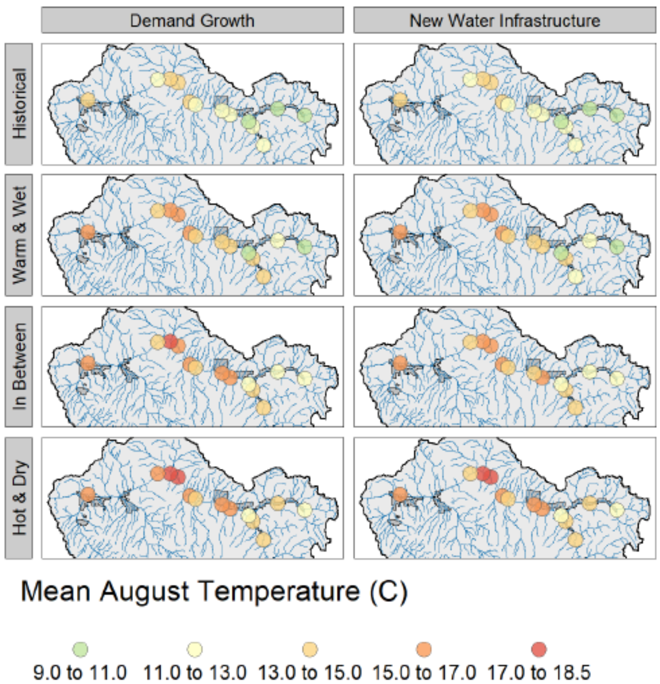


**Figure 19. Map of mean August stream temperatures across all simulation years. Nodes with warmer colors have higher temperatures.**

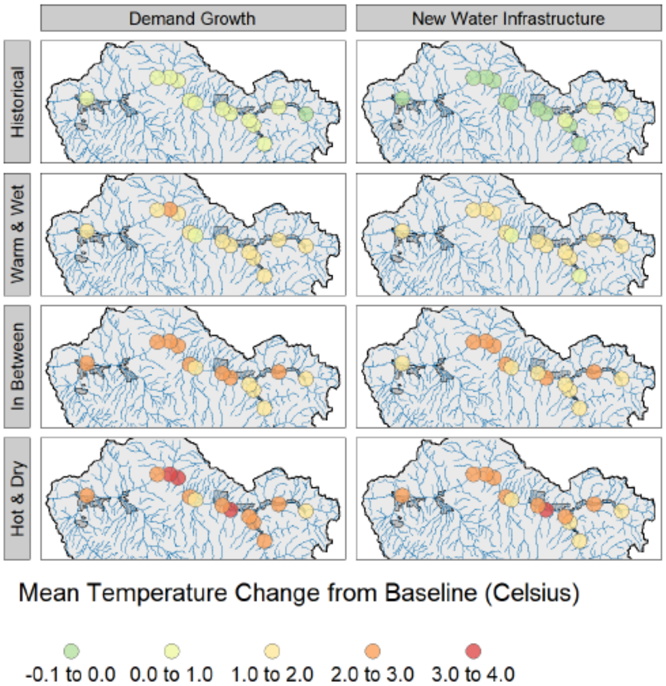


**Figure 20. Map of mean stream temperature change from the Baseline scenario across all simulation years. Nodes with warmer colors have higher temperatures.**

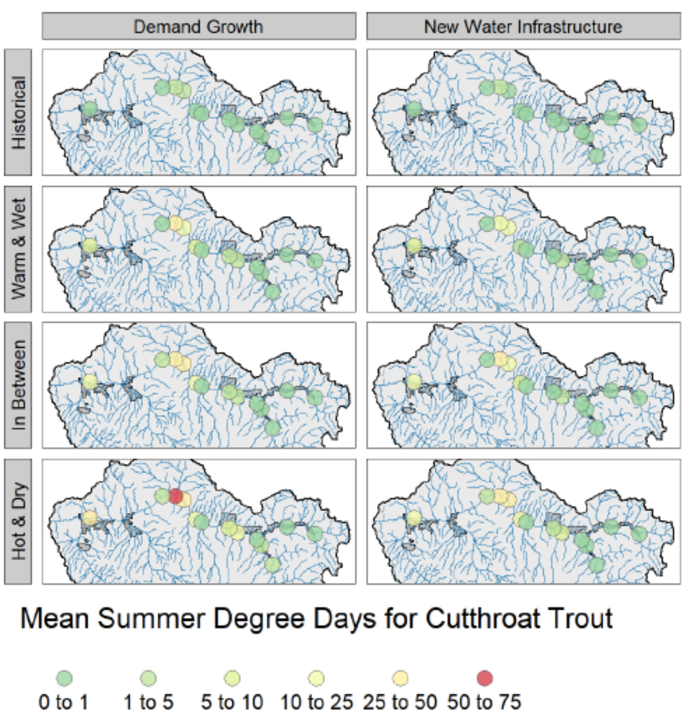


**Figure 21. Map of mean summer degree days for cutthroat trout.**

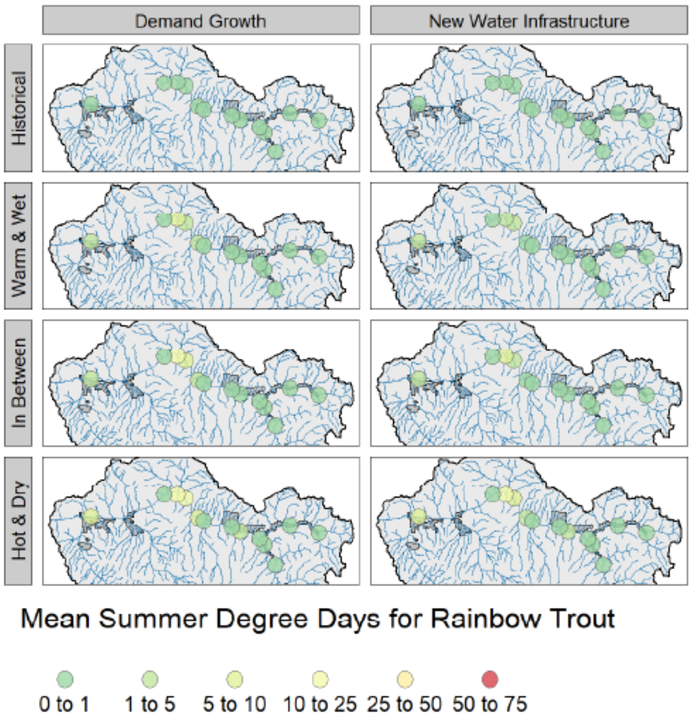


**Figure 22. Map of mean summer degree days for rainbow trout.**

## 3.7 Water Quality below Eagle Mine

The Eagle Mine Superfund Site has been a source of historic and current water quality pollution on the upper Eagle River. The site was placed under Superfund status in 1986 with cleanup and remediation efforts beginning in 1988. The site remains a continuous source of heavy metal loading to the Eagle River despite ongoing site cleanup. A water quality treatment plant was constructed in 1990, and there are ongoing efforts to divert clean groundwater from entering the site. Subsequent efforts to improve water quality have not fully alleviated water quality concerns. Ongoing water quality concerns include the loading of zinc, copper, manganese, lead, and cadmium to the river. Previous investigations indicated that heavy metals reach the Eagle River through both surface and groundwater pathways. Heavy metal concentrations have been reported to spike during early spring (March/April) with a secondary spike for some constituents of concern also reported during the fall. The springtime spike is thought to be the result of spring snowmelt that generates hydrologic conditions conducive for increased loading to the river. When this loading co-occurs with relatively low streamflow levels, metals concentrations in the river can reach water quality thresholds that threaten aquatic and human health.

The reliance on Eagle River flows to dilute metal loading from the Eagle Mine Superfund site raises questions about how future streamflow changes on the Eagle River might affect water quality on impacted reaches.

Recent observed water quality and discharge data were examined to describe patterns between the timing of current metal loading, metal concentrations, and Eagle River streamflow (Appendix G). A quantitative assessment of changes to dissolved metal concentrations on the Eagle River was evaluated using hydrological model scenarios that incorporate changes in infrastructure and water demand under historical hydrology patterns. A similar assessment was not possible for climate change scenarios due to uncertainty in how climate change (e.g., snowmelt dynamics) may impact the timing and magnitude of metal loading from the Eagle Mine. The potential implications of climate change on water quality were considered in a qualitative manner, and recommendations were made for future work required to model climate change risks related to Eagle River water quality.

Water quality data was obtained from the Water Quality Portal for sampling sites co-located with the USGS Eagle River near Minturn streamflow gage (USGS ID: 09064600). The sampling site is approximately 2.5 river miles below the Eagle Mine. Samples were collected by multiple agencies, including the USGS, Colorado River Watch, and CBS Operations Inc. Additional water quality data was obtained directly from the Eagle River Water and Sanitation District. Data was screened for availability, data quality, and sampling density. Water quality parameters evaluated in this study were dissolved zinc, copper, manganese, iron, and cadmium. Due to a lack of information on detection limits, samples below detection limits (non-detects) were removed from the dataset. Instantaneous daily loads (kg per day) for each sampling date were calculated for each water quality parameter as the product of measured dissolved concentrations and daily mean streamflow.

Visual assessment of water quality parameter timeseries revealed that springtime metal concentrations and loading declined throughout the early 2000s. As a result, only data from 2009 to 2016 were used in this study to reflect recent conditions that also overlap with the ERCWP streamflow model simulation period.

The timing of observed dissolved metal concentrations, metal loads and discharge were evaluated graphically using timeseries plots. Plots were examined to identify general patterns of the beginning of metal loading and compared to the timing of the snowmelt-driven high flows and late season low-flows observed in the annual hydrograph. These relationships were further examined with concentration-discharge (C-Q) and loading-discharge (L-Q) plots. Concentration-discharge and loading discharge plots are a graphical approach used to infer solute loading behavior from water quality timeseries at a sampling location. The plots can help identify multiple characteristics of water quality behavior, including the occurrence of hysteretic relationships between concentrations and discharge, the timing of a solute's delivery to the river and whether it is transport or supply limited, and the behavior of resulting streamflow concentrations which can be diluted, homeostatic or increasing at higher flows.

Predictions of water quality under ERCWP scenarios using historical hydrology were developed in combination with observed water quality concentrations and simulated daily streamflow. Observed daily instantaneous loads were linearly interpolated to generate daily predicted loads for each day in the water quality record from 2009 to 2016. Instantaneous loads were smoothed to the 14-day rolling mean to remove artifacts based on sampling frequency and variability. Water quality concentrations were then computed under each ERCWP scenario as the predicted smoothed daily load divided by the ERCWP simulated streamflow for the corresponding day and scenario. These predictions assume that historical metal loading patterns are independent of discharge. Assumptions in the analysis were required, including metal loading from the broader watershed is minimal and changes to surface-groundwater gradients driven by changes to stream discharge at the Eagle Mine have negligible impacts on metal loading. The results describe how water quality would have changed if different water use scenarios were applied during the 2009-2016 study period.

Risks to aquatic and human health based on water quality predictions under the ERCWP scenario were compared by evaluating predicted concentrations to thresholds in metal concentrations set by State of Colorado water quality standards. The State of Colorado developed specific acute and chronic local water quality standards for aquatic life on reaches affected by the Eagle Mine that differ from state-wide standards. The local standards for zinc, copper, and cadmium were first developed for the least tolerant aquatic species of interest but were modified to a less stringent standard because the more stringent standard was determined to be unattainable. Water quality predictions were compared to both the stricter and looser local standard to provide a more complete depiction of impacts to aquatic life. These standards are equation based, and numeric thresholds are dependent on stream hardness. Monthly mean hardness was calculated for the study period and applied to the standard equations to develop numeric water quality thresholds (WQT) for each month.

Iron and manganese are water quality constituents of primary concern for drinking water supplies. Results for both constituents were compared to the statewide chronic domestic water supply standard value as indicated in Water Quality Control Commission Regulation 31 (Table 2). Domestic water supply intakes for the Eagle River Water and Sanitization District are downstream of the chosen sampling site. Results, therefore, may overestimate the risk at the drinking water intakes but provide useful information about the changes to the relative risks for drinking water under modeled scenarios.

**Table 2. Water Quality Thresholds (WQTs) by Month. Units for all parameters are in ug/L except mean hardness which is in mg/L.**

| Parameter | Use Classification | Time Scale | Species of Concern | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Hardness | - | - | - | 91.3 | 95.6 | 89.1 | 65.3 | 59.8 | 58.7 | 59.7 | 78.6 | 79.5 | 91.3 | 89.2 | 89.5 |
| Cadmium | aqL | acute | - | 1.6 | 1.7 | 1.6 | 1.2 | 1.1 | 1.1 | 1.1 | 1.4 | 1.4 | 1.6 | 1.6 | 1.6 |
| | aqL | chronic | - | 2.0 | 2.1 | 2.0 | 1.5 | 1.4 | 1.4 | 1.4 | 1.8 | 1.8 | 2.0 | 2.0 | 2.0 |
| Copper | aqL | acute | mayfly | 16.4 | 17.1 | 16.0 | 11.8 | 10.8 | 10.6 | 10.8 | 14.2 | 14.3 | 16.4 | 16.0 | 16.1 |
| | aqL | chronic | mayfly | 8.5 | 8.7 | 8.3 | 7.0 | 6.6 | 6.5 | 6.6 | 7.8 | 7.8 | 8.5 | 8.4 | 8.4 |
| | aqL | acute | tubifex | 26.5 | 27.7 | 25.8 | 19.1 | 17.5 | 17.2 | 17.5 | 22.9 | 23.1 | 26.5 | 25.9 | 26.0 |
| | aqL | chronic | tubifex | 13.7 | 14.1 | 13.5 | 11.2 | 10.7 | 10.5 | 10.7 | 12.5 | 12.6 | 13.7 | 13.5 | 13.5 |
| Zinc | aqL | acute | sculpin | 190.6 | 198.2 | 186.6 | 143.2 | 132.9 | 130.8 | 132.7 | 167.8 | 169.4 | 190.7 | 187.0 | 187.4 |
| | aqL | chronic | sculpin | 162.0 | 168.5 | 158.6 | 121.7 | 113.0 | 111.1 | 112.8 | 142.6 | 144.0 | 162.0 | 158.9 | 159.3 |
| | aqL | acute | rainbow | 388.2 | 403.8 | 380.1 | 291.6 | 270.7 | 266.3 | 270.3 | 341.7 | 345.0 | 388.3 | 380.8 | 381.7 |
| | aqL | chronic | rainbow | 329.9 | 343.1 | 323.0 | 247.8 | 230.0 | 226.3 | 229.7 | 290.4 | 293.2 | 330.0 | 323.6 | 324.3 |
| Manganese | DWS | chronic | - | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 |
| Iron | DWS | chronic | - | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 |

[a] aqL = Aquatic Life Standard
[b] DWS = 'Drinking Water Standard

Predicted water quality concentrations were compared to WQTs. These calculations do not follow exact methods laid out in the Colorado water quality standards and use the standards as a guideline to provide an assessment of the relative ecologic and human health risks under ERCWP scenarios. The following metrics were computed, summarized by month, and compared between ERCWP scenarios:

- **Number of days above threshold**: The number of days parameter concentrations exceeded WQTs.
- **Magnitude above threshold (ug/L)**: The amount predicted concentrations were above WQTs. Only calculated for days parameter concentrations were predicted to be above WQTs.
- **Loading surplus (kg)**. Calculated for each day as the difference between the total predicted daily loading and the maximum daily loading that would not exceed the WQT. Only calculated for days parameter concentrations were predicted to be above WQT.
- **Discharge dilution gap (af)**: Calculated as the additional discharge needed to dilute predicted metals loads to ensure parameter concentrations were not higher than WQTs. Only calculated for days parameter concentrations were predicted to be above WQT.

### 3.7.1 Key Findings

- Water quality and aquatic health below the Eagle Mine are currently impacted by heavy metal loading to the river from historic mining infrastructure and waste.
- Heavy metal concentrations for constituents of concern to aquatic life are highest during the early spring when loading from mine sites initiates prior to the initiation of the rising limb of the Eagle River. High heavy metal loading to the river continues into the later

spring and early summer but is less impactful to aquatic life during this period due to dilution by elevated Eagle River streamflow (Figure 23).

- Streamflow patterns predicted under future water uses may increase risks to aquatic life later in the spring due to shifts in streamflow magnitude and timing. Risks are highest under the New Water Infrastructure scenario when discharge is diminished during higher flows.
- Iron and manganese, constituents of concern for drinking water, are highest during the spring but also are elevated in low streamflow months in the fall and winter. Loading is generally highest in late spring or early summer with moderately high flows on the rising limb of the snowmelt hydrograph.
- Future reservoir storage under new water infrastructure may reduce iron and manganese concentrations during low-flow months if operations enhance baseflows but may also increase metal concentrations during the early summer by reducing streamflow during high loading periods.

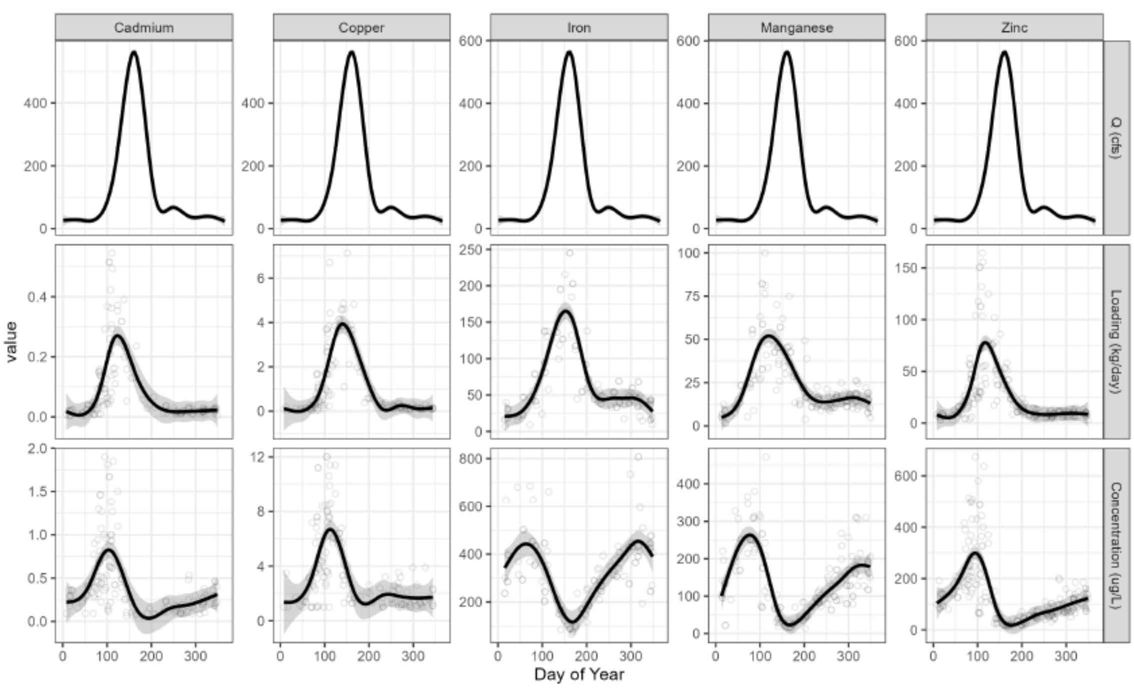


**Figure 23. Seasonal timing of observed discharge (Q), metal loading, and streamwater concentrations. Black lines indicate LOESS trends in seasonal timing across the 2009 to 2016 study period. Points represent individual sampling results during the study period. Columns are distinct water quality constituents of concern. Y-axis values for loading and concentration vary by water quality constituents.**

- Significant uncertainty remains regarding the role of changing snowmelt dynamics on metals loading under climate change, and a larger study is necessary to better understand the relationships between climate, snowmelt, metal loading, and discharge concentrations. Managing the risk may require mitigating metal loading sources and/or ensuring late winter/early spring streamflow is sufficient to dilute metal loads to acceptable concentrations (Figure 24).

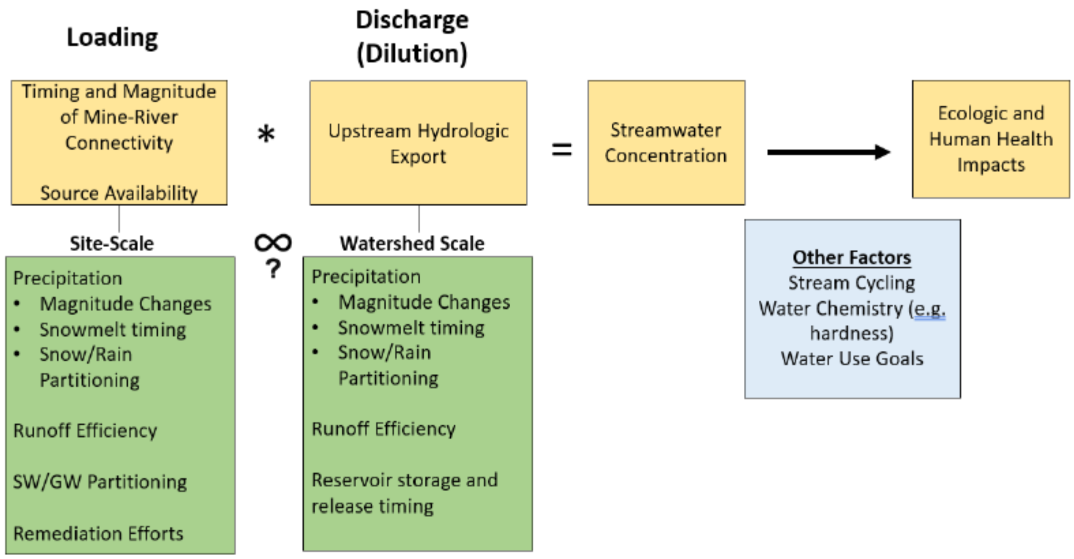


**Figure 24. Flow chart of hydro-climatic and human activities that may impact future parameter concentrations under climate change and future water use scenarios.**

### 3.7.2 Sediment Transport and Eco-geomorphic Process

The mobilization, transport, and deposition of river sediment during high streamflow helps maintain suitable habitat for the life cycle of aquatic life, including fish and macro-invertebrates. Higher flows are critical for sediment and eco-geomorphic processes because in gravel and cobble bed rivers, processes, such as flushing of fine sediments and the maintenance of channel forms, primarily occur at higher flow conditions. The degree that eco-geomorphic processes occur on a given reach depends on the complex interaction between sediment deposition and mobilization. Watershed characteristics, including land-use, geology, climate, and human water use, determine flood frequency, flood magnitude, and sediment supply to a given reach. Reach-scale characteristics interact with these fluxes of water and sediment to control reach-scale sediment behavior. Critical reach-scale characteristics that contribute to this relationship include channel geometry, channel gradient, river confinement, riparian vegetation, and sediment grain size.

Streamflow modeling results illustrate fluctuations in the frequency, timing, and magnitude of spring runoff under a variety of future scenarios. Potential hydrological shifts may impact sediment dynamics and, therefore, aquatic habitat within the Eagle River watershed. Identifying complex connections between sediment dynamics and aquatic ecosystems requires extensive data to characterize geomorphic and ecologic conditions. The relative risks of changes to eco-geomorphic processes were assessed using complementary approaches that reflect the potential for geomorphic and habitat change on specific reaches of the Eagle River and Gore Creek (Appendix H).

The mobility of gravel for trout spawning beds was analyzed under this assessment. The analysis incorporated potential changes across differing process domains, including an identifiable area characterized by distinct suites of geomorphic processes that govern sediment dynamics. The results provide a description of the relative degree of potential change in eco-geomorphic processes on study reaches. Results are intended to provide decision-makers with insights into spatial patterns and to identify locations where future hydrologic change may result in undesirable changes. Analysis results also inform reach prioritization for more detailed geomorphic and ecologic analysis that further explore linkages between changes in sediment dynamics and aquatic ecosystem health.

Sediment dynamics were characterized at 15 sites on Eagle River and at two sites on Gore Creek. Field data collected in 2019 and 2021 was used to estimate grain size distributions for each site. Grain size distributions were determined from pebble counts on active lateral bar features. Lateral bars were parallel to a riffle or along a bend or point bar adjacent to a riffle/pool habitat. This sampling approach aims to sample sediment from locations most representative of the coarse sediment load moving along the streambed annually. Two to three 100-foot pebble count transects were conducted at each site with random samples collected every one foot. Pebble counts were averaged over the three transects. Grain-size distributions were truncated at 4 mm, and three grain size percentiles, D16, D50 & D84, were estimated from the pebble count distributions.

A River Styles Framework Phase 1 assessment was conducted to assess broad spatial patterning of river geomorphology and process domains. The River Styles Framework describes river behavior, explains how the river behaves, and can help predict how the river may adjust its form. Site-scale characterizations were conducted using stream slope and grain size distributions to classify stream type, such as step-pool, plane-bed, and pool-riffle. Sites were further characterized by their valley confinement ratio, which was calculated as the ratio of valley width to river width. Sites were classified as confined with valley width to river width ratios below 2, as moderately confined with ratios between 2 and 4, and as unconfined if ratios were above 4.

Hydraulic parameters, including discharge (Q), hydraulic radius (R), velocity (V), width (W) and depth (D), were obtained by running ER20 streamflow predictions through a HEC-RAS one-dimensional models developed for the Eagle River and Gore Creek. Model simulations incorporated a range of discharges that encompassed higher flows observed at nearby USGS streamflow gauges. The friction slope (Sf), a critical variable for sediment transport, was calculated as the energy slope for the 2-year recurrence interval (RI-2yr) of the three-day maximum flow using the Current Conditions scenario from the ER20 model.

Bed sediment mobilization potential was evaluated by identifying the effective discharge. Effective discharge (*eff* Q) estimates are based on the concept that there is a dominant discharge that predominantly controls channel form and initiates mobilization of bedforms. This dominant discharge is the discharge that is most effective for geomorphic work (i.e. transports the most bedload sediment). Many channels adjust to these flows over time and if in equilibrium may have bed sediments that reflect the interaction of these discharges and the sediment supply from the watershed. The effective discharge was calculated by multiplying the flow frequency curve by a sediment discharge rating curve and locating the discharge that maximized the resulting geomorphic work curve.

Effective discharge was identified using the baseline scenario (*eff*Qbc), and its corresponding recurrence interval was calculated using annual 3-day maximum flows. Fluctuations in the recurrence interval of *eff*Qbc were observed across each hydrological scenario. This provided a relative metric of the degree that a given reach might experience geomorphic change from peak flow alterations.

There are several limitations to the effective discharge approach that motivated an additional analysis on sediment mobilization potential. The effective discharge approach cannot distinguish between changes to mobilization of different grain sizes. Impacts to specific eco-geomorphic functions, such as mobilization of gravel, cannot be assessed independently. The approach also does not fully indicate the competency of effective discharge to mobilize bed sediment.

Sediment mobilization potential is an approach that defines sediment mobilization in terms of the ratio of the boundary shear stress to the critical value of entrainment. Sediment mobilization potential at a given flow state can be calculated separately for each bed sediment class size. The approach is adapted from the relative bed stability criteria approach and is described in detail in Davidson and Eaton (2018). The mean boundary shear stress was obtained for variable discharge values using HEC-RAS model outputs of friction slope and hydraulic radius. The critical shear stress for entrainment for a specific class size Di was calculated in two parts based on Wilcock and Crow (2001) transport equations. Once the ratio between mean boundary shear stress and critical shear stress for entrainment ($t$) is calculated, it is transformed into a sediment mobilization potential.

The sediment mobility analysis provides an alternative view of how hydrologic changes impact a reach by providing an assessment of class sizes required for trout spawning habitat. This approach helped to identify changes in mobilization frequency for gravel sizes ideal for trout spawning. The total spawning-sized gravel present at each reach was identified as a proportion of all bed material. This represents a coarse estimate of the potential for trout spawning habitat at a given site. Results do not represent a direct estimate of spawning habitat because field pebble counts did not explicitly target spawning beds. The fraction of the spawning-sized gravel that is mobile under the 1.5-year recurrence interval discharge event was estimated for each hydrological scenario. Sediment mobilization potential was considered equivalent to the percent mobility of a given grain size. Changes in sediment mobilization potential for each scenario were assessed relative to the mobile fraction for the Current Conditions scenario. Mobile fractions of spawning-sized gravel were reported as a proportion of the full bed.

### 3.7.3 Key Findings

- Eco-geomorphic processes might be sensitive to changes in peak flows predicted under some scenarios at pocket floodplains on the Upper Eagle and at the discontinuous floodplains on the Lower Eagle.
- Confined and unconfined sites on the Middle Eagle appear only moderately sensitive to peak flow changes with moderate changes to effective discharge RI but less change in spawning sized gravel mobility. At sites that may be more sensitive, decreases in peak flows under hotter, drier climate futures and under New Water Infrastructure increase the recurrence intervals of effective discharge and decrease the mobility of spawning-sized gravel under 1.5-year RI peak flows. These predicted changes indicate a risk of aquatic habitat degradation because they may suggest deposition of finer sediments and an increase of embeddedness of existing gravels (Figure 27).
- On Gore Creek, results indicate that lower-gradient floodplain reaches with spawning-sized gravel might be susceptible to changes in gravel mobility while higher gradient systems with little gravel will be less impacted. Predicted changes in the recurrence intervals of effective discharge is also smaller on Gore Creek.
- The impacts of changing streamflow patterns on eco-geomorphic process and aquatic habitat may depend on factors not considered in this analysis including watershed-scale sediment supply and fine-scale sediment deposition/mobilization patterns.
- Findings provide a coarse look at relative risks across the watershed. Further work may be needed to better predict site-level changes and to identify potential opportunities to mitigate habitat degradation in response to a known disturbance (e.g. wildfire) or expected disturbance (e.g. reservoir development).

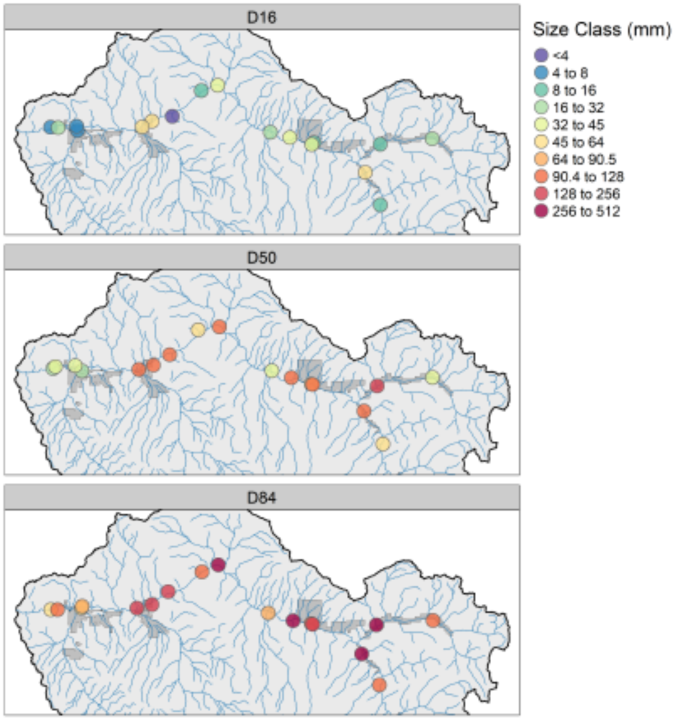


**Figure 25. Grain size distributions for D16, D50 and D84 across sediment study sites within the Eagle River watershed.**

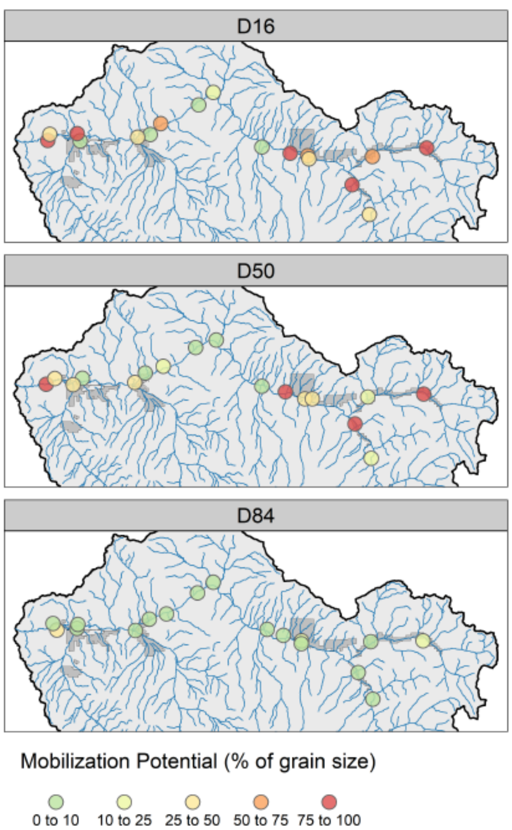


**Figure 26. Sediment mobilization potential for D16, D50, and D84 distributions for baseline effective discharge.**

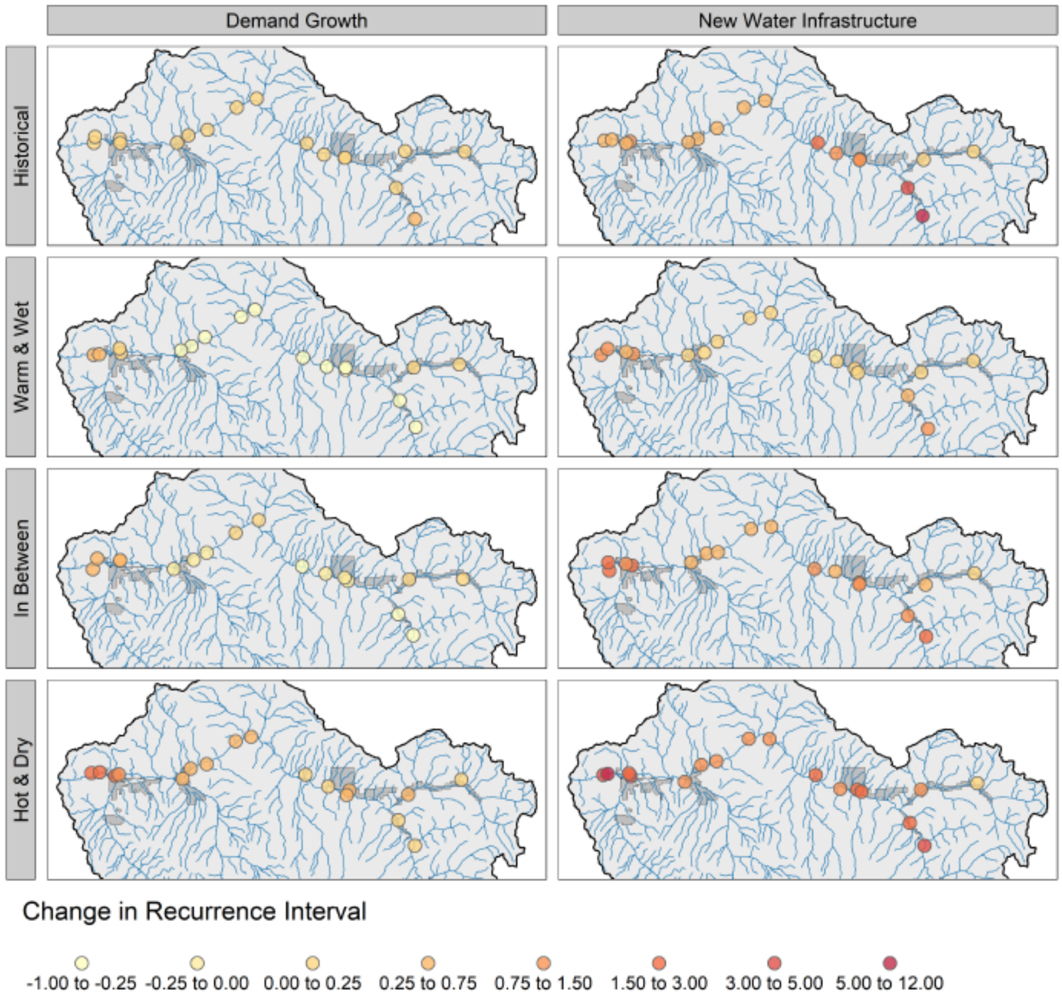


**Figure 27. Change in recurrence interval of baseline effective discharge under ERCWP scenarios.**

## 3.8 Aquatic Habitat and Trout Carrying Capacity

Predictions of aquatic habitat quality as a function of streamflow are of interest to practitioners and water managers seeking to identify ecologically meaningful flow targets, optimize management of flows for the benefit of aquatic organisms, and predict future ecosystem conditions. Such efforts are typically focused on establishing targets for minimum and optimal flows that maintain sufficient habitat availability and quality for organisms of interest during lower streamflow periods. Streamflow simulation outputs indicate that the frequency, timing, and magnitude of low and moderate discharge could change based on future water use and climate scenarios. An assessment was performed to assess how future hydrologic changes may propagate into changes in aquatic habitat quality for trout on seven reaches of the Eagle River and on two reaches of Gore Creek (Appendix I). Predicting these outcomes required three sequential analyses: (1) characterization of relationships between aquatic habitat conditions and streamflow; (2) identification of streamflow thresholds that describe optimal and sub-optimal trout habitat conditions; (3) evaluation of streamflow frequency and duration below identified thresholds under water use and climate change scenarios.

A bioenergetic model was used to evaluate habitat quality for three different trout sizes. The smallest size was used to approximate conditions for fry, the intermediate size was used to approximate conditions for juvenile trout, and the largest size was used to approximate conditions for adult fish of spawning age. The sizes and weights selected for each class were assessed against historical data collected on the Eagle River (Colorado Parks and Wildlife, unpublished data, 2013); and Gore Creek (Wynn, 1999) as a reasonableness check.

Macroinvertebrate drift density inputs to the bioenergetic model are not available from site-specific data sets collected on the Eagle River or Gore Creek. Such data sets are, in fact, difficult to find for most rivers. Synthetic values approximating biomass density and the fractional distribution of drifting organism size classes were instead informed by the available academic literature (Dodrill et al., 2016; Danehy et al., 2011). Three different drift macroinvertebrate densities were selected for use: 2 individuals per cubic meter, 4 individuals per cubic meter, and 8 individuals per cubic meter.

Bivariate distributions of Net Rate of Energy Intake (NREI) values were created for each unique combination of fish size and drift density. Two-dimensional hydraulic modeling using River2D was perfumed at numerous locations along the Eagle River and Gore Creek. NREI values were computed for each node in the hydraulic model mesh across a range of flows. In this way, two-dimensional NREI surfaces were created at each study site for each unique combination of fish size, drift density, and discharge (Figure 28).

Relationships between NREI and streamflow were explored by developing NREI-streamflow (NREI-Q) curves. Translating these curves to streamflow thresholds required identifying thresholds in NREI with meaningful significance for fish habitat. There are no firm guidelines defining NREI values that are acceptable for fish success. Rather the NREI-Q relationships provide information about conditions that are most or least optimal for fish habitat. The relative patterns generated from this analysis define a streamflow threshold as the low flow condition where the mean weighted NREI is 75% of the peak observed mean weighted NREI for a specific site. This reflects a sub-optimal streamflow condition that is less suitable for fish habitat. This sub-optimal threshold was constrained below the streamflow at which peak NREI occurs to reflect a low-flow condition. To automate the extraction of these streamflow thresholds, we fit a spline curve with four knots to the NREI-Q curve for each site. Figure 29 is an example of the spline fit and stream threshold extraction at the Avon site. Streamflow thresholds were only identified for adult fish and moderate macroinvertebrate densities (4 individuals per cubic meter).

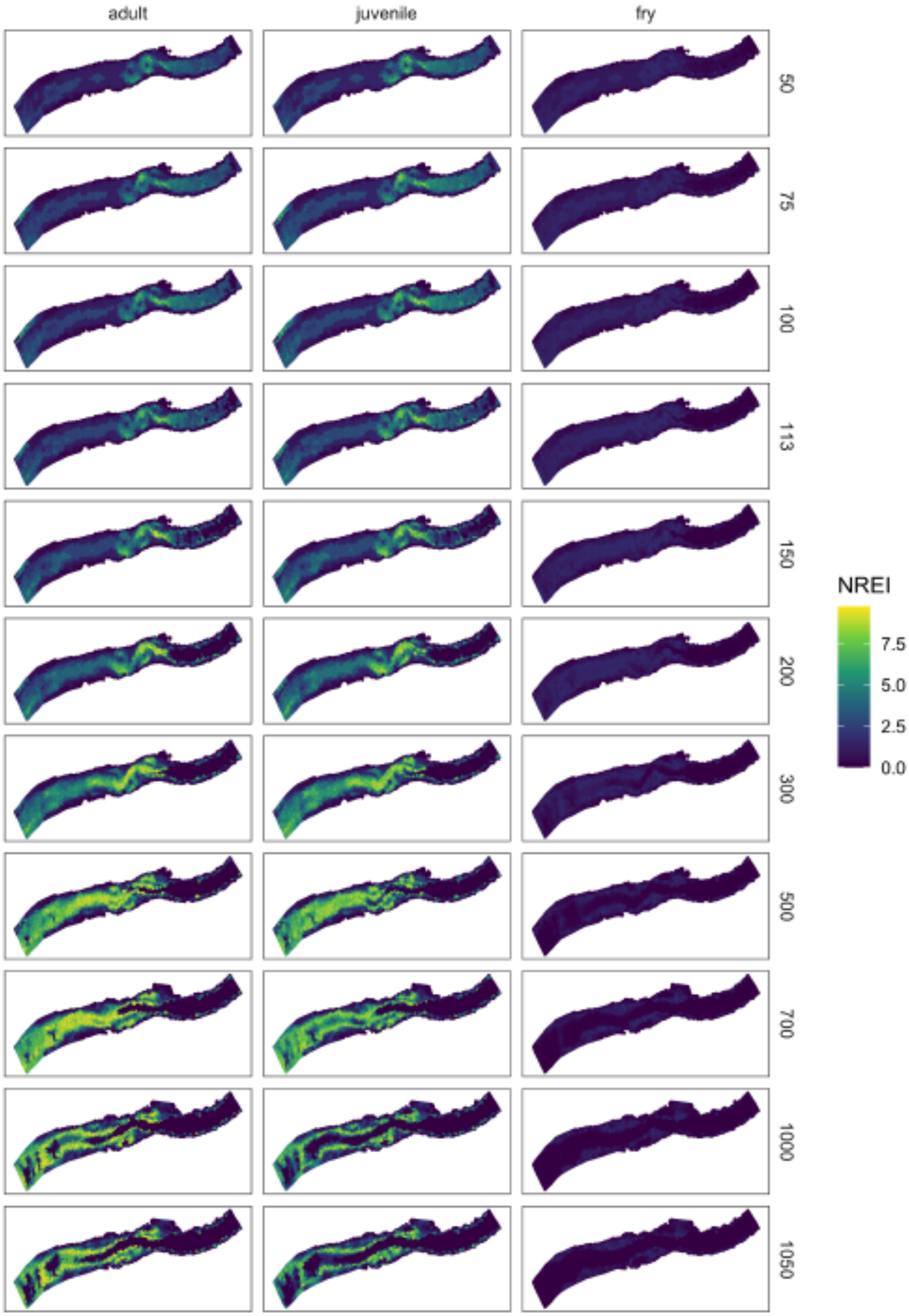


Figure 28. NREI surfaces at the Wolcott site on the Eagle River across flow states and trout class size.

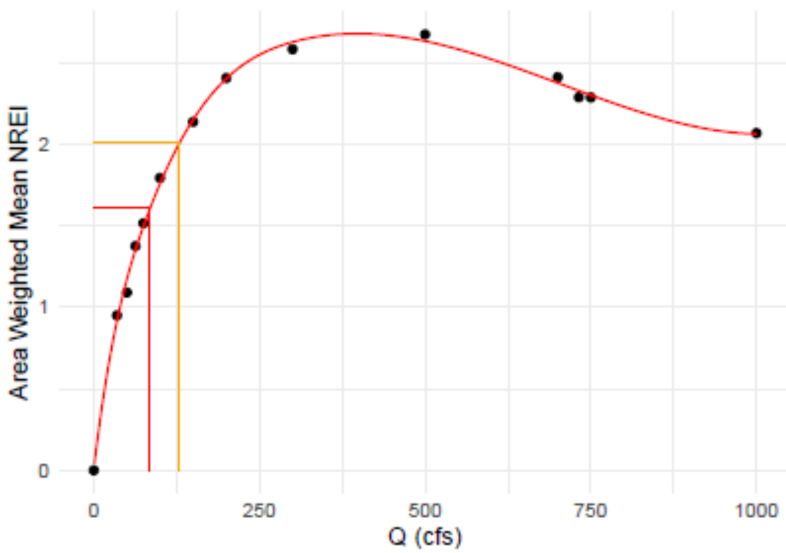


**Figure 29. Example of spline fit and streamflow threshold at the Avon site on the Eagle River for both the NREI threshold (orange line) and ISF (summer) threshold (red line).**

We also included a complementary approach to aquatic streamflow thresholds based on CWCB in-stream flow rights (ISF). The existing summer instream flow right was identified for each site. These flow thresholds are based on an analysis independent from the work here with an alternate set of aims and assumptions. ISF's are developed to establish a minimum flow level that prevents harm to aquatic life while recognizing water availability constraints within a watershed. We choose to use the summer ISF value rather than the winter value (the winter value is typically lower) because it is more reflective of the conditions used in the bioenergetic simulation. The two methods for identifying streamflow thresholds are complementary. The ISF method estimates a threshold of the minimum streamflow below which aquatic life might be at high risk while the NREI-derived threshold provides a threshold of the streamflow level below which optimal conditions no longer exist for maximizing the adult fish population. The NREI-derived streamflow threshold, therefore, is likely to be higher than the ISF streamflow threshold.

NREI curves depict biological relationships between habitat quality and streamflow. Following the lead of Hayes et al. (2007), two-dimensional NREI surfaces were used to approximate the carrying capacity for adult fish on each reach across the range of simulated flows. An assumed NREI threshold value greater than or equal to 1.0 was assumed necessary for an adult fish to reproduce annually. The 2-dimensional modeling space was searched for suitable conditions and approximate fish holding patterns were mapped. The resulting adult fish count was normalized to simulation reach length (fish per mile) and area (fish per acre) to ease inter-site comparisons.

The number of days streamflow was below the NREI and ISF streamflow thresholds was calculated annually at each site for the summer period (May to September) using the outputs for each water use and climate change scenario. The impacts associated with each scenario was explored by estimating the change in duration below the selected streamflow thresholds between a given scenario and the Current Conditions scenario. This relative metric provided an opportunity to identify risks from future streamflow regime changes on aquatic habitat (e.g., increasing duration below a streamflow threshold may signal increasing degradation of aquatic habitat availability and quality).

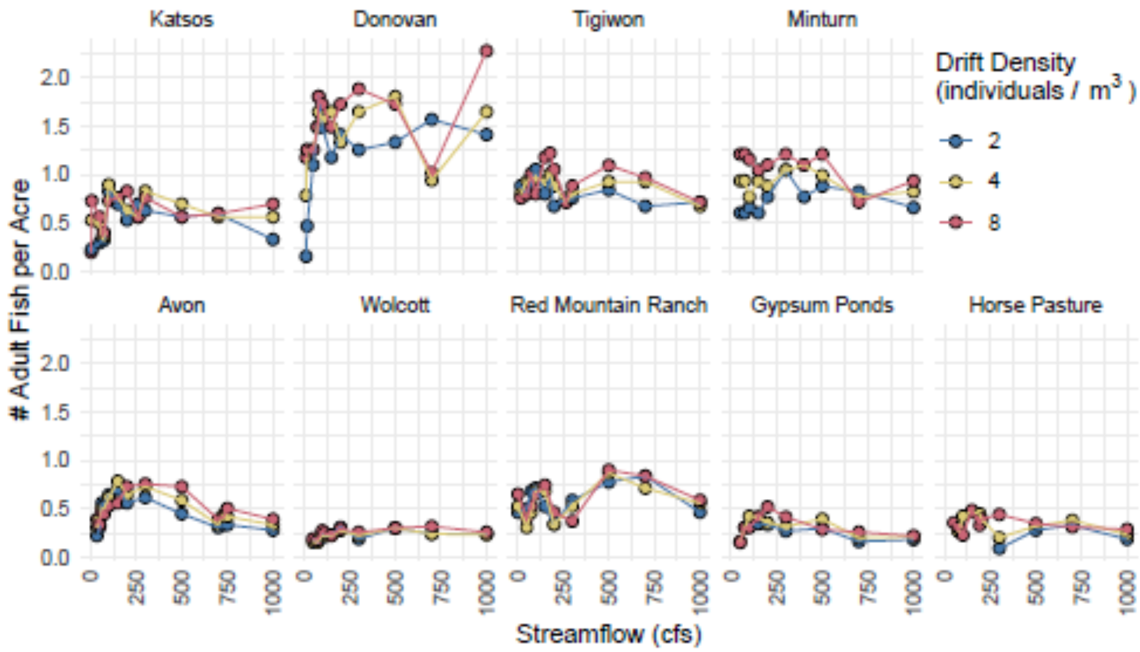


**Figure 30. Weighted average NREI across flow states and variable macroinvertebrate drift density concentrations for all sites.**

### 3.8.1 Key Findings

- Minimum streamflow thresholds (based on NREI) to support optimal trout habitat ranged from 52 to 323 cfs across all sites on the Eagle River and Gore Creek. Flow threshold values based on the NREI analysis are substantially higher than targets defined by summer ISF water rights.
- Sites on both Gore Creek and the Eagle River generally supported moderate to high carrying capacities for adult trout within optimal flow ranges.
- Increased water use projected under the Near Future and Demand Growth without climate change scenario predicted minimal impacts to the number of days aquatic habitat streamflow targets were below the threshold (Figure 32). Reservoir releases during low flows, as currently outlined under New Water Infrastructure scenario, are predicted to decrease the number of days with sub-optimal streamflow levels compared to baseline conditions on the Upper Eagle, and to a lesser degree on the Middle and Lower Eagle.

- Climate change is predicted to substantially increase the number of days streamflow is below the summer ISF thresholds on both Gore Creek and the Eagle River and increase the number of days with sub-optimal conditions for aquatic life on sites on the Eagle River. Reservoir releases during low flows, as currently outlined under New Water Infrastructure, are predicted to prevent increases in the number of days streamflow is below the ISF threshold. The operational strategy, however, under the New Water Infrastructure does not prevent substantial increases under climate change conditions in the number of days with sub-optimal conditions for aquatic life on the Middle and Lower Eagle.

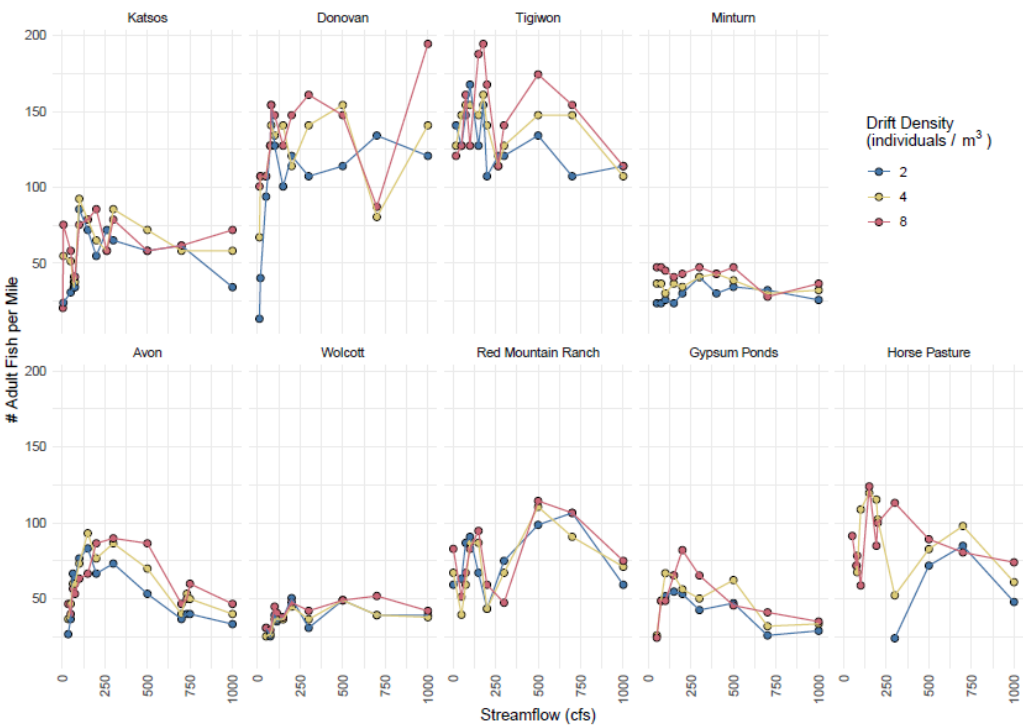


**Figure 31. Number of adult fish per mile across flow states for all sites and variable macroinvertebrate drift density concentrations.**

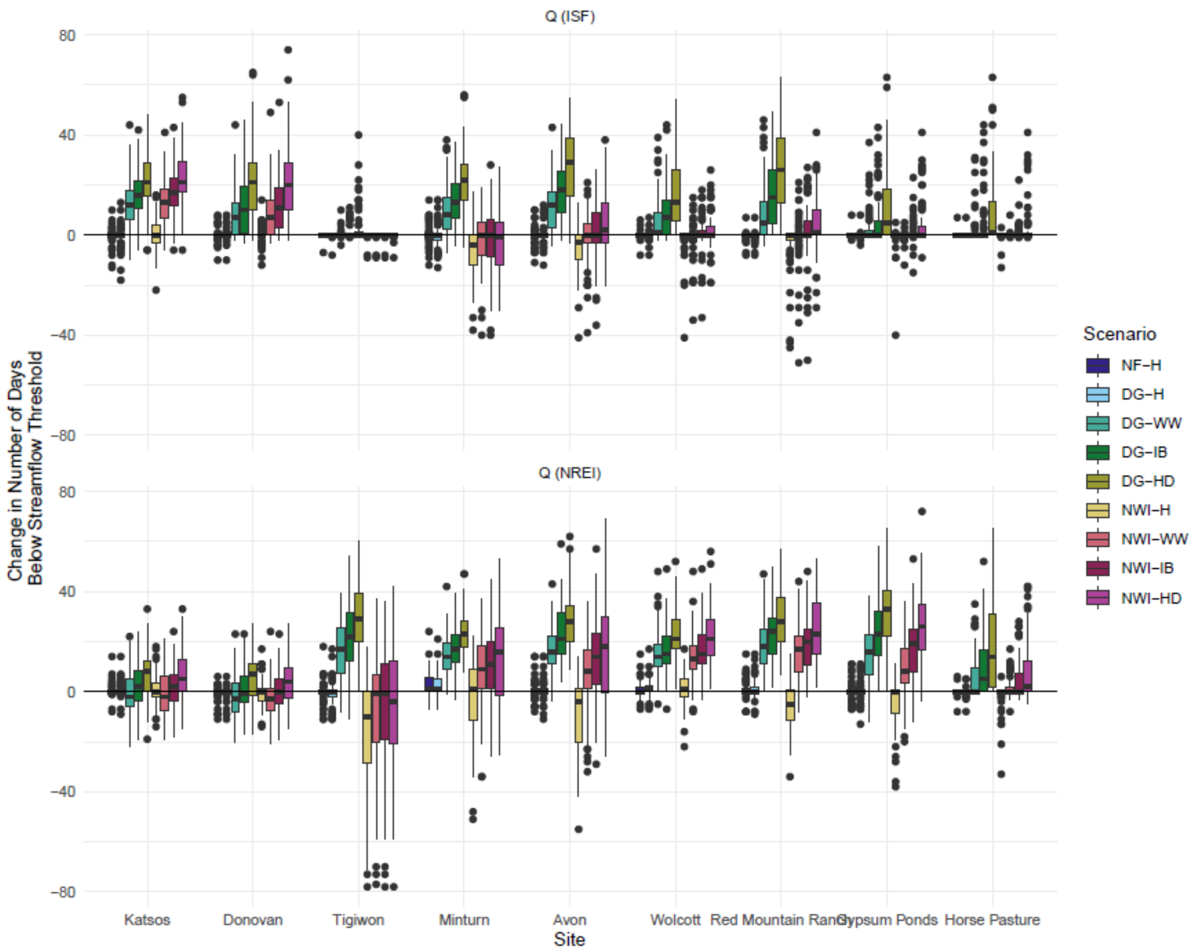


**Figure 32. Change from baseline in duration of days below NREI and ISF based streamflow thresholds for ERCWP scenarios across all simulation years. Values above zero indicate increasing numbers of days below the threshold. Only the summer period between May through September is included in the analysis.**

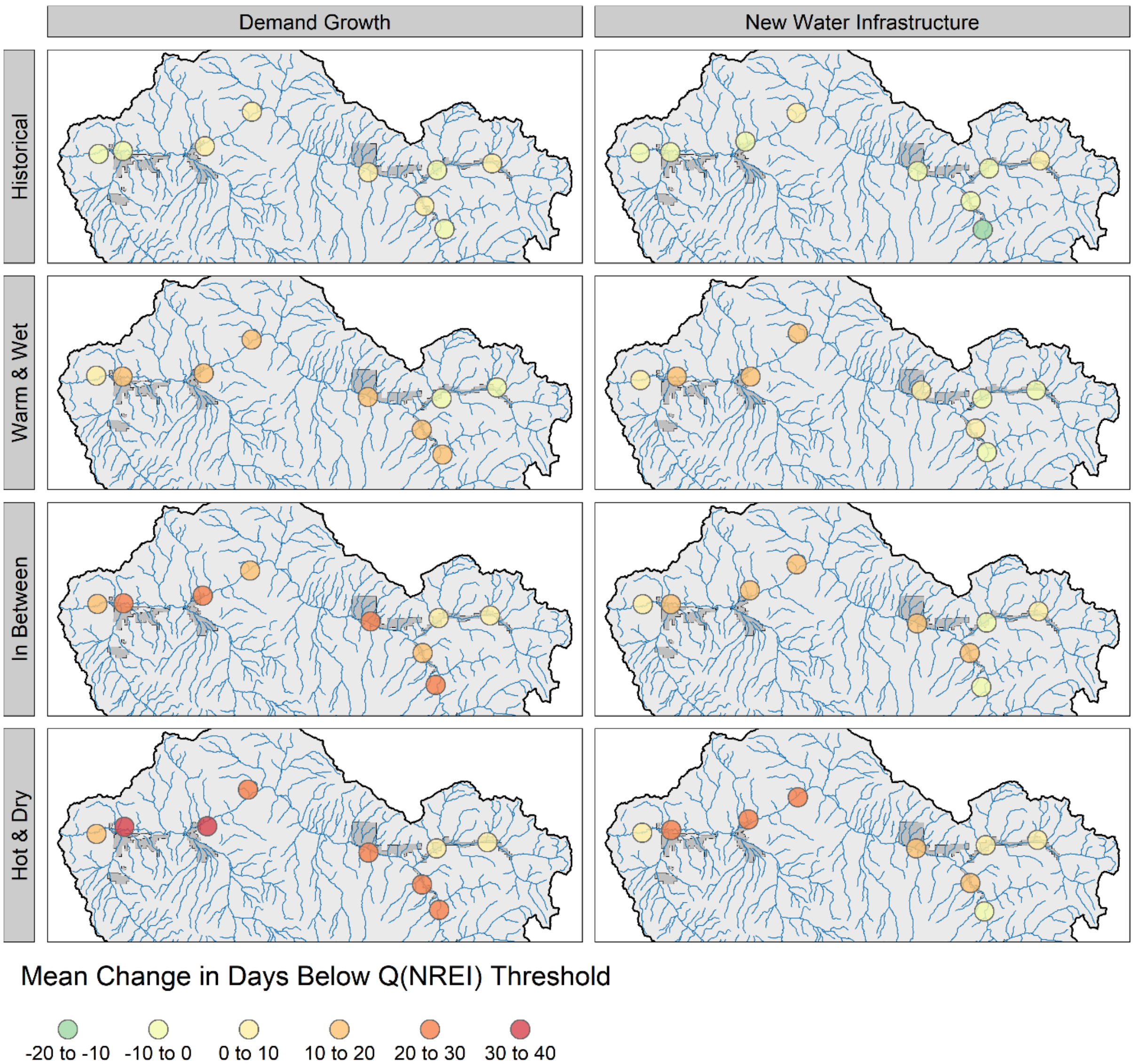


**Figure 33. Mean change in the number of days below the NREI threshold under various water use and climate change scenarios.**

## 3.9 Lateral Connectivity and Riparian Habitat

Riparian areas are dynamic ecosystems adjacent to streams and rivers that are molded by interactions between the river and surrounding landscape. Riparian areas provide critical habitat for aquatic and terrestrial organisms and help regulate vital river network ecosystem services, including flood attenuation, water quality, and sediment fluxes. Riparian zones can be confined to small areas near the river within narrow valley bottoms or extend laterally in unconfined valleys to form wide, extensive riparian habitat. The extent of riparian habitat in the Eagle River watershed is often limited by land uses, such as urban development, roads, reservoirs, and agriculture.

The health of riparian zones depends on lateral connectivity with the river. Lateral connectivity is defined as the surface and subsurface bi-directional exchanges of water between rivers and adjacent areas. Lateral connectivity supports a host of functions important for both riparian and riverine ecosystems. Surface lateral connectivity is particularly important because it maintains sufficient soil moisture for riparian vegetation during the growing season, promotes species diversity by creating zones of variable flood inundation, and generates conditions necessary for plant recruitment and establishment. Lateral connectivity likely contributes more to riparian soil moisture on reaches at lower elevations within the Eagle Watershed where precipitation is lower and hydrologic contributions from hillslopes decline. These lower elevation riparian zones are often more dependent on connectivity with the river corridor to maintain sufficient water availability for riparian plants.

Streamflow simulations predict that hydrologic regimes may change under future water use and climate scenarios. Changes in magnitude and timing of peak flows are likely to impact riparian zones by altering the frequency and spatial extent of overbank flooding that drives lateral surface connections. The impacts of changes to peak flows can be spatially variable and depend on the geomorphology of a particular reach. An assessment was performed to characterize spatiotemporal changes in surface lateral connectivity under various future streamflow simulations (Appendix J). Results intend to provide Eagle River stakeholders with improved understanding of potential future risks to riparian zones.

An assessment of lateral connectivity extent (LCE) was conducted by integrating HEC-RAS one-dimensional hydraulic modeling with the simulation outputs from the ER20 model. HEC-RAS model cross-sections were associated with nearby ER20 streamflow simulation nodes to extract flood frequency information for each ERCWP scenario. Flood frequency curves were calculated at each corresponding node for annual daily peak flow by fitting a Log Pearson Type 3 curve to the simulated annual peak flow record. Flood frequency curves were fit separately for each streamflow scenario. Discharge values were calculated using the fitted curve for flood recurrence intervals (RI) ranging from 1-50 years.

HEC-RAS model outputs were generated for seven discharge values that varied from low-flow conditions to flow levels that were estimated to reflect 500-year floods. Outputs were interpolated between flow states and used to predict cross-sectional inundation width for each discharge across the range of RIs. Inundated area was calculated as the product of the inundation width and the channel length that each cross section represented in the HEC-RAS model. Plots were generated to compare inundation area across a range of discharges for each hydrological scenario. Inundation width and inundation area included both the channel and inundated floodplains.

The inundated area at the 10-year recurrence interval was selected as the metric to evaluate changes in lateral connectivity extent. The 5- to 10-year recurrence intervals are considered good approximations for the spatial extent of riparian zones. They reflect the zone where surface lateral connectivity occurs frequently enough to promote riparian plant recruitment and where floodplain elevations are low enough relative to the riverbed elevation to support soil moisture for riparian species. Patterns of differences in inundation area for a given RI between hydrological scenarios are relatively insensitive to the choice of RI. Patterns in changes to LCE, therefore, described here with the 10-year RI reflect changes to lateral connectivity across a broader range of flood recurrence intervals.

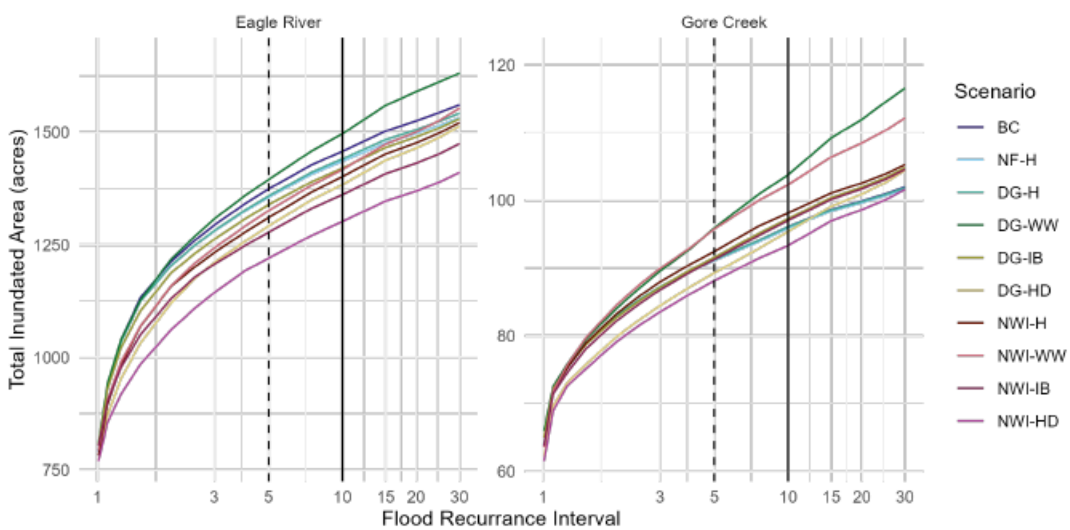


**Figure 34. Total inundated area by flood recurrence interval for Eagle River and Gore Creek by ERCWP scenario. Total inundation Area is the sum of inundated area at all cross-sections. Lines indicate the 5-year recurrence interval (dashed line) and 10-year recurrence interval (solid line), which reflect the commonly used range for delineating riparian zones. X-axis is on a log-scale.**

Lateral connectivity extent was compared between the Current Conditions scenario and other water use and climate change scenarios to identify the change in LCE from current conditions. The change in LCE was calculated in absolute terms (total acreage) and as a percent change in width for each modeled location. Model locations were binned by their degree of valley confinement to reflect differences in geomorphology and expected lateral connectivity behavior. Valley confinement was calculated as the ratio of the floodplain to the channel width. Sites were classified as confined with floodplain to the channel width ratios below 2, as moderately confined with ratios between 2 and 4, and as unconfined if ratios were above 4.

LCE and changes in LCE reflect quantification of a potential areal extent of riparian zones but may not reflect actual riparian area. Human impacts, such as development, agriculture, roads, levees, and drainage ditches, may alter floodplain areas and limit the development of riparian areas within the modeled 5- to 10-year floodplain extents. Results should, therefore, be considered in the context of floodplain land cover within the Eagle River watershed.

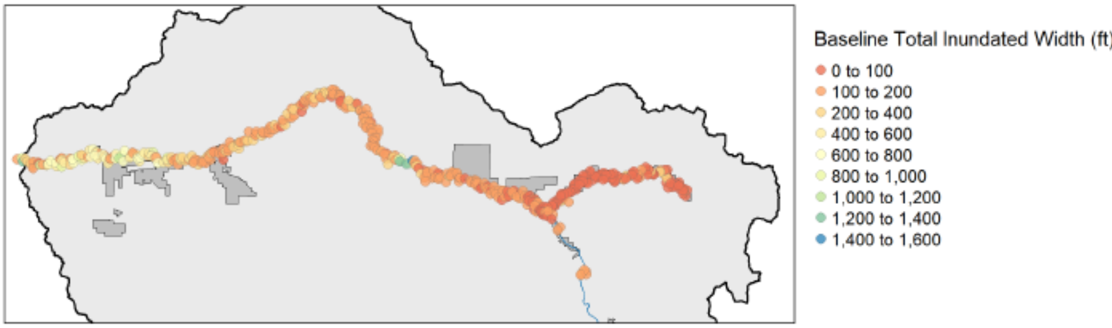


**Figure 35. Total inundation width (ft) at 10-year recurrence interval at HEC-RAS cross-section locations under Baseline scenario. Cross-sectional areas are represented by jittered points to improve result visualization.**

### 3.9.1 Key Findings

- Lateral connectivity extent varies widely across the study areas. Much of the upper portion of the Eagle River and Gore Creek have relatively small LCE. Pocket floodplains with LCE above 200 ft are interspersed along these reaches. Riparian areas with larger LCE are more common lower on the Eagle River (Figure 35).
- Declines to lateral connectivity are greatest in the lower watershed and in pocket floodplains higher in the watershed under scenarios with reduced peak flows (Figure 36).
- The greatest impacts are predicted under New Water Infrastructure with moderate to large declines across both historical and climate change futures and potential losses of inundation extent across the watershed of over 100 acres under hotter and drier climate futures (Figure 37). Declines to inundation extent are also projected under Demand Growth under hotter and drier climate futures while inundation extent may increase slightly under a wetter climate future.
- Areas with reduced LCE may experience decreases in riparian extent and/or health due to decreasing water availability and reduced plant recruitment and establishment success.

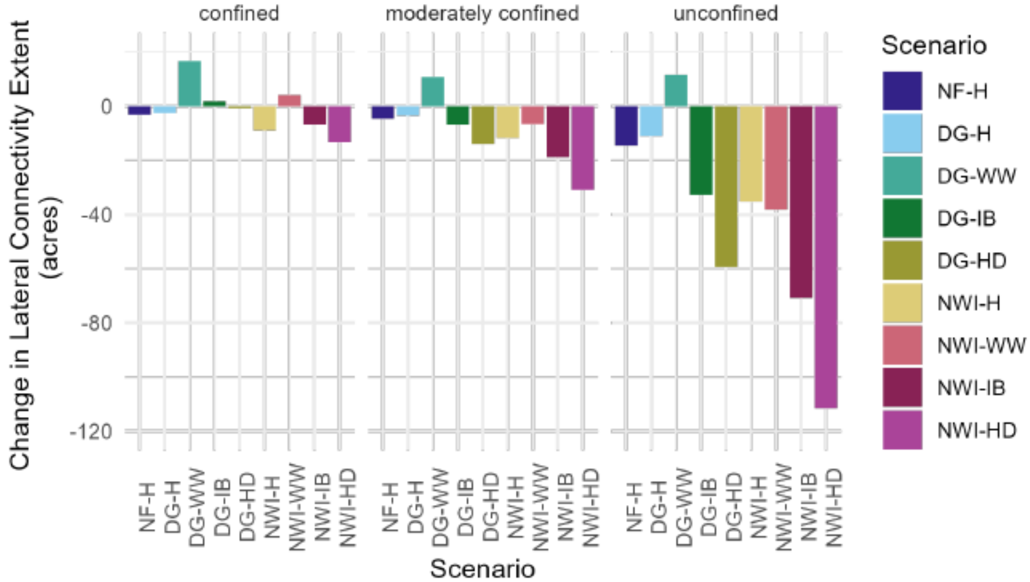


**Figure 36. Total change from baseline in LCE extent (acres) by confinement class for the Eagle River under ERCWP scenarios.**

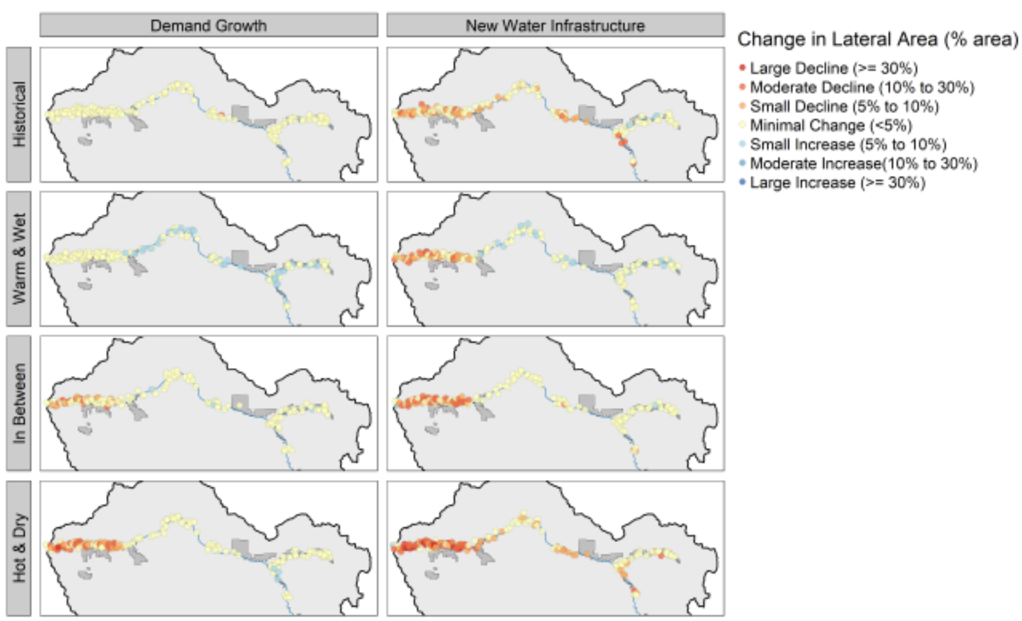


**Figure 37. Maps depicting percent change from Baseline in lateral connectivity extent under Demand Growth and New Water Infrastructure scenarios. Maps are faceted by water use and climate change scenarios. Only segments that are either moderately confined or unconfined are included in the map. Points are spatially jittered to improve visualization.**

## 3.10 Recreational Uses

A river recreation assessment was undertaken as part of the development of the ERCWP (Appendix K). This assessment entailed completing a boatable days assessment. The characterization of boatable days provides an objective, science-based measure of recreation opportunities related to variability in streamflow on reaches throughout the assessment area. This information aims to support conversations about how hydrologic conditions impact river recreation opportunities. This assessment considered recreational opportunities under historic conditions that match boatable days assessments conducted elsewhere in the region. The assessment was further extended to identify recreational impacts based on hydrological conditions under varying future water use and climate change scenarios.

River reaches considered in this assessment were identified collaboratively between American Whitewater and Lotic Hydrological staff. Six segments on Eagle River and two segments on Gore Creek were determined to have significant recreational values and were, therefore, included in the assessment (Table 3). Each segment was mapped to an existing United State Geological Society (USGS) streamflow gauging station. Mapping streamflow gauge locations to each assessment reach considered: 1) the historical period of record (POR) for streamflow observations; 2) the distance between the gauge and river segment; and 3) the gauge most used by recreationalists to inform their use of the segment. A single stream gauge was used to represent flows for adjoining river segments in multiple locations.

**Table 3. River segments and corresponding streamflow measurement gauges considered in this study.**

| Reach | River | Reach Description | USGS Gauge ID & Simulation Node ID | USGS Gage Description | Historic Period of Record |
|---|---|---|---|---|---|
| 1 | Eagle River | Tigiwon to Dowd Junction | 09064600 | Eagle River near Minturn | 1989-2020 |
| 2 | Eagle River | Dowd Junction | 09067020 | Eagle River below Wastewater Treatment Plant | 1999-2020 |
| 3 | Eagle River | River Run to Edwards | 09067020 | Eagle River below Wastewater Treatment Plant | 1999-2020 |
| 4 | Eagle River | Edwards to Eagle | 394220106431500 | Eagle River below Milk Creek near Wolcott | 2006-2020 |
| 5 | Eagle River | Eagle to Gypsum | 09070000 | Eagle River below Gypsum | 1989-2020 |
| 6 | Eagle River | Gypsum to Colorado River | 09070000 | Eagle River below Gypsum | 1989-2020 |
| 7 | Gore Creek | East Vail to Vail Center | 09066510 | Gore Creek at Mouth near Minturn | 1995-2020 |
| 8 | Gore Creek | Vail Center to Eagle River | 09066510 | Gore Creek at Mouth near Minturn | 1995-2020 |

User streamflow preferences were determined via distribution of a web-based survey. The stated flow preferences for different recreational activities were the basis for computation of boatable days. The computation of boatable days is the dominant quantitative approach used by American Whitewater to characterize recreational use opportunities on rivers (Fey and Stafford, 2009; Shelby and Whittaker, 1995; Whittaker et al., 1993). The metric itself reflects the number of days each year that fall within certain defined flow ranges (i.e., lower acceptable flows, optimal flows, and upper acceptable flows). The boatable days analysis performed on reaches within the assessment area responded to the inter-annual natural and management-induced variability in streamflow by computing the number of boatable days that occur in each of four hydrological year types: wet-year, wet-typical-year, dry-typical-year, and dry-year.

**Table 4. Flow preference thresholds delineated for whitewater activities on each reach in the assessment area. All values are reported in cubic feet per second (cfs).**

| Reach | River | Reach Description | Min. Acceptable | Min. Optimal | Max. Optimal | Max. Acceptable |
|---|---|---|---|---|---|---|
| 1 | Eagle River | Tigiwon to Dowd Junction | 400 | 600 | 1200 | 1500 |
| 2 | Eagle River | Dowd Junction | 650 | 1000 | 2700 | 4000 |
| 3 | Eagle River | River Run to Edwards | 900 | 1350 | 3500 | 4000 |
| 4 | Eagle River | Edwards to Eagle | 900 | 1400 | 3800 | 5000 |
| 5 | Eagle River | Eagle to Gypsum | 800 | 1300 | 3600 | 5000 |
| 6 | Eagle River | Gypsum to Colorado River | 900 | 1400 | 3400 | 4750 |
| 7 | Gore Creek | East Vail to Vail Center | 400 | 650 | 1350 | 1500 |
| 8 | Gore Creek | Vail Center to Eagle River | 350 | 600 | 1200 | 1500 |



Representative streamflow time series for each of the year types on each reach required synthesis of historical USGS streamflow data. Daily streamflow data was collected from stream gauges throughout the assessment area for a 30-year period (1990 – 2020). Several USGS gauges were not operational for the full period and have shorter streamflow records, including USGS gauges: #09067020 (1999 – 2020), #09066510 (1995-2020) and #39422010643150 (2006-2020). ). Streamflow time series data from each gauge was ordered by annual peak flow. Average daily streamflow across all years in the lower 25th percentile of the ordered list were computed to produce a representative dry year streamflow time series. The same approach was used to create representative streamflow series for dry typical years, wet typical years and wet years where dry typical years fell between the 25th and 50th percentiles of annual peak flows, dry wet years fell between the 50th and 75th percentiles of annual peak flows, and wet year types were those years above the 75th percentile of the ordered list.

**Table 5. Flow preference thresholds delineated for float fishing activities on each reach in the assessment area where float fishing was popular. All values are reported in cubic feet per second (cfs).**

| Reach | River | Reach Description | Min. Acceptable | Min. Optimal | Max. Optimal | Max Acceptable |
|---|---|---|---|---|---|---|
| 3 | Eagle River | River Run to Edwards | 650 | 800 | 1350 | 1750 |
| 4 | Eagle River | Edwards to Eagle | 525 | 750 | 1250 | 1900 |
| 5 | Eagle River | Eagle to Gypsum | 550 | 800 | 1400 | 2400 |
| 6 | Eagle River | Gypsum to Colorado River | 600 | 900 | 1800 | 2700 |

**Table 6. Flow preference thresholds delineated for wade/bank fishing activities on each reach in the assessment area where fishing was popular. All values are reported in cubic feet per second (cfs).**

| Reach | River | Reach Description | Min. Acceptable | Min. Optimal | Max. Optimal | Max Acceptable |
|---|---|---|---|---|---|---|
| 3 | Eagle River | River Run to Edwards | 50 | 200 | 600 | 900 |
| 4 | Eagle River | Edwards to Eagle | 50 | 100 | 600 | 925 |
| 5 | Eagle River | Eagle to Gypsum | 100 | 200 | 650 | 1250 |
| 6 | Eagle River | Gypsum to Colorado River | 100 | 200 | 650 | 1500 |



Boatable days in each flow preference category ranges (i.e., lower acceptable flows, optimal flows, and upper acceptable flows) were calculated at each reach for each year type hydrograph. Boatable days were evaluated at both yearly and monthly timesteps. Boatable days were only analyzed for whitewater and float fishing using historic streamflow records.

The boatable days analysis of hydrological simulation results followed a similar approach with several small but key differences. Boatable days were calculated in each flow preference category ranges (i.e., lower acceptable flows, optimal flows, and upper acceptable flows) at simulation nodes from the ER20 model representing locations of USGS Gauges used in the historic analysis

### 3.10.1 Key Findings

- Recreational impacts under simulated water use and climate scenarios were found to diverge both by activity, by different scenarios and by location in the basin. Whitewater opportunities were found to depend on durations of high to intermediate streamflow.
- Reductions to peak flows on the Eagle River were the largest driver of changes to whitewater activities based on the ERCWP scenarios. These impacts were most strongly observed under the New Water Infrastructure scenario and in recreational segments on the Upper Eagle River with more moderate impacts lower on the Eagle River and minimal impacts on Gore Creek.
- Float fishing opportunities depend on the duration intermediate streamflow. Float fishing opportunities are more strongly impacted by the interactions between year type and predicted wetness under climate change. For example, under the Warm & Wet climate scenario, there may increases in float fishing opportunities while under the Hot & Dry scenario, opportunities were observed to be more likely to decrease. wade/bank fishing opportunities depend on durations of non-peak flow periods. wade/bank opportunities were most impacted under scenarios where very low flows become more common such as under a Hot & Dry climate scenario. Under these conditions, we observed a shift from optimal days to lower acceptable days but did not necessarily observe large changes in total days.
- Climate change is predicted to strongly alter the timing of recreational opportunities for all activities. Shifts to earlier peak flows in the spring and earlier streamflow recessions in the summer will change when opportunities exist for each activity. In general, both whitewater and float fishing opportunities will shift earlier in the year. Wade/bank fishing will have fewer opportunities in the spring but more opportunities in the summer. Such timing changes could have important implications for users and for recreation-based economies in the Eagle River basin.

# 4 Values at risk

Water resources are highly valued by the local community. Streams and rivers provide municipal water supply, enhance natural beauty of the landscape, support the local tourism economy and provide numerous cultural, social and intrinsic functions. The ERCWP seeks to identify how these values may be at risk in a changing and uncertain world. A shared understanding of system behavior is a crucial foundation for conversations regarding the potential impact of alternative water management approaches on ecosystem function or recreational use opportunity. The technical information discussed in the sections above intends to support the development of that shared understanding.

Understanding how to weigh the relative importance of the numerous values at risk can be a difficult exercise for both the public and water managers. A useful framework is to consider risks through the lens of 'how likely is this event or outcome to occur?' and 'how impactful will it be if it does?' Values at risk can then be differentiated by the likelihood of a negative impact on a value or issue of concern, and the severity of the consequence associated with that impact. Dividing the risk space into four quadrants yields risk ratings and treatment pathways where:

> **Risk Rating 1** *High priority.* Rating 1 corresponds to impacts that are both likely and are expected to produce significant negative consequences. These high-priority risks require sufficient allocation of resources and proactive treatment to reduce likelihood and/or the consequences associated with an event.
>
> **Risk Rating 2** *Medium priority.* Rating 2 corresponds to impacts that are likely but are expected to be manageable and/or not produce significant negative consequences. These medium-priority risks should be managed strategically over the long-term.
>
> **Risk Rating 3** *Medium priority.* Rating 3 corresponds to impacts that are rare or difficult to plan for but are expected to produce significant negative consequences if/when they do occur. These medium-priority risks compel additional investigation into the event triggers and response pathways in order to be better prepared for reactive management of an event.
>
> **Risk Rating 4** *Low priority*. Rating 4 corresponds to impacts that occur regularly but are of relatively minor consequence to the issue or value of interest. These low-priority risks entail periodic monitoring or assessment of conditions to alter stakeholders to changing event likelihood or consequence severity.

Potential future risks to the values derived from local streams and rivers were explored and identified through a process of stakeholder elicitation and workshops. Community workshop activities included causal chain diagramming, small group discussion, and multi-voting. Outcomes of these stakeholder processes were reviewed and summarized into two categories:

- Environmental and Recreational Uses
- Consumptive and Municipal Uses

The relatively high ranking of environment and recreation water uses by community members, coupled with the relative surplus of existing planning activity and information conducted in other venues for municipal and agricultural water uses, provides a rational basis for focusing on these uses in future decision-making processes regarding water resource use and development.

## 4.1 Key Risks for Environmental and Recreational Uses

The sections below present the primary environmental and recreational values at risk identified by local stakeholders following a review of the technical information provided above. Not all values at risk identified by community members correspond to a particular analysis completed under the ERCWP and may indicate need or opportunity for further investigation.

### 4.1.1 Risk Rating 1

**Risk:** Increases to in-basin municipal diversions of surface water due to the combined effects of climate change and population growth may alter patterns of streamflow in a manner that negatively impacts **riverine ecosystems** along the Eagle River below Cross Creek, Gore Creek, Brush Creek and Gypsum Creek (Appendix J). Predicted changes in streamflow patterns under Demand Growth without climate change are generally minimal to small except for on Gore Creek where moderate declines are predicted during low flow periods along reaches near Vail. Gore Creek has already experienced recent trends toward lower late summer/fall streamflows (Appendix C) and low flows also already appear to be substantially altered from natural conditions (Appendix D). Elsewhere in the basin, suggesting forecasted increases in municipal diversions alone will likely not have large broad impacts on streamflow and riverine ecosystems. However, throughout the basin, these diversions may exacerbate streamflow deficits in low-flow conditions under climate-change, especially under hotter and drier climate futures.

**Risk:** Instream flow water right deficits, indicative of constrained **aquatic habitat quality**, are limited in most areas of the watershed but are more prevalent in upper reaches of Gore Creek and on the Eagle River near Avon (Appendices E). Instream flow water rights are developed to maintain minimum flow targets necessary for aquatic life. Persistent streamflow below these environmental targets can have negative outcomes for fish and macroinvertebrate communities. Streamflow deficits are currently most common in dry years with low snowpack and early snowmelt but are also influenced by current water use and diversions patterns. The duration and magnitude of deficits may become more severe on the mainstem Eagle River and on Gore Creek near Vail, especially during dry years, due to growing water demands and a changing climate. Deficits are predicted to be most severe under hotter and drier climate futures but increased deficits occur even under wetter climate futures, likely due to earlier snowmelt. Reservoir storage and releases as operationalized under New Water Infrastructure may help reduce the frequency and duration of deficits even under more severe climate change if reservoir operations are designed and actively managed for this outcome.

**Risk:** Elevated summer and fall water temperatures driven by changes in water use and climate lead to more **fishing closures** and reduced **fishery quality**; the largest impacts are expected below Edwards (Appendix F). Increasing stream temperatures can create sub-lethal or lethal conditions that degrade fishery health. Fishing closures are mandated to protect fisheries when conditions reach critical levels. Summer and fall stream temperatures are predicted to increase from 2-5 °C under future climate change with the largest increases under hotter and drier climate futures. Mean daily stream temperatures on most reaches are predicted to stay below sub-lethal temperature thresholds for rainbow and brown trout. However, stream temperature increases may still lead to increased durations and severity of periods with high temperature stress for rainbow trout. Such periods of high temperature stress may lead to fishing closures and/or long-term declines in fishery quality. Reservoir releases during low-flow periods may be able to slightly reduce high stream temperatures on the Eagle River during low-flow years but are unlikely to substantially reduce overall patterns of stream temperature increases driven by higher air temperatures.

**Risk:** Altered streamflow on the Eagle River due to changes in water use and climate may reduce the frequency and duration of suitable conditions for a variety of **whitewater boating activities** and shift a greater number of those suitable conditions to the early spring period (Appendix K). Whitewater boating activities including rafting and kayaking are popular along a number of reaches on both the Eagle River and Gore Creek and rely on moderate to high flow for optimal conditions. Optimal conditions were historically most common in May and June. New reservoir development/storage and subsequent reductions to peak flows (Appendix D) will likely lead to reduced and less optimal whitewater boating opportunities on the Eagle River, especially on the reaches above Edwards. Climate change will result in a shift towards more whitewater boating opportunities earlier in the season and fewer opportunities in the later summer across all reaches on both the Eagle River and Gore Creek. Climate change may also cause moderate reductions in whitewater boating opportunities under hotter and drier climate futures on all reaches.

**Risk:** Development in floodplains and placement of infrastructure within the river corridor degrades the aesthetic quality of the landscape and the **health of riparian forests**, particularly on Gore Creek.[7] Similar urban encroachment has occurred or may continue to occur in Avon and Edwards, although geomorphic characteristics of the river limit development to some extent in these areas. High potential for future degradation exists along the Eagle River between Wolcott and Gypsum and along the lower reaches of Brush Creek and Gypsum Creek where low-density rural residential or agricultural lands are currently being replaced by newer residential and urban development. Near-stream development, with its attendant alteration or removal of riparian vegetation and associated pollutant fluxes via stormwater runoff, contributes to water quality degradation and aquatic macroinvertebrate impairment, placing streams at regulatory risk for Clean Water Act standards violations.

**Risk:** Warming winter air temperatures may lead to an inability for local ski resorts to make snow in the early winter months, which may reduce the total available **skier days**. Ski area opening dates have trended continuously earlier in the recent decade, in an apparent desire to lengthen revenue generating seasons and improve shoulder season business cycles at resorts and resort-dependent service and retail communities. Earlier opening dates may lead to increased diversion water demand during low fall baseflows. Moving the beginning of snowmaking earlier in the season

[7] Leonard Rice Engineers. 2013. Gore Creek Water Quality Improvement Plan. Prepared for the Eagle River Urban Runoff Group.

means operations may face difficulties with moderate temperatures too warm for snowmaking.[8] Warmer air temperatures combined with unreliable ground freezes in the fall may also increase early melt, meaning that retention of snow made in early periods is poorer. Efficiency ratios of successfully converting diverted water to season-long usable snow during early periods are thus likely to be much less than for snow made later in the season, further raising operational costs and requiring larger total stream diversions.[9]

**Risk:** Warming climate and shifting precipitation patterns may mean that snowmaking is required for a longer period in any given year; increasing the duration of the impact of snowmaking activities on **streamflows and aquatic habitat**, particularly in Gore Creek. Snowmaking is a primary climate adaptation in the ski industry; the desire for resorts to open earlier each season combined with the trend of non-freezing, warmer weather extending later each fall amplifies both the need for snowmaking and the resultant impacts on water resources. The main period of snowmaking on Vail Mountain from late October to January each season requires that water be drawn from Gore Creek during some of the lowest seasonal instream flow periods. Gore Creek withdrawals occur downstream of Lionshead near ERWSD's WWTP discharge location. Augmentation water is supplied from Green Mountain Reservoir to the Colorado River mainstem, without direct benefit to Gore Creek or Eagle River flows.[10] However, transactional agreements between Vail Resorts and ERWSD may optionally utilize Black Lakes releases or other local methods to cover downstream water users and ensure flows below the intake still achieve minimum targets tied to Gore Creek instream flows and ERWSD's wastewater plant discharge permit. Even with augmentation plans, water extraction during very low flow periods that frequently depletes the creek to just above the instream flow target is a potential source of increased stress on aquatic life communities. With extended snow making seasons, impacts to Gore Creek and Eagle River will occur earlier in the year and for long periods of time each year.

### 4.1.2 Risk Rating 2

**Risk:** Increases to transmountain diversions due to increasing water demand on the Front Range may alter **patterns of streamflow** in a manner that negatively impacts riverine ecosystems on the Eagle River (Appendices C, D, E, G, H). Transmountain diversions in the near-term are assumed to increase due to full-utilization of existing decreed water rights and collection infrastructure of the Homestake Project. Streamflow impacts from such near-term changes are likely to be confined to the Upper Eagle. Larger increases in transmountain diversion yields will occur if proposed reservoir construction moves forward to meet yield objectives defined by the Eagle River Memorandum of Understanding. Moderate to large reductions to streamflow total volumes and peak flows are predicted under the development of this new water infrastructure on the Upper

[8] Steiger, R and Mayer, M. 2008. Snowmaking and climate change. Mountain research and development, 28(3), pp. 292-298.,

[9] Ibid.

[10] Vail Resorts and SE Group. 2007. Vail Master Development Plan Update to White River National Forest

Eagle (above Gore Creek) with relatively small to moderate reductions on the Middle and Lower Eagle respectively. These reductions are predicted to be proportionally largest in the wettest years but are predicted to occur in most years except for the driest years. Reductions in the frequency and magnitude of peak flows may negatively impact multiple aspects of riverine ecosystems on the Eagle River including: reducing recurrence intervals of flows that mobilize bed sediment and maintain channel forms (Appendix H), decreasing the inundation extent of riparian habitat (Appendix J) and increasing risk of high heavy metal concentrations below the Eagle Mine (Appendix G).

**Risk:** Out-of-basin augmentation of local municipal water use fails to **mitigate impacts of that use on local ecosystems**. Many water users in the Eagle Watershed divert streamflows with junior water rights that require augmentation plans to prevent injury to senior downstream users in the Colorado basin during out-of-priority diversion periods. Many of the senior water rights able to call-out junior Eagle River water rights are on the mainstem Colorado, west of Glenwood Springs. While some augmentation plans in the Eagle basin are satisfied via releases from in-basin reservoirs like Eagle Park or Black Lakes, many other augmentation plans are serviced from reservoirs on the Colorado River system like Green Mountain Reservoir in Summit County. Releases on the Colorado system to augment out-of-priority diversion on the Eagle Mainstem do not benefit Eagle River streamflows for aquatic life or recreation. Since reservoirs like Green Mountain still tend to have more available water remaining for purchase or lease, future augmentation plans in the Eagle basin are likely to utilize these storage pools, further exacerbating effects on the Eagle River.

**Risk:** Warm stream temperatures coupled with increased durations of streamflow below optimal levels for adult trout habitat may degrade the **health of the cold-water fishery** in the middle and lower watershed under climate change. Increasing stream temperatures can create sub-lethal or lethal conditions that degrade fishery health. Summer and fall stream temperatures are predicted to increase from 2-4 °C under future climate change on the Middle and Lower Eagle River (Appendix F). These reaches generally have the highest current summer and fall stream temperatures in the basin. If stream temperatures increases are closer to the higher end of this predicted range, as expected under hotter and drier climate futures, there will likely be increasing acute and/or chronic high stream temperatures that degrade the health of cold-water species. Effects on fisheries may be exacerbated by lower summer and fall streamflow levels that reduce habitat quality and carrying capacities for adult fish (Appendix I). On the Middle and Lower Eagle, such effects are predicted under climate change scenarios regardless of water use scenarios. Reservoir releases under New Water Infrastructure are not predicted to mitigate the loss of optimal streamflow conditions. It should be noted that there is additional uncertainty for future stream temperature conditions on the Lower Eagle because there is currently a lack of long-term stream temperature measurements that limit modeling on the reach.

**Risk:** Sedimentation impacts from large wildfires may produce acute **fish-kill or macroinvertebrate loss events**. Post fire, downstream aquatic habitat conditions may be degraded from sedimentation and turbidity events, requiring several years to recover. Impacts may occur broadly across the watershed. Impacts from sedimentation on downstream aquatic habitat may be further exacerbated by less frequent 'flushing flows' that mobilize bed sediment, as is predicted under New Water Infrastructure development and under Hotter and Drier climate futures (Appendix H).

**Risk:** Continued water quality impacts from Eagle Mine may impact **fishery structure and health** on the Eagle River near Minturn (Appendix G). Combined effects of climate change and upstream water development may exacerbate water quality impacts from Eagle Mine on the fishery near Minturn. Water quality and aquatic health below the Eagle Mine are currently impacted by dissolved heavy metal loading to the river from historic mining infrastructure and waste. Heavy metal concentrations for constituents of concern to aquatic life are highest during the early spring when loading from mine sites initiates prior to the initiation of the rising limb of the Eagle River. High heavy metal loading to the river continues into the later spring and early summer but is less impactful to aquatic life during this period due to dilution by elevated Eagle River streamflow.

Changes to streamflow patterns under future water uses may create the potential for increased concentrations of some metals later in the spring due to shifts in streamflow magnitude and timing. Risks are highest under the new water infrastructure scenario under which streamflow is diminished during spring/summertime high flow. Significant uncertainty remains regarding the role of changing snowmelt dynamics on metals loading under climate change with more study needed to better understand the relationships between climate, snowmelt, metal loading, and streamwater concentrations. Managing the risk may require further mitigating metal loading sources and/or ensuring late winter/early spring streamflows are sufficient to dilute metal loads so that streamwater concentrations are acceptable enough to support desired aquatic life communities.

**Risk:** Climate change and future municipal and agricultural water demands may deplete streamflows on Gypsum Creek, disconnecting **headwater segments** from the mainstem Eagle River (Appendix C). Existing water use patterns have reduced streamflow substantially from natural conditions on lower Gypsum Creek, creating existing moderate-to-high risks for fish and riparian health. Streamflow predictions on Gypsum Creek indicate substantial additional reductions in streamflow metrics under climate change. Of particular concern, streamflow predictions indicate that streamflow below some diversions may be reduced to near zero flow in the late summer under climate change, eliminating usable habitat and disconnecting movement routes and tributary access from the mainstem. Anywhere from 20% to over 50% of years could experience a near zero flow period with an increasing likelihood under a hotter and drier climate future. Operational changes as predicted under the new water infrastructure scenario somewhat decrease but don't eliminate the likelihood of such near zero flow conditions.

**Risk:** Traction sand and road salts sourced from the I-70 corridor over Vail Pass may impact **aquatic habitat quality** on Gore Creek. Road expansion on West Vail Pass will increase impervious surfaces in the highway corridor by ~30%, requiring a proportional increase in traction sand and liquid deicer applications. Although new construction will offer opportunities for new sediment control BMPs, the potential for both increased sedimentation and salinity impacts downstream in Gore Creek continues or increases in the future.

**Risk:** Native **cutthroat trout populations** that exist in small tributary streams at high elevations may be at risk for fire, hybridization with non-native species, or future fragmentation of habitat due to infrastructure development. Cutthroat trout in the Eagle River basin exist in a diminished capacity, with competition from non-native sport fish like brook, brown, and rainbow trout a major driver of habitat fragmentation and retreat. Stream network connectivity and habitat range has also been degraded from road networks and other legacy land management activities (forestry, livestock range use, etc.) Continued loss of range to non-native species and total population loss in isolated tributaries from stochastic events like fire-associated debris flows may place further extirpation pressure on local populations.

**Risk:** Ongoing agricultural activities and suburban development on select parcels in the river corridor near Edwards and between Eagle and Gypsum suppress **recovery of riparian forests**. Legacy livestock practices in West Slope Colorado communities frequently included leveling of floodplain wetlands and partial removal or total elimination of woody shrub riparian vegetation. In locations where these pressures have been removed, many riparian communities have either partly or fully recovered, with attendant gains in stream channel geomorphic stability, wildlife habitat, and water quality buffering. Small portions of Eagle River in Edwards and significant stream reaches west of Red Canyon in the Eagle and Gypsum areas still face negative pressure from livestock activity, and in some cases, increasing suburban development.

**Risk:** Recovery trajectories for **recently burned** areas of **riparian forest** are uncertain along the Eagle River near Gypsum; ongoing climate change, water use and development pressures may limit natural recovery potential. The recovery trajectory of the burned cottonwood forest west of Gypsum may also be impacted by changes to streamflow under future climate change and water use, which may reduce the frequency of lateral surface connectivity and decrease soil moisture. Such changes may reduce the recruitment and establishment success of native riparian species (Appendix J).

**Risk:** Development in floodplains and placement of infrastructure within the river corridor fragments critical **terrestrial wildlife habitats** on streams and rivers throughout the watershed.The majority of suburban, urban, and transportation development in the Eagle Basin has occurred in valley bottoms and wider, flat floodplain terraces. This pattern disconnected terrestrial and aquatic-dependent wildlife movement corridors both longitudinally (up and down the valley) and laterally (across the valley).  In many locations the thin riparian corridor provides the only remaining longitudinal movement corridor available.  Further loss of riparian and floodplain corridors will continue to exacerbate wildlife impacts.

**Risk:** Altered streamflow on the Eagle River below Edwards due to changes in water use and climate may reduce the frequency and duration of **suitable conditions for float fishing** and shift a greater number of those suitable conditions to the late winter/early spring period (Appendix K). Float fishing activities are popular along the middle and lower Eagle River and rely on intermediate streamflow flow for optimal conditions. Optimal conditions were historically most common from May through July. Increased water demands and new reservoir development/storage and subsequent reductions in durations of moderately high flows will likely lead to small reductions in float fishing opportunities in some years. Climate change will result in a shift towards more float fishing opportunities earlier in the spring season, changes in the timing of peak flows when flows are above acceptable limits for float fishing, and fewer opportunities in the later summer. Climate change may also cause reductions in float fishing boating opportunities under hotter and drier climate futures but may actually slightly increase float fishing opportunities in more average and wetter years under a warm and wet climate future.

**Risk:** Increasing likelihood of fishing closures on some stream/river reaches in the region may increase angling pressures on other reaches, degrading the **fishing experience** and the quality of the fishery on those reaches. The increased likelihood of stream temperature exceedances of standards (Appendix F) and/or increased periods of low-flow (Appendix E) under climate change and future water use may increase the likelihood of fishing closures and alter angling pressures across the basin. An example of typical impacts is to shift angling use during times of temperature concerns on the lower Eagle to river reaches in the higher elevation eastern portions of the watershed.  Increased angling pressure could occur even when local river conditions are acceptable if closures of more marginal trout fisheries occur in neighboring basins that cause more anglers to recreate in the Eagle Basin. An additional concern is that lower high streamflow and earlier peak flows may create more opportunities for wade/bank fishing in May and June under climate change (Appendix K). This increased pressure from a longer angling season could have negative consequences for fishery

**Risk:** Increased recreational uses of local streams and rivers may degrade the collective **angling**, **floating and/or whitewater experience**. Population growth and increased tourism may increase the number of recreational users on popular local reaches. The shifts to an earlier season for recreational use on the river under climate change may reduce the windows of opportunity for floating and/or whitewater activities in the summer (Appendix K). This may further increase the number of recreational users per day as users try to maximize recreation in these shorter optimal windows in the summer. In some locations where suitable access locations are already somewhat limited (i.e., Dowd Chute, Avon), user access conflicts may arise.

**Risk:** Increased recreational uses of local streams and rivers may degrade the **health of riparian areas** at river access points. Where public access locations exist between large private parcel complexes, concentrated access can result in multiple social-use trails, trampling of vegetation, loss of habitat values, etc.

### 4.1.3 Risk Rating 3

**Risk:** Future water temperature increases driven by changes in climate may lead to the complete **loss of the cold-water fishery** and a shift in species composition to a warm-water fishery in the lower (western) watershed (Appendix F). Current cold-water fisheries on the Eagle River and Gore Creek are supported by a high degree of hydrological connectivity among reaches and between mainstem channels and various tributaries in the watershed. Increasing summer and fall stream temperatures are predicted to increase from 2-4 °C under future climate change on the Middle and Lower Eagle River. These reaches generally have the highest current summer and fall stream temperatures in the basin. If stream temperature increases approach or exceed the higher end of this predicted range under the simulated climate futures, there is an increasing cumulative risk of the loss of the cold-water fishery in the lower watershed.

While current modeling suggests this risk is not likely in the near to medium term, there exists sufficient uncertainty to warrant further investigation of this possibility. Current modeling was limited to only daily average temperature and did not consider changes to maximum daily temperatures that can generate acutely lethal conditions. Such impacts in the lower watershed could impact fisheries across the basin if transient or more permanent thermal barriers to movement of more thermally sensitive fish species occur either on the mainstem Eagle or on tributaries such as Brush Creek and Gypsum. If thermal barriers do occur on the Lower Eagle, it may also generate barriers between the Eagle River basin and the Colorado River. Thermal barriers may not arise in all years, but as warming trends persist, the frequency and duration may increase to some threshold capable of significant fishery impacts.

**Risk:** Existing **high-quality riparian areas** along the mainstem Eagle River near Edwards and between Wolcott and Gypsum appear at greatest risk for change due to altered peak flow hydrology under various climate change and water use scenarios (Appendix J). Reduced peak flows is predicted to reduce the inundation frequency and extent in riparian areas, decreasing lateral connectivity between the Eagle River and existing riparian areas. This lateral connectivity supports sufficient soil moisture for riparian vegetation, promotes species diversity and establishes conditions for plant recruitment and establishment. Impacts to lateral connectivity are greatest in the lower watershed where semi-confined floodplains allow overbanking flows on at a greater frequency and in pocket floodplains higher in the watershed. New Water Infrastructure generates the largest impacts with moderate to large declines in peak flows across climate scenarios and potential losses of inundation extent across the basin of over 100 acres.  Without the reservoir buildout, declines to inundation extent are only projected under Hotter and Drier climate futures while inundation extent may increase slightly under a wetter climate future.

**Risk:** Changes to streamflow, water quality and/or fishing pressures may alter the **status of the Gold medal fishery** on lower Gore Creek and the candidate Gold Medal reaches on the Eagle River near Avon and Gypsum. The number of days below in-stream flow minimum flow targets may increase under climate change on Lower Gore Creek, especially under hotter and drier climate futures (Appendix E). To a lesser degree, there may also be increases to the number of days below optimal streamflow levels for trout habitat that may limit trout carrying capacities (Appendix I). On the Eagle River, there is a similar risk of increases in the number of days below in-stream flow minimum flow targets under climate change unless they are mitigated by releases from upstream reservoirs (Appendix E). There are moderate to larger increases under climate change in the number of days below optimal streamflow levels for trout habitat, suggesting larger risks to the fishery (Appendix I). Reservoir releases during low-flow periods as outlined under the New Water Infrastructure scenario may partially mitigate the impact of climate change on trout habitat on the Eagle River near Avon but provide more minimal improvement near Gypsum.

**Risk:** Wildfire in river corridors may directly degrade **aesthetic quality** along some river reaches. Loss of mature riparian overstory and woody shrub bank communities removes their valuable temperature-attenuating impacts, decreases foodweb material inputs from organic litter and debris, and reduces stream bank stability. In addition to significant ecosystem impacts, loss of forests will remove the valuable social benefits provided such as breaking up human-built viewscapes, shielding and shading of buildings, sound buffering, etc.

### 4.1.4 Risk Rating 4

**Risk:** Water quality degradation from urbanization may degrade macroinvertebrate communities and qualifying conditions for **Gold medal fishery status** on lower Gore Creek and on the Eagle River near Avon and near Gypsum. While impaired aquatic life conditions on Gore Creek have not appeared to severely impact fisheries on the lower stream thus far, further impacts to the primary trout food source may have negative long term consequences for local populations.

**Risk:** Structural/physical habitat degradation caused by legacy agricultural activities and infrastructure placement occurs sporadically along the Eagle River mainstem below Town of Eagle and along Gore Creek in the vicinity of the public golf course, **fragmenting** reaches of otherwise moderate- to high-quality **aquatic habitat**. Loss of riparian habitats has attendant implications for wildlife habitat, aquatic food webs, stream channel geomorphic stability, and water quality buffering. Restoration and recovery of riparian systems increases stream system resilience and provides a protective hedge bet for aquatic communities against future land use, water use, and climate change impacts.

**Risk:** Growing resident and visitor populations may increase nutrient loading from wastewater treatment plants and stormwater runoff while changing streamflows under climate change may reduce the **assimilation capacity of receiving waters** during some times of year, creating problematic conditions for aquatic life. Waste treatment plant discharge volumes and permits are tied to how much a receiving stream can safely assimilate without violating instream water quality standards to protect aquatic life communities and downstream human users. Increasing human populations will increase treated wastewater volumes while new development will also potentially increase pollutant loads in stormwater runoff. Streams that face depleted flows from new water development and climate change will have reduced dilutory assimilative capacity, impacting instream water quality as well as discharger permits.

## 4.2 Key Risks Identified for Consumptive and Municipal Uses

The sections below present the primary consumptive and municipal use values at risk identified by local stakeholders following a review of the technical information provided above. Not all values at risk identified by community members correspond to a particular analysis completed under the ERCWP and may indicate need or opportunity for further investigation.

### 4.2.1 Risk Rating 1

**Risk:** Growing populations and warming air temperatures may increase demand for **municipal water supply** in systems throughout the watershed. New residential and commercial development driven by population growth increases water demand or requires rethinking of the patterns and methods by which current demand is serviced. A significant portion or majority of all residential use is for outdoor landscaping needs (domestic irrigation). Longer and warmer growing seasons will increase landscaping evapotranspiration demand, driving the need for additional irrigation to maintain existing landscapes as well as supply potential new developments.

**Risk:** Growing populations and increasing urban/suburban development pressure leads to conversion of agricultural lands and a loss of **open, green space** in upland areas buffering communities. Conversion of agricultural lands occurs due to both the pressure for developable land and the desire for conversion of water rights to municipal uses. Eagle County's ranching heritage remains esteemed by both original residents who have practiced this lifestyle on the West Slope for generations, and newer communities that value local food production, thoughtful urban community growth, and preservation of open spaces for wildlife movement and aesthetic benefits. Rapid conversion of agricultural lands for urban and suburban development represents an irreversible change. Agricultural land conversion has significant and lasting implications for natural stream flow regimes due to attendant changes in water seasonal diversion timing, local groundwater recharge and baseflow timing, loss of pervious landscapes and land infiltration capacity, and non-point source pollution runoff characteristics.

### 4.2.2 Risk Rating 2

**Risk:** Metal loading from historical and ongoing mining activities negatively impacts **drinking water supply quality** on the Eagle River above Avon (Appendix G). Constituents of concern near Minturn for drinking water treatment processes at downstream facilities include iron and manganese, Concentrations of both are highest during the early spring flush, but also are elevated in lower streamflow months in the fall and winter. Total metal loading is generally highest in late spring or early summer as flows increase on the rising limb of the snowmelt hydrograph. Future reservoir storage under the New Water Infrastructure scenario may reduce concentrations during low-flow months if reservoir releases enhance baseflow during these times. New Water Infrastructure may also increase metal concentrations during the early summer by reducing available streamflow dilution during high loading periods. Significant uncertainty remains regarding the role of changing snowmelt dynamics on metals loading under climate change. More study is needed to better understand the relationships between climate, snowmelt, metal loading, and river concentrations.

**Risk:** Aging water supply infrastructure may increase operation and maintenance costs for some agricultural producers, eroding the **economic viability of local farming/ranching** enterprises. Agricultural producers often operate on thin profitability margins and face strong negative pressures when supply or operation and maintenance costs increase. Aging ditch infrastructure can require costly upgrades if increased efficiency measures are required to fully access water rights and avoid inefficient or wasteful delivery can both harm streams and decrease potential production capacity. Inability to deliver water efficiently may at some point become a deciding factor in whether a particular producer continues to operate or not.

**Risk:** Changing economic and social pressures may lead to a progressive reduction in the **number of productive agricultural operations**. As water costs rise, higher value economic sectors may be better-positioned to obtain water rights changes and supply certainty than traditional agricultural producers. Over time, producers may leave the market either by selling water rights, land, or both, leading to a permanent reduction of lands under cultivation in Eagle County and attendant loss of local food production and ranching culture.

### 4.2.3 Risk Rating 3

**Risk:** Warming air temperatures may decrease the overall **effectiveness of outdoor water conservation** programs/projects. Increasing air temperatures increases evapotranspiration (ET) demand of all plants, including both crops and managed decorative landscapes (urban and suburban lawns, trees, parks, recreation fields, etc.). Water supply gains and savings made by implementing conservation measures in local water use may be partially or fully eroded by increased water demand at the landscape scale.

**Risk:** Consolidation of water supply to a smaller number of diversion points following low-frequency/high-impact events (e.g., hazardous material spill on Vail Pass, catastrophic wildfire) may lead to **increasingly altered streamflows** on some reaches of stream. When many dispersed users take smaller surface water diversions at multiple locations from the Eagle headwaters to its western end, the mainstem can still maintain somewhat regular instream flows via return flows and groundwater recharge throughout the valley. Community users like municipalities or larger agricultural producers may realize infrastructure efficiency gains over time by taking larger quantities of water at a smaller number of diversion locations in the watershed. This change in the spatial distribution and size of water diversions may inadvertently cause stream reaches below larger diversions to face increased regularity of dewatering risks or associated problems with instream flows, aquatic habitat refugia, pollutant dilution, temperature issues, and lack of regular occurrence of necessary geomorphic flows.

**Risk:** Large wildfires may significantly degrade the **quality of drinking supply** for smaller municipal systems (e.g., on Brush Creek and Gypsum Creek). Post-wildfire watersheds face higher risk of debris flow, water quality degradation, and more frequent turbidity events that increase pre-processing requirements.[11] [12] Debris flows may cause siltation and direct damage to intake infrastructure, even fully taking facilities offline for short periods of time (days to weeks). Turbidity events deliver poor quality source water, interfering with treatment process trains and leading to increased costs and equipment maintenance/replacement. Risks for large post-erosion events are generally greatest in the first year, while risks for smaller turbidity events and degraded chemical water quality may persist for multiple years after a large fire.

**Risk:** Administration of a Colorado Compact Call may lead to curtailment of **agricultural water use** among some set of water users holding junior water rights. The Colorado River Basin is currently experiencing a supply crisis due to an ongoing imbalance of human consumptive uses with the actual native annual water yield in the basin. Continuing conflict between states and risk of intervention by federal management agencies to forcibly curtail water use may cause disruptive and significant impacts to junior water users in Colorado River tributary basins, including the Eagle River. Water rights in the Colorado Basin junior to the 1922 Colorado River Compact are most at-risk of being impacted or fully curtailed by a compact call, either directly or via impacts to the numerous complex augmentation plans that have been deployed in the region. The Colorado River Risk study did not provide down-scaled estimates for the Eagle Basin, but estimated that in

[11] Smith, HG, Sheridan, GJ, Lane, PN, Nyman P, & Haydon S. 2011. Wildfire effects on water quality in forest catchments: A review with implications for water supply. Journal of Hydrology, 396(1-2), 170-192.

[12] Hempel P. 2020. Town of Eagle Sourcewater Protection Plan. Prepared with support from the Colorado Rural Water Assocation.

the Colorado Basin as a whole, 626,000 af of water faced post-compact exposure, of which approximately 532,000 af or 85% was transmountain diversion water.[13]

### 4.2.4 Risk Rating 4

**Risk:** Questions regarding the impact of arsenic on municipal **water supply quality** remain due to uncertainty in the regulatory environment. As additional scientific information on connections between arsenic intake and health problems accumulated, water quality standards for arsenic were lowered from 50 ug/l to 10 ug/l in 2001.[14] This created regulatory difficulty since many analytical laboratories were incapable of detecting levels near the standard, and water providers may be unable to implement technology to treat sourcewater to the standard. Western Slope Colorado, including Eagle County, frequently features soil and geologic characteristics that produce background arsenic levels in surface and groundwater that exceed the 10 ug/l standard. This creates a regulatory conundrum in which many streams are naturally out of attainment for the drinking water standard, and many small providers and individual private wells are incapable of either testing for or treating background levels.



[13] Hydros Consulting. 2019. Colorado River Risk Study Phase III Final Report. Prepared for the Colorado River District and Southwestern Water Conservation District

[14] Colorado Code of Regulations 2020 Regulation 31 Basic standards and methodologies for surface waters.