CRYSTAL RIVER MANAGEMENT PLAN

FINAL REPORT 04.2016

lōtic hydrological

ROARING FORK WATERSHED PLAN at work

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CRYSTAL RIVER MANAGEMENT PLAN 2016

Identifying, prioritizing and guiding management actions that honor local agricultural production, preserve existing water uses, and enhance the ecological integrity of the river.

EXECUTIVE SUMMARY

Changing demographics and local economies place increasing value on the Crystal River's aesthetic, environmental and recreational attributes. At the same time, the community retains important cultural and economic ties to a strong agricultural heritage and ongoing agricultural production. Residents in the Town of Carbondale enjoy large shade trees, verdant gardens, and green parks and open spaces supported by a free raw-water supply sourced from the River. Agricultural producers, in turn, depend on use of the Crystal River to support their livelihoods and maintain vast open spaces terraced along the flanks of Mount Sopris and across the valley floor. The convergence of these diverse and sometimes competing demands with water scarcity on the Crystal River during periods of drought leads to demand shortages for some agricultural producers and impairment of various measures of ecosystem function.

Despite the challenges involved in managing water for multiple uses when resources are limited, diverse stakeholders continue to recognize the importance of balancing agricultural production and ecosystem function on the Crystal River. However, without comprehensive quantitative and social frameworks for understanding the costs and benefits associated with any proposed management alternative, uncertainty prevails and stakeholders default to the status quo. Planning around water needs on the Crystal River required development of a scientifically rigorous and consensus-based framework for predicting the ecological and social consequences of proposed projects or management strategies. The Crystal River Management Plan (the "Plan") utilized a science-based and stakeholder-centered approach to consider complex interactions between the physical components driving watershed structure; the biological components of riverine ecosystems; the social context of competing perspectives, needs, and values; and the existing legal and administrative frameworks governing water use in an effort to identify and evaluate management and structural alternatives that honor local agricultural heritage, preserve existing water uses, and enhance the ecological integrity of the river. A series of stakeholder meetings held throughout the planning process served to clarify outstanding questions, summarize results from previous studies, refine planning goals and objectives, and evaluate the feasibility of various management alternatives.

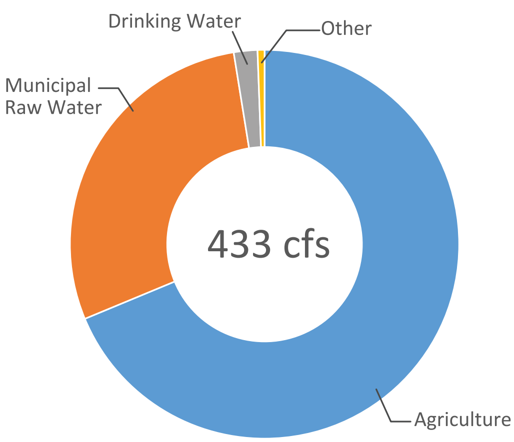
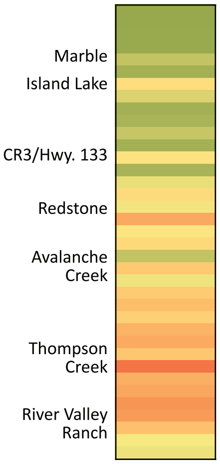


Figure ES-1: Agricultural and non-potable municipal water uses represent the dominant surface water diversions on the Crystal River

The functional assessments detailed in Section 2 conclude that few external stressors exist in the headwaters of the Crystal contributing to a generally healthy ecosystem above Redstone. Constraints on function increase in the downstream direction due to the cumulative effects of floodplain development and surface water diversions (Figure ES-1). The reaches of Crystal River between Thompson Creek and the confluence with the Roaring Fork exhibit the most degraded overall functional condition. This pattern most strongly reflects late summer modifications to the hydrological regime and cascading impacts on channel hydraulics, water temperature, habitat quality and availability, and biotic structure. The dominant nature of the impacts to streamflow and habitat suggest that management strategies that focus on these two variables will yield the greatest overall environmental benefit.

Characterizations of water management and use presented in Section 3 identified the prominent limiting circumstances for management of consumptive and non-consumptive use needs on the Crystal River. Legal and administrative frameworks governing the use of water on the Crystal River allocate water among multiple uses—agricultural production, municipal water use, operation of a fish hatchery, and a minimum instream flow right (Figure ES-2)—according to a seniority system that places the oldest existing uses ('senior rights') in priority over newer uses ('junior rights'). The convergence of water availability and water administration under the Prior Appropriation System creates both chronic and transient water shortages. Agricultural use shortages impact users on tributaries more significantly than on the mainstem of the Crystal River. The most persistent shortages on the Crystal River mainstem are the CWCB ISF right, and the junior water rights on the East Mesa Ditch, Sweet Jessup Canal, Helms Ditch, and Kaiser & Sievers Ditch. The presence of agricultural shortages highlights the difficulties associated with managing water to satisfy ecosystem needs without burdening existing water users.

The alternative management strategies detailed in Section 4 respond to the overlapping themes and management prospects that emerged from reviews of water use patterns, legal and administrative considerations, and evaluations of ecosystem function. The Plan considered the relative effectiveness of a wide array of market-based programs, efficiency measures, water supply projects, and channel modifications for meeting planning goals and objectives. Unfortunately, no single management option represented a panacea for meeting existing needs and addressing observed ecosystem impairments. Rather, each alternative was associated with a unique set of environmental, capital, and social costs and benefits. Section 5 presents the results of consideration of these factors by local stakeholders and a prioritization of management actions over the short and long-term. Stakeholders groups involved in the cost-benefit analysis process included: agricultural producers, State water administrators, local municipalities, natural resource agencies, local and national environmental organizations, recreational advocates, and other water rights holders.



Grade	Score	Level of Impairment
A	90-100	Negligable
B	80-90	Mild
C	70-80	Significant
D	60-70	Severe
F	50-60	Profound/Unsustainable

Figure ES-2: Constraints on ecosystem function are greatest on the lower Crystal River where surface water diversions modify the hydrological regime and limit the quality and availability of aquatic habitat

The findings and recommendations presented in the various sections of the Plan are summarized below:

- Few external stressors exist in the headwaters of the Crystal contributing to a generally healthy ecosystem above Redstone.
- Constraints on ecosystem function slowly increase in the downstream direction due to the cumulative effects of floodplain development and surface water diversions.
- The reaches of the Crystal River between Thompson Creek and the confluence with the Roaring Fork exhibit the most degraded overall functional condition.
- Reductions in late summer baseflows produce cascading impacts on channel hydraulics, water temperature, and physical habitat quality and availability.
- Supply shortages on water-limited tributaries are common. Demand shortages on the Crystal River exist for the junior rights on the East Mesa Ditch, Sweet Jessup Canal, Helms Ditch, and Kaiser & Sievers Ditch. The CWCB ISF right is frequently short in late summer.
- Water efficiency upgrades (e.g. sprinkler irrigation and ditch lining) can significantly reduce the frequency and magnitude of demand shortages experienced by agricultural producers.
- The most feasible and effective management options for meeting planning goals include 1) Non-Diversion Agreements between the Sweet Jessup Canal and Carbondale Ditch, and 2) ditch lining and short term water leasing by the Town of Carbondale on the Carbondale Ditch and Weaver and Leonhardy Ditch.
- Non-Diversion Agreements of approximately 25 cfs in severe drought and 10-15 cfs during moderate drought will meet management goals for maintaining moderate risk to ecosystem function. Current conditions place the ecosystem at high risk for unfavorable change.
- Reaching management targets will require diversion reductions between 5-18% (depending on drought severity) between the Sweet Jessup Canal and the Carbondale Ditch.
- Stakeholders should continue to investigate the feasibility of stand-alone water efficiency infrastructure projects, off-channel reservoir development, and channel modifications to simultaneously promote ecosystem function and the long-term sustainability of local agricultural production.

Population growth trends indicate that the Town of Carbondale will experience a doubling in size in the coming decades. Projections from climate data indicate that climbing temperatures will shift the timing of snowmelt runoff and increase the frequency and severity of hot and dry summer conditions. These changes will place increasing strain on the riverine environment at the same time that demand shortages for existing uses become more common. Without tools and structured plans for responding to these challenges, tensions between stakeholders in the Crystal River watershed will continue to mount. This Plan recommends several high-priority actions for balancing water use needs. Implementation of these actions will equip the community with flexible tools to deal with shifting community values, economic diversification, and climate change in a manner that minimizes conflict between user groups and achieves high levels of environmental resiliency.

ACKNOWLEDGEMENTS

The Crystal River Management Plan (CRMP) evolved from years of planning, studies and assessments that underscored the need for further investigation into water use patterns, ecological health and associated impacts in order to justify and produce on-the-ground improvements. In 2013, equipped with knowledge of successes and shortcomings of prior efforts, Roaring Fork Conservancy, Public Counsel of the Rockies, and Lotic Hydrological, LLC (the "Project Team") met with water rights holders and water users, listening to concerns and soliciting ideas to enhance riparian and instream conditions in and along the Crystal River. Combining prior knowledge with community input created a strong foundation for the CRMP and brought together river science and community values. The long-term efficacy of the CRMP depends on continued participation and input by stakeholders whose knowledge and values inform the options for water management and river stewardship now and in the future.

The CRMP benefitted from the expertise and guidance of a diverse and passionate group of experts, stakeholders, and community members. CDR Associates worked closely with the team through the final stages of planning and stakeholder engagement. Colorado Water Trust provided invaluable expertise, thoughtful insights and creative water management ideas. A long list of individuals and organizations informed and advised the Project Team throughout the planning process:

Crystal River water rights holders and agricultural producers, including representatives from the Sweet Jessup Canal, East Mesa Ditch, Lowline Ditch, Ella Ditch, Helms Ditch, Pioneer Ditch, Bowles and Holland Ditch, Rockford Ditch, Carbondale Ditch, Weaver and Leonhardy Ditch, Kaiser and Sievers Ditch, and Southard and Cavanaugh Ditch; the Town of Carbondale; Trout Unlimited; Western Resource Advocates; Crystal Valley Environmental Protection Association; Pitkin County Open Space and Trails; American Rivers; United States Forest Services, Natural Resources Conservation Service, Colorado Parks and Wildlife, Jake DeWolfe and Kevin Rein (Colorado Division of Water Resources); Kara Steeland (University of Michigan); Sandra Ryan-Burkett (Rocky Mountain Research Station); Chris Treese (Colorado River District); Peter Nichols (Berg Hill Greenleaf & Ruscitti LLP); Mark Beardsley (EcoMetrics); Karin Boyd (Applied Geomorphology, Inc.); Scott Gillilan (Gillilan Associates); and the outstanding engineering staff at RiverRestoraton. Any omissions are regretted.

Finally, we appreciate the interest and investment of the following supporters who recognized the potential of this ambitious project and without whom none of this work would have been accomplished: Colorado Water Conservation Board and the Colorado Basin Roundtable, Gates Family Foundation, Dornick Foundation, and Environment Foundation of the Aspen Ski Company.

TABLE OF CONTENTS

INTRODUCTION

Predicted ongoing population growth, shifts in the local economy, and changes in climate portend future conflicts over water resource management for the satisfaction of multiple and diverse user groups. Management of water on the Crystal River will continue to support the livelihoods of many local families and will impact the high quality of life enjoyed broadly by local residents over the coming years. Ensuring continued support for historical uses and optimizing management to reflect changing local expectations and values requires careful and focused planning. The Crystal River Management Plan (CRMP) expresses the results of a collaborative community process that endeavors to alleviate constraints on important ecosystem functions on the Crystal River without injuring local agricultural producers.

1.1 PLANNING CHALLENGES

The nexus of growing populations, recurring droughts, and limited water supply in basins across Colorado leaves many streams and rivers with substantially modified flow regimes. Where these conditions occur frequently or with great enough magnitude, some corresponding shift in functionality of the riverine ecosystem likely results. Altered ecological functionality impacts streams' and rivers' ability to provide important ecosystem services critical for protecting native species, supporting local tourism and recreation-based economies, and improving or maintaining local residents' high quality of life. Conversely, many of the resource management decisions that impact ecosystem function support the development of municipal water supplies, local industries, and maintain the livelihoods of local families. In short, some degree of hydrological modification is inevitable where humans inhabit semi-arid ecosystems in the Colorado Rockies. Management of scarce water resources at local, regional, and State levels must, therefore, strive to balance consumptive and non-consumptive water uses in a way that optimizes multiple use needs without compromising the ecological, social, or economic stability of local communities.

Ongoing community dialogue and patterns of water use in the Crystal River (the "River") watershed reflect this resource management paradigm. Changes in the local economy and demographics drive changing expectations for resource use and the delivery of ecosystem goods and services by the River and its tributaries. Historically, the use of irrigation water to support farming and cattle ranching and to supply raw water and drinking water to the Town of Carbondale constituted a primary local management objective. In recent years, a growing chorus of stakeholders expressed concerns about historical patterns of agricultural use and its impact on aesthetic values, ecosystem resiliency and function. While these stakeholders express concerns about the impacts of water diversions, all parties recognize the value of continued agricultural production as an important cornerstone of a vibrant community culture that places significant value on the aesthetic of vast, open, green spaces and economic and social ties to the history of agricultural production in the valley.

Despite the challenges involved in managing water for multiple uses during times of resource constraint, diverse stakeholders representing multiple water uses continue to recognize the importance of balancing consumptive and non-consumptive water uses of the Crystal River. However, without comprehensive quantitative and social frameworks for understanding the costs and benefits associated with any proposed management alternative, uncertainty reigns and stakeholders default to the status quo. Consumptive and non-consumptive water use planning therefore benefits from a scientifically rigorous and consensus-based framework for predicting the ecological and social consequences of proposed projects or management strategies.

The Crystal River Management Plan (CRMP, or the "Plan") addresses this situation. The Plan utilizes a science-based and stakeholder-centered approach to consider complex interactions between the physical components driving watershed structure; the biological components of riverine ecosystems; the social context of competing perspectives, needs, and values; and the existing legal and administrative frameworks governing water use in an effort to identify and evaluate management and structural alternatives that support the overall project goal (the "Goal"):

> **"IDENTIFY, PRIORITIZE AND GUIDE MANAGEMENT ACTIONS THAT HONOR LOCAL AGRICULTURAL PRODUCTION, PRESERVE EXISTING WATER USES, AND ENHANCE THE ECOLOGICAL INTEGRITY OF THE RIVER."**

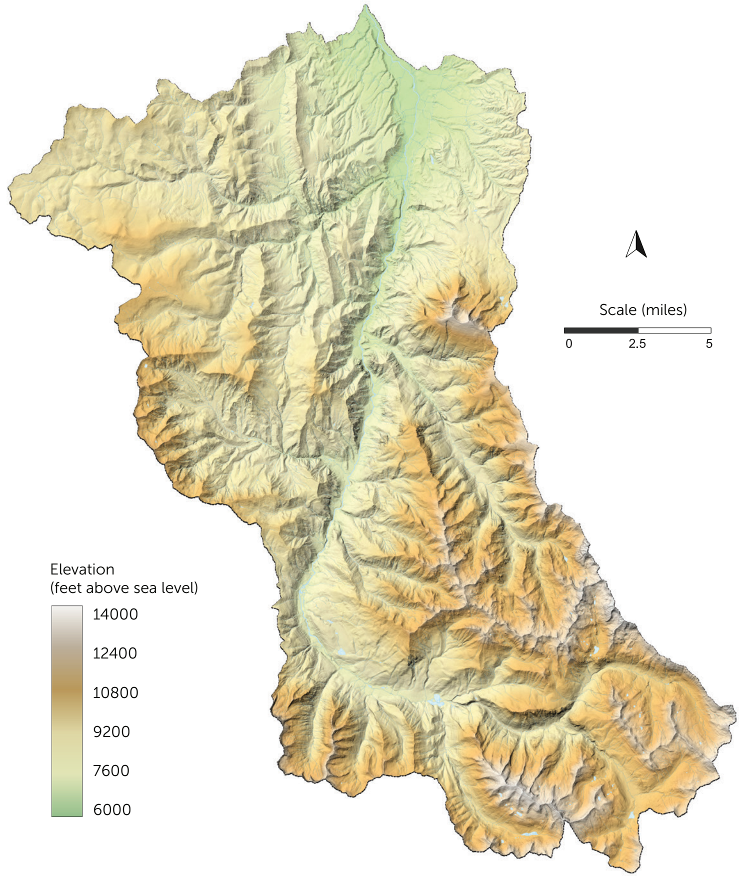


Figure 1-1: Crystal River Watershed

1.2 THE LOCAL CONTEXT

The Crystal River flows 35 miles from its headwaters in the Elk Mountains to its confluence with the Roaring Fork River. It is one of the longest remaining undammed rivers in the state of Colorado, and its biologically diverse ecosystem is home to mammals, birds, and aquatic organisms. The river corridor provides critical summer and winter habitat to elk, deer, coyotes, and red fox. Grouse, band-tailed pigeon, water fowl, prairie falcon, warblers, golden eagles, bald eagles, and western grebe depend on the Crystal's lush riparian vegetation. The river channel provides crucial habitat to native cutthroat trout, rainbow and brown trout, whitefish, and sculpin.[15]

Residents, conservation groups, environmental advocates, and government agencies recognize the unique virtue of the Crystal River. Starting in the 1980's, valley residents sought protection of the river corridor under the Wild and Scenic Rivers Act. Since then, the United States Forest Service (USFS) deemed Thompson Creek and most of the National Forest land bordering the Crystal River eligible for inclusion in the Federal Wild and Scenic Rivers System. In response to proposed dams and trans-basin water supply projects, American Rivers included the Crystal River on its "America's Most Endangered Rivers" list in 2012.1 Although the conditional water rights supporting the proposed reservoirs were recently abandoned, the administration of water rights in other parts of the River continue to pose challenges to concurrent management of consumptive and non-consumptive water uses.

An in-stream flow (ISF) water right held by The Colorado Water Conservation Board (CWCB) represents the only administrative mechanism in place to accommodate management for the environmental needs in the lower Crystal River. The right (100 cfs summer / 60 cfs winter) extends from Avalanche Creek to the Roaring Fork River. As a tool for meeting local ecosystem management objectives, the CWCB ISF on the Crystal is problematic in two respects. First, the summer ISF right is often not met from August-October[7] in moderate and severe drought conditions because of its junior priority under Colorado water law. Second, maintaining a flow of 100 cfs in the lower Crystal River during moderate or severe drought would require the dry-up of significant tracts of existing irrigated agricultural land. The latter scenario is largely unacceptable to the agricultural community and highlights the tension that exists between multiple competing value systems and different priorities for use and management of water in the Crystal.

Agricultural production represents a critical cornerstone of the Crystal River Valley culture and economy. Early settlers to the valley subsisted on sheep and cattle operations. Development of an extensive irrigation water conveyance system buttressed the growth of potato farming and, later, widespread production of hay and alfalfa. As the ski industry transformed the Western Slope, the Town of Carbondale expanded, incorporating historical ranchland into the municipal boundary. Several ranches and farms subsequently converted to subdivisions. However, numerous hay and cattle operations totaling approximately 4,800 acres remain, contributing to the sublime vistas appreciated equally by residents and visitors to the valley.

In addition to agricultural production, Crystal River water also supports drinking water supply needs of three small municipalities. In the upper Crystal, Marble and Redstone maintain small year-round populations. The Town of Carbondale, near the Crystal River's confluence with the Roaring Fork River, saw steady growth over recent decades and now is home to more than 6,000 people. Carbondale's projected population growth trajectory coincides with increased demand for drinking water and raw water for irrigating residential lawns and municipal open spaces. The Town's drinking water needs are supported by surface water diversions on Nettle Creek, a tributary to the lower Crystal, and well fields in the alluvial aquifers along the Crystal and Roaring Fork rivers. A network of surface water diversions and ditch systems provide irrigation water for lawns and gardens. An expected near doubling of population in Carbondale by 2035 portends steady increases in municipal water demands in the coming decades.

Growing populations and changing demographics in Carbondale bring new focus to the aesthetic and recreational values of the Crystal River. High spring flows attract whitewater enthusiasts to boat sections of the Crystal from Marble to the Roaring Fork. Anglers frequent many of the publically owned sections of the river throughout the summer and fall. The Crystal River is also a main focal point of the West Elk Loop, one of Colorado's Scenic and Historic Byways. Additionally, multiple outdoor education organizations use the valley as venue for programs that engender increased environmental awareness and stewardship among participants. Each of these activities place an aesthetic and/or recreational use value on Crystal River water that does not always align with the existing patterns of water use within the watershed.

Over the last decade, growing concern over water resources in the greater Roaring Fork watershed led to numerous efforts by public, private and government stakeholders to explore the effects of land and water resource development and management decisions on watershed health. The following reports comprise the foundational body of literature supporting the development of the Plan:

State of the Roaring Fork Watershed Report[8]

Documents the water quality, water quantity, and water-dependent ecosystem status of the Roaring Fork Watershed, and points out areas where insufficient data prevent an accurate assessment of that status. The late summer/fallow flow issues on the Lower Crystal River were documented in this report.

Watershed Flow Evaluation Tool Pilot Study for Roaring Fork[3]

Pilot study in the Roaring Fork basin to support use of the Watershed Flow Evaluation Tool (WFET) as a coarse-scale method of assessing non-consumptive water needs in the Colorado River Basin. Colorado's StateMod for the Upper Colorado River simulated water allocation and accounting in the Roaring Fork. WFET evaluated important ecosystem health indicators using flow-ecology relationships based on scientific literature review. Site-specific data results collected at sites within the watershed generally validated WFET results.

Crystal River Snapshot Assessment[45]

Synoptic streamflow assessment that demonstrated the spatial and temporal variability of flow associated with water depletions from diversion on the Lower Crystal. The study suggested that several miles of the lower Crystal River are vulnerable to stream health degradation during times of low streamflow. Study illuminates the ancillary environmental, economic, and cultural impacts of poor river health and encourages proactive management to address potential issues.

Roaring Fork Watershed Plan[9]

Watershed planning document that recognized the impact significantly altered flow regimes, wetland degradation, and sediment issues on various reaches of the Crystal River. Identified the Crystal as a location for opportunities to improve fish passage, improve ecological health through land-use change, and explore grazing impact mitigation.

Crystal River Water Leasing Threshold Study[43, 44]

Study to identify water leasing threshold to support and protect aquatic habitat in the Crystal River near Carbondale. Interim target management flows estimated using the R2CROSS and Wetted-Perimeter Methods. Study indicated a water leasing threshold of 40-60 cfs could be appropriate to protect aquatic life. Effort endeavored to support future potential water leasing programs on the Crystal River.

Stream Conditions Assessment: Crystal River[29]

Assessment built upon previous local efforts and intended to provide information on streamflows, water quality, and aquatic life in the lower Crystal River (Avalanche Creek to the Roaring Fork confluence). Indicates the ways that diversions, return flows, and tributaries affect the discharge of the stream on a longitudinal (upstream-to-downstream) profile. Clarifies understanding of the magnitude and location of flow stress and dewatering along the lower Crystal River. Stream reaches to the south of the Town of Carbondale consistently experienced very low flows and near dewatering from the cumulative effect of upstream diversions. Temperature observations approached, but did not exceed, state standards. Macroinvertebrate sampling indicated the presence of healthy insect communities that met state standards for aquatic life use.

Water Rights Allocation and Accounting Model Development for the Lower Crystal River[28]

Study simulated streamflow conditions in the Lower Crystal based on Prior Appropriation water allocation and accounting principles. Changes in spatial and temporal streamflow patterns were characterized in existing and three potential municipal water conservation management plans in order to inform development and evaluation of water conservation measures by the Town of Carbondale. Results indicate that the most effective TOC conservation measures exist at the Carbondale Ditch and Weaver and Leonhardy Ditch, but none generate enough streamflow to meet existing instream-flow rights. TOC water savings is an important part of watershed-wide efforts to address lower Crystal streamflow depletions, but efforts focused on enhancing ecological and functional conditions should continue considering options for either increasing flows above the Carbondale Ditch or make available flows more supportive of ecosystem services most highly valued by stakeholders.

Rushing Rivers-Ag Project: Town of Carbondale[48]

Spearheaded by Western Resource Advocates, the Rushing Rivers project investigated opportunities for improving municipal water efficiency by demonstrating conservation savings by West Slope municipalities with extensive agricultural water rights. The project promoted efficiency gains through the use of "smart" irrigation infrastructure. The Town of Carbondale qualified as one of the West

Slope municipalities with the greatest opportunity to improve local streamflow through improved efficiency. Carbondale resource managers and local irrigators attended presentations about automated headgates and similar technology for improving agricultural water management

Roaring Fork Watershed Regional Water Efficiency Plan[16]

Effort aims to build on municipal Water Efficiency Plans in the watershed by providing a platform to coordinate efforts and identify opportunities that would benefit from resource sharing or a watershed-wide effort.

Carbondale Municipal Water Efficiency Plan[17]

Following Colorado's statutory water conservation planning requirements, Carbondale developed a Water Efficiency Program as part of the Roaring Fork Watershed Regional Water Efficiency Plan. This effort forecasted three water demand scenarios, inventoried current supply, and investigated several tiers of conservation to meet demand in a cost-effective way. Carbondale established a 24 AF savings per year efficiency goal (2%). Metering, water loss control, conservation-oriented water rate structure, development codes and ordinances, and raw water system mapping, inventory and management were selected as the most reasonable efficiency measures to pursue. Although water savings would be consistent with Carbondale's leadership as a conservation-minded community, Carbondale's water rights are sufficient to meet all foreseeable growth projections.

These assessments and planning efforts laid the groundwork for development of the CRMP by illuminating certain patterns of water use, impacts to the River's ecological health, and the need for further investigation. Furthermore, questions raised by these studies provided important context for identifying initial planning goals and objectives.

1.3 STAKEHOLDER PROCESS

As a strategic planning document for local communities, the CRMP strives to integrate sound scientific and engineering evaluations, competing local value systems and resource use priorities, and feasibility constraints imposed on identified management alternatives. Human values largely shape the way these concerns are measured in cost-benefit analyses that guide local planning priorities. Therefore, development of the CRMP relied heavily on stakeholder input. Stakeholder groups involved in the process include: agricultural producers, State water administrators, local municipalities, natural resource agencies, local and national environmental organizations, recreational advocates, and other water rights holders. A series of group and individual meetings held throughout the planning process served to clarify outstanding questions, summarize results from previous studies, refine planning goals and objectives, and evaluate the feasibility of various management alternatives. The stakeholder group contemplated a wide array of questions during these meetings, including:

- How are longitudinal patterns in flow affected by agricultural and municipal diversions between Thompson and Prince Creeks during dry, average, and wet years?
- How much water is needed to make a difference for the ecological health of the Crystal River?
- How do observed high sediment loads impact aquatic life? Are these loads natural or human caused?
- If shortages exist for the support of environmental function, where and when is water needed most? At what frequency?
- To what extent can local management 'solve' low streamflow issues on the Crystal?
- Are there practical engineering solutions to reaching planning goals?
- What is the potential for water leasing as a solution?
- How do conservation savings vary spatially and temporally for potential alternative management strategies?
- What is the most effective conservation strategy for each water rights holder to contribute to increased stream health?

The pursuit of actionable project recommendations required understanding the multiple dimensions of decision-making criteria. Therefore, answering the above questions (the "Socio-Economic Context") required characterizing the condition of riverine resources in the Crystal River watershed (the "Resource Condition") and the physical processes that govern the movement of water, its interaction with local channel forms, and its impacts on aquatic biota (the "Physical Processes").

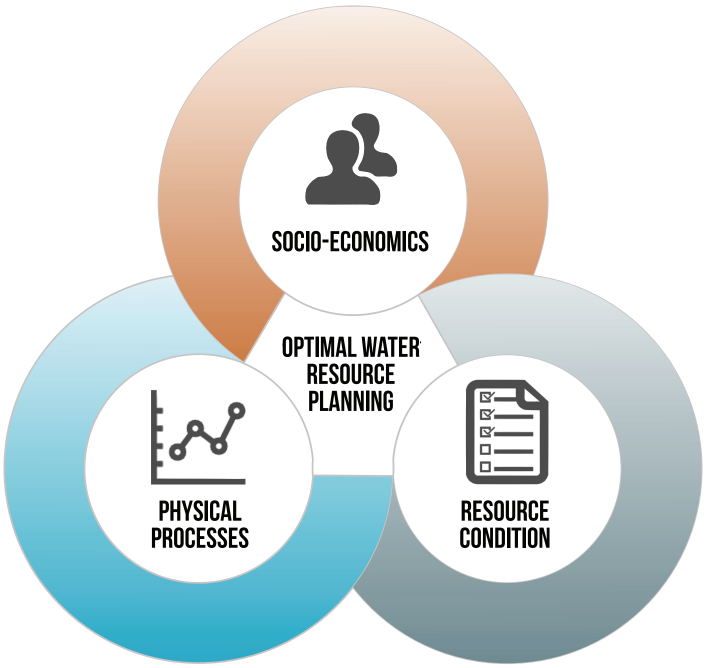


Figure 1-2: The CRMP planning framework

1.4 REGIONAL AND STATE LEVEL PLANNING CONTEXT

The general paucity of non-consumptive water use planning across the State emerged as a prominent issue during the recent development of the Colorado Water Plan (CWP). Focused efforts by the Colorado Basin Roundtable and others led to the inclusion of stream management planning in the CWP as a concept for resolving conflict and realizing optimized management of water for the benefit of both consumptive and non-consumptive uses. The CWP identifies stream management planning as a priority for streams with significant environmental or recreational value. The CWCB describes stream management plans as follows:

> *Well-developed stream management plans should be grounded in the complex interplay of biology, hydrology, channel morphology, and alternative water use and management strategies. They should also consider the flow and other structural or management conditions needed to support both recreational uses and ecosystem function. A stream management plan should: 1) involve stakeholders to ensure their acceptance of the plan; 2) assess existing biological, hydrological, and geomorphological conditions at a reach scale; 3) identify flows and other physical conditions needed to support environmental and recreational water uses; 4) incorporate environmental and recreational values and goals identified both locally and in a basin roundtable's BIP; and 5) identify and prioritize alternative management actions to achieve measurable progress toward maintaining or improving flow regimes and other physical conditions.*[14]

Stream management planning presents a unique pathway towards collaborative integrated watershed planning and management rooted in robust understanding of local physical processes. Ideally, SMPs provide a comprehensive review of stream characteristics using available data and facilitate stakeholder input to identify a set of alternative management strategies or projects for a given section of river. SMPs can address a multitude of water-related issues, including: sedimentation and erosion, flooding risk and mitigation, drinking water quality and supply, agricultural and industrial water supply, water storage, urban runoff, and habitat for aquatic life. Such planning exercises are well suited to decision-making and project identification in situations where competing water use needs produce potential for conflict. Once completed, these plans are meant to assist water users in planning for a sustainable future with the underlying assumption that a healthy watershed will support vibrant local economies and the high quality of life enjoyed by local residents.

Colorado's Western Slope is especially disadvantaged by the lack of non-consumptive use planning due to the geographic density of streams with high environmental or recreational value, widespread economic dependence on recreation and tourism, and the value local residents place on a healthy ecosystem. As a result, the Colorado River Basin Roundtable recently identified establishment of a basin-wide stream management planning effort as a high-priority action.[11] This Crystal River Management Plan (CRMP) was developed with consideration of the CWP and the Roundtable's water planning goals.

2 ECOSYSTEM FUNCTIONAL ASSESSMENT

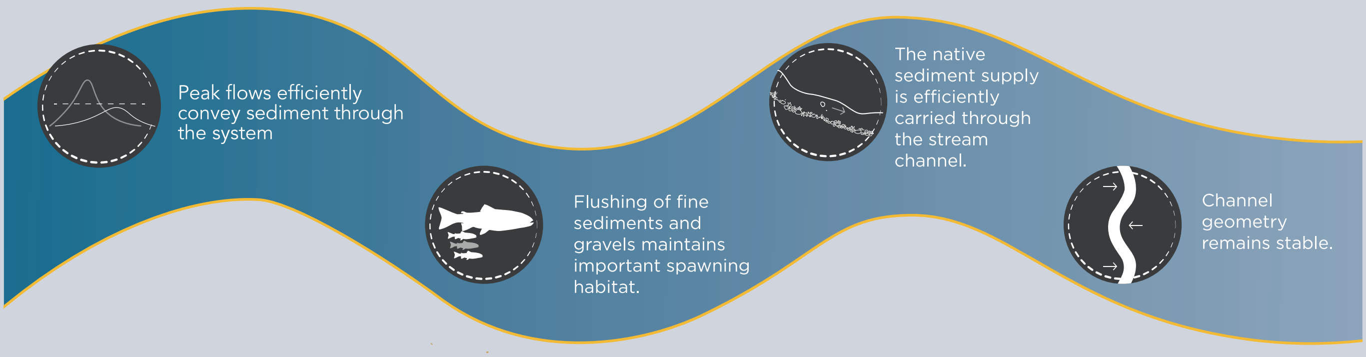
The CRMP provides recommendations for optimizing water management decisions to support existing uses while, simultaneously, alleviating constraints on the delivery of important ecosystem goods and services (EGS). It is often difficult to quantify EGS value given their nature as non-market common public amenities. Clean water, healthy fisheries, or stunning viewscapes provide intangible benefits that do not easily fit within the economic valuation and cost-benefit frameworks that typically drive resource management decisions. However, when delivery of EGS is acutely constrained, some corresponding impact—direct or indirect—to local economies, livelihoods, or quality-of-life frequently arises, driving the need to identify alternative resource management strategies. The CRMP considers three primary attributes (the “Attributes”) commonly associated with EGS and frequently affected by water resource management activities: channel dynamics, riparian health, and aquatic habitat.

CHANNEL DYNAMICS

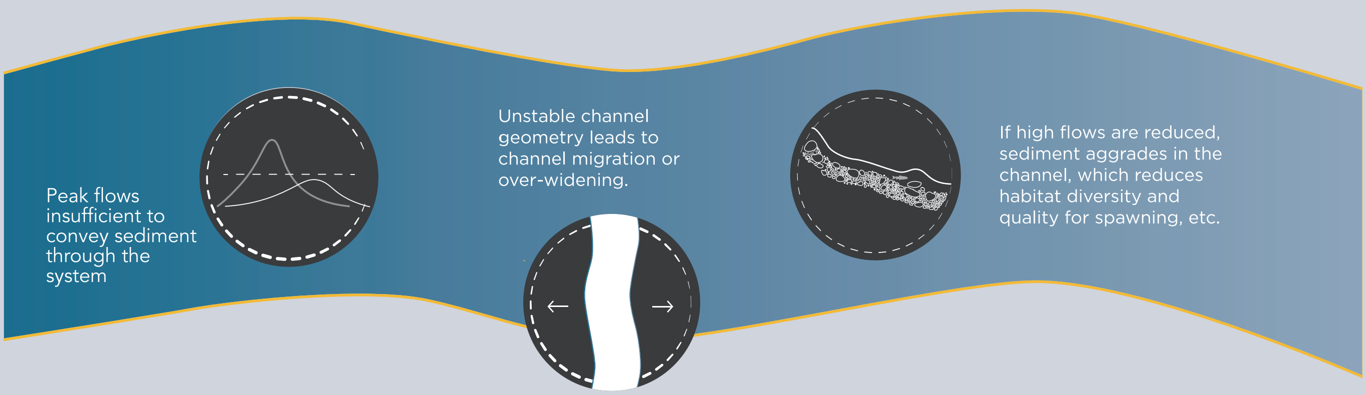
Channel dynamics encompass the fluvial and geomorphological processes that interact to control channel form and evolution across a range of spatial and temporal scales. Channel dynamics respond to interactions between patterns of rainfall and runoff, catchment-scale physical attributes (e.g. surficial geology, topography), riparian community structure, and local use practices (e.g. transportation corridor alignment, grazing practices). As a result, human management activities that modify the hydrological regime, alter patterns of erosion, adjust the structure of the channel bed, or modify riparian vegetation may yield fundamental shifts in the geometry and behavior of the stream at the channel (tens of yards) or reach (hundreds of yards) scale.

Alteration of sediment supply, channel forming flows, or streambank vegetation may lead to complex interactive effects that result in reduced resiliency of local channel forms. For example, in unconfined alluvial streams, degradation of riparian forests frequently results in diminished bank cohesion, an increased rate of channel avulsion, and a progressive widening and filling of the stream channel itself. These high-dynamic channel states generally provide poor aquatic habitat and present a risk to streamside property and infrastructure.

FUNCTIONING SYSTEM:



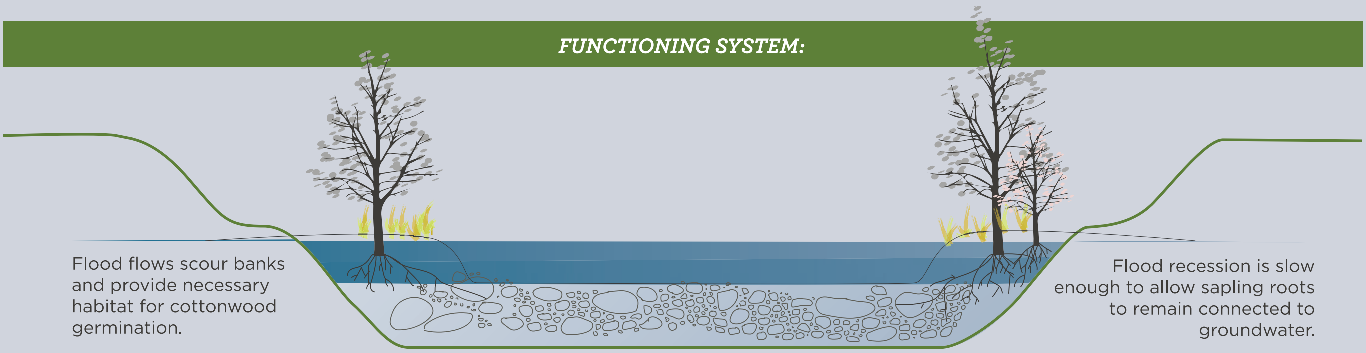
NON-FUNCTIONING SYSTEM:

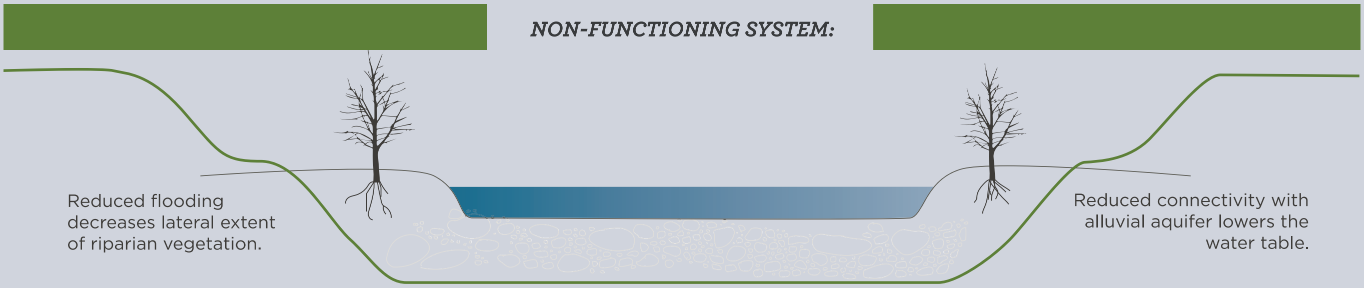


RIPARIAN HEALTH

Riparian areas support a wide variety of physical, biological, and ecological processes. Riparian zones generate important organic inputs for stream ecosystems, support streambank cohesion, perform vital nutrient cycling roles, and lend to the quality of aquatic habitat by providing shade and buffering against temperature extremes. The hydrological regime, sediment and channel dynamics, invasive vegetation, and near-stream land uses frequently impact the functionality of riparian areas.

Riparian areas exist in a complex equilibrium state governed by the local geometry of the channel/floodplain system and the inter-annual pattern of flood flows and baseflows. Occasional scouring of overbank areas provides the necessary habitat for germination of many riparian plant species. Following germination, seedlings require a relatively slow reduction in water table height over the progression of the growing year. Rapid water table reduction or late season water table heights that drop below the rooting depth of cottonwoods and other riparian plants stresses vegetation and can lead to mortality. Management activities that alter the magnitude, timing, or frequency of peak flows and baseflows, therefore, may limit riparian recruitment leading to decadent stands with little or no regeneration.





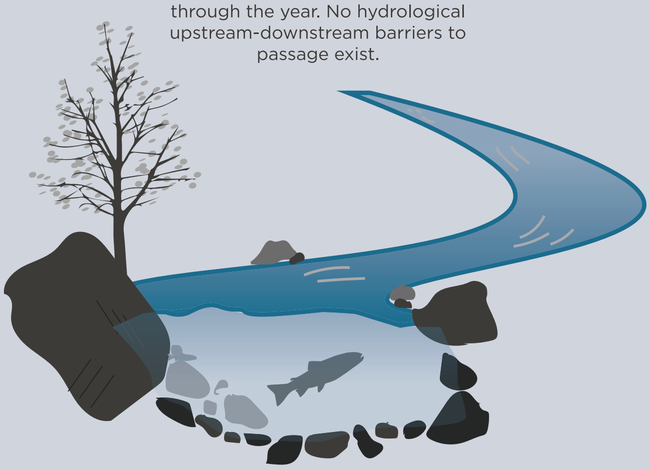
AQUATIC HABITAT

Interactions between streambed structure, channel hydraulics, water chemistry, vegetative shading, and organic matter inputs dictate the quality of habitat available for fish, macroinvertebrates, and macrophytes. In alluvial stream systems, high quality habitat typically supports vibrant and productive aquatic ecosystems—the kind of ecosystems that sustain robust trout fisheries. Habitat quality shares a directly proportional relationship to food-chain length in many systems. Ecosystems supporting long food chains tend to display greater resilience to changing external forcing variables like climate. Land and water management activities that affect sediment transport dynamics, streambed complexity, riparian shading, and local hydraulics comprise important primary controls on aquatic habitat quality.

Many aquatic species rely on specific and relatively narrow ranges of water depth, velocity and substrate types to perform various feeding/resting behaviors or complete different life stages. Fragmentation or degradation of habitat for aquatic species may, therefore, arise from modification of the hydrological regime, which alters local channel hydraulics and the spatial distribution of water depths and velocities. In a similar fashion, activities that physically alter the structure of the streambed may impact habitat quality by transforming the local hydraulic channel response to a given streamflow. The critical interaction between local structure and hydraulics gives credence to restoration approaches that aim to improve ecosystem function by reconfiguring channel cross-sectional geometry or planform patterns.

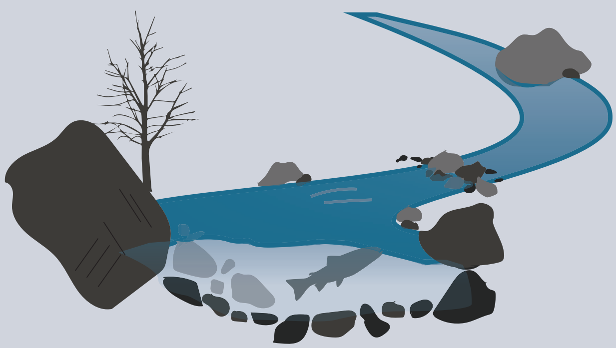
FUNCTIONING SYSTEM:

A variety of habitat types remain connected and available to organisms through the year. No hydrological upstream-downstream barriers to passage exist.



NON-FUNCTIONING SYSTEM:

High quality or critical habitats are isolated and unavailable to organisms in times of high stress. Hydrological barriers preclude organisms from utilizing the entirety of a stream network to complete important parts of their life cycle.



2.1 ASSESSMENT CRITERIA

The complex interplay between the human, physical, chemical, and biological components of the Crystal River, and of riverine systems in general, complicates the task of identifying appropriate management strategies that respond to local concerns about one or more of the Attributes (Figure 2-1). Each Attribute aggregates a suite of connected processes or characteristics. Therefore, evaluating the functional condition of multiple components of the system represents the first step towards developing a management plan that focuses actions on those components of the system constraining the delivery of highly valued EGS.

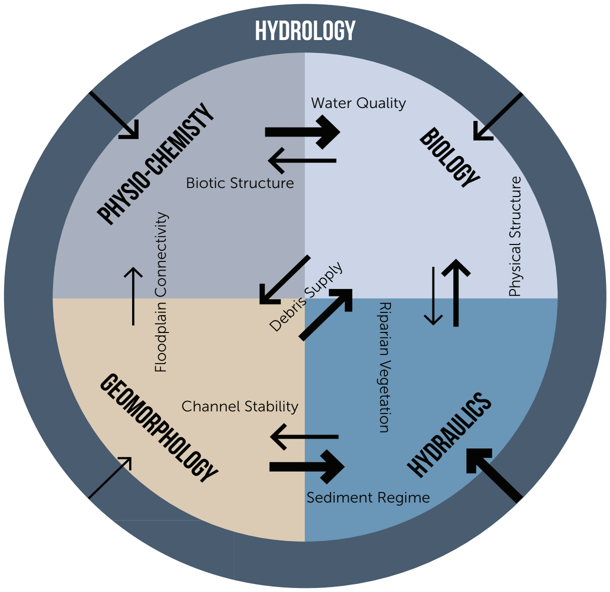


Figure 2-1: Complex relationships exist between hydrological, physiochemical, biological, geomorphological, and hydraulic river processes

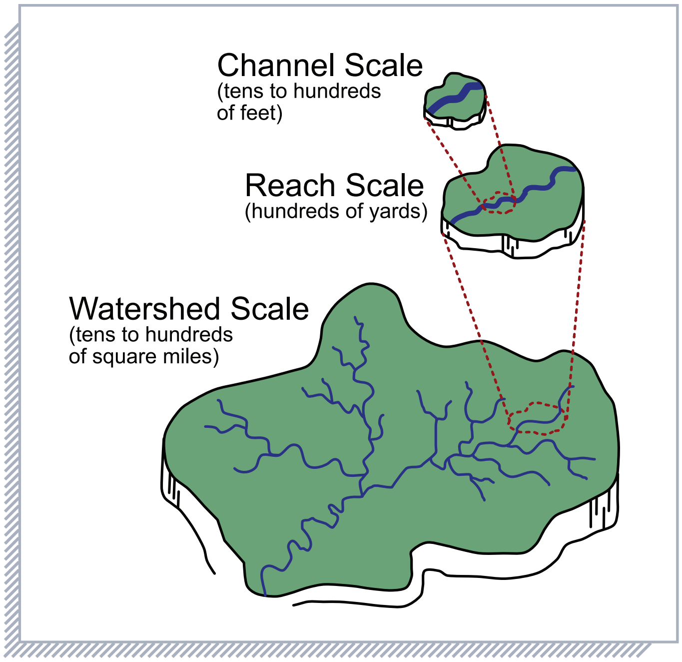
The existence of complex interactions between Attributes makes it necessary to disaggregate them into a collection of state variables. These variables describe more fundamental ecosystem processes and provide a more straightforward basis for measurement and evaluation. The CRMP assessed functional condition and identified constraints on the delivery of EGS based on a suite of physiochemical, biologic, geomorphic, hydrologic and hydraulic state variables. These include: flow regime, sediment regime, water quality, floodplain connectivity, riparian vegetation, debris supply, morphology, stability, physical structure, and biotic structure. Comprehensive evaluation of each variable through application of the Functional Assessment of Colorado Streams (FACStream) framework enabled a robust characterization of existing conditions and supported predictive assessments of changes in future state across a range of spatial scales.

Experts in geomorphology, riparian ecology, fisheries, and hydrology completed focused evaluations of the ten state variables and associated sub-variables (Table 2-1). State variable assessments evaluated current conditions and characterized the degree of departure from an unimpacted reference state using a forensic, weight-of-evidence approach.[24] A variety of assessment methodologies—some rapid and coarse, some focused and intensive—produced evidence that reflects ecosystem processes across a range of spatial scales with varying degrees of objectivity. The coarsest approaches (Level 1) produced qualitative, reconnaissance-level variable assessments that guided more targeted investigations. Rapid assessments (Level 2) focused on specific areas of concern and involved more field-intensive surveys to identify opportunities for ecological lift and reinforced expert opinions regarding the presence and magnitude of functional impairment. Where evidence of impairment persisted, intensive quantitative (Level 3) evaluations sought to explicitly account for the complex interactions between state variables and management activities. (Table 2-1). Utilization of this tiered evaluation structure facilitated a "drill-down" investigative approach that focused functional performance evaluations on the most degraded components of the river system.

SCALE	VARIABLES	SUB-VARIABLES
Watershed	Flow Regime	Total Volume, Peak Flows, Base Flows, Flow Variability
	Sediment Regime	Land Erosion, Channel Erosion, Transport
	Water Quality	Temperature Regime, Organics/Nutrients, Inorganics/Toxins
Channel	Floodplain Connectivity	Saturation Frequency, Floodplain Width, Saturation Duration
	Riparian Vegetation	Woody Vegetative Structure, Herbaceous Vegetative Structure, Species Diversity
	Debris Supply	Large Woody Debris, Detritus
Reach	Morphology	Evolutionary Stage, Planform, Dimension Profile
	Stability	Dynamic Equilibrium, Resilience
	Physical Structure	Hydraulic Structure, Coarse Scale Bedforms, Fine Scale Bedforms
	Biotic Structure	Macrophytes, Macroinvertabrates, Fish

Table 2-1: Hierarchical arrangement of state variables and sub-variables

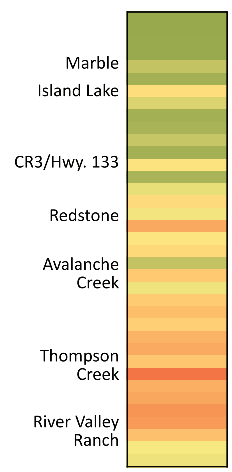
Assignment of functional condition scores for each state variable generally followed FACStream scoring criteria (Table 2-3) where a score of 100 indicated pristine conditions and a score of 50 indicated severe impairment. The overall size of the CRMP focus area necessitated delineation of the Crystal River into 36 separate assessment reaches to provide the appropriate spatial resolution for assessment activities focused on reach or channel-scale conditions. Local channel form and the degree of valley confinement informed the upstream and downstream boundaries of each reach. Individual reaches received a score for each of the ten state variables and associated sub-variables, as well as a composited score based on scoring for all state variables (Appendix D).



State variables assessed for the CRMP represent important ecosystem processes that occur at cascading hierarchical scales. Processes occurring at the contributing watershed scale (tens to hundreds of square miles) exert varying degrees of influence on reach scale (hundreds of yards) and channel scale (tens to hundreds of feet) processes. The inverse is generally not true. In a similar manner, reach scale processes generally influence channel scale characteristics and dynamics. The strength of the directional impact is limited in this case. Under some conditions, channel scale processes may alter those occurring at the reach scale. Nonetheless, it is often useful to conceptualize a hierarchical arrangement for state variables when identifying the primary stressors propagating through the ecosystem that constrain a given process or diminish some EGS of interest. The scale of the limiting process is generally commensurate with the scale of the effort required to address it. Thus, the consideration of scale is not only critical for ensuring the correct identification of stressors, but also for identifying a suite of appropriate management response opportunities.

ASSESSMENT LEVEL	DESCRIPTION	EXAMPLE METHODOLOGIES
Level 1 *remote assessment*	Coarsest level of investigation designed to provide a general estimation of functional condition and document obvious clues of impairment	• Collection of anecdotal evidence from local residents • Review of published literature and reports focused on streamflow, erosion, water quality, and aquatic life. • Aerial imagery assessments • "Windshield" surveys
Level 2 *rapid assessment*	Domain scientists and other experts use best professional judgement to score variables based on qualitative observations and data gathered during field visits.	• Rapid (1-2 day) functional condition assessments of stream reaches conducted by teams of geomorphologists, hydrologists, engineers and riparian ecologists
Level 3 *intensive assessment*	Predictive models generate quantitative parameters to validate and refine Level 1/2 assessment results.	• Indicators of Hydrological Alteration analysis • 1D/2D hydraulic modeling • Recruitment Box modeling • Aquatic habitat modeling

Table 2-2: Assessment methodologies employed during development of the CRMP



Grade	Score	Level of Impairment
A	90-100	Negligable
B	80-90	Mild
C	70-80	Significant
D	60-70	Severe
F	50-60	Profound/Unsustainable

Table 2-3: FACStream scoring criteria and associated color maps describing longitudinal patterns in functional condition for each state variable discussed in subsequent sections

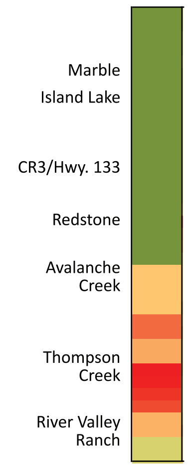
2.2 WATERSHED SCALE ASSESSMENTS

2.2.1 Flow Regime

Broad patterns of precipitation and topography largely determine a river's flow regime. In turn, fluvial ecologists generally treat flow regime as the "master variable" exerting the largest influence on riverine ecosystem form and function.[33] Activities that deplete or augment streamflow have the potential to impact important regime characteristics, including: total annual volume, magnitude and duration of peak and low flows, and variability in timing and rate of change. Changes to total annual volume and peak flows may impact channel stability, riparian vegetation, and floodplain functions. Impacts to base flows frequently alter water quality and the quality and availability of stream habitat. Alterations to natural patterns of flow variability, including the frequency and timing of floods, impact fish, aquatic insects and other biota with life history strategies tied to predictable rates of occurrence or change.[24]

information regarding flow conditions at multiple locations and across a range of flood/drought conditions produced the need for a more robust assessment approach.

Unfortunately, the arrangement of stream gauges, tributary inflows, and surface water diversion infrastructure on the Crystal River presents significant challenges to a data-driven understanding of historical and current flow regime characteristics at all locations along the stream channel. Development of an Ecological Decision Support System (EcoDSS) for the Crystal River watershed responded to this need (Appendix A). The EcoDSS is a collection of loosely coupled hydrological, hydraulic, and ecosystem-response models that jointly simulate and predict the impact



Flow Regime

IHA Metric	Location Along the Crystal River													
	Avalanche Creek Confluence	Sweet Jessup Canal	Nettle Creek Confluence	Lowline Ditch	Ella Ditch	Thompson Creek Confluence	Prince Creek Confluence	Rockford Ditch	Carbondale Ditch	Fish Hatchery	Weaver & Leonhardy Ditch	Kaiser & Sievers Ditch	Southard & Cavanaugh Ditch	Roaring Fork Confluence
Median Annual Flow (cfs)	0%	5%	9%	6%	10%	11%	11%	11%	14%	12%	10%	9%	10%	3%
Median August Flow (cfs)	0%	23%	41%	24%	48%	52%	51%	44%	59%	49%	37%	25%	27%	5%
Median September Flow (cfs)	0%	22%	41%	14%	42%	44%	44%	40%	52%	41%	33%	20%	22%	3%
Median 3-day Maximum Flow (cfs)	0%	0%	0%	0%	2%	3%	3%	3%	4%	4%	4%	3%	3%	3%
Julian Date of Maximum Flow	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Median January Flow (cfs)	0%	0%	0%	0%	0%	0%	0%	3%	3%	5%	7%	7%	7%	10%
Base Flow Index (cfs)	0%	6%	28%	15%	85%	81%	80%	60%	95%	528%	2%	1%	2%	9%
Julian Date of Minimum Flow	0.00	10.00	243.00	237.00	236.00	244.00	244.00	251.00	234.00	249.00	239.00	33.00	36.00	33.00
Median Positive Rate Change (cfs)	0%	0%	2%	9%	12%	13%	13%	13%	8%	3%	8%	6%	3%	2%
Median Negative Rate of Change (cfs)	0%	2%	1%	7%	10%	5%	2%	0%	5%	3%	2%	5%	2%	3%

Table 2-4: IHA analysis results indicating the absolute percent change in various metrics of hydrological behavior due to existing patterns of water use and management

Assessment Methodology

Assessment of flow regime alteration initially relied on literature reviews and interviews with local residents. These yielded some sparse quantitative observations, but generally produced anecdotal evidence of the location and timing of patterns of flow depletion by surface water diversions during severe drought. Conflicting evidence and a dearth of comprehensive

of water use and channel structure on stream hydrology and ecology. The hydrological modeling component of the EcoDSS provided 30 years of daily hydrological simulation results for reaches of the Crystal River below Avalanche Creek—reaches where management activities impact the flow regime. Results encompassed a range of drought and flood conditions and mimicked patterns of flow withdrawal for municipal and agricultural uses. Running the EcoDSS with all

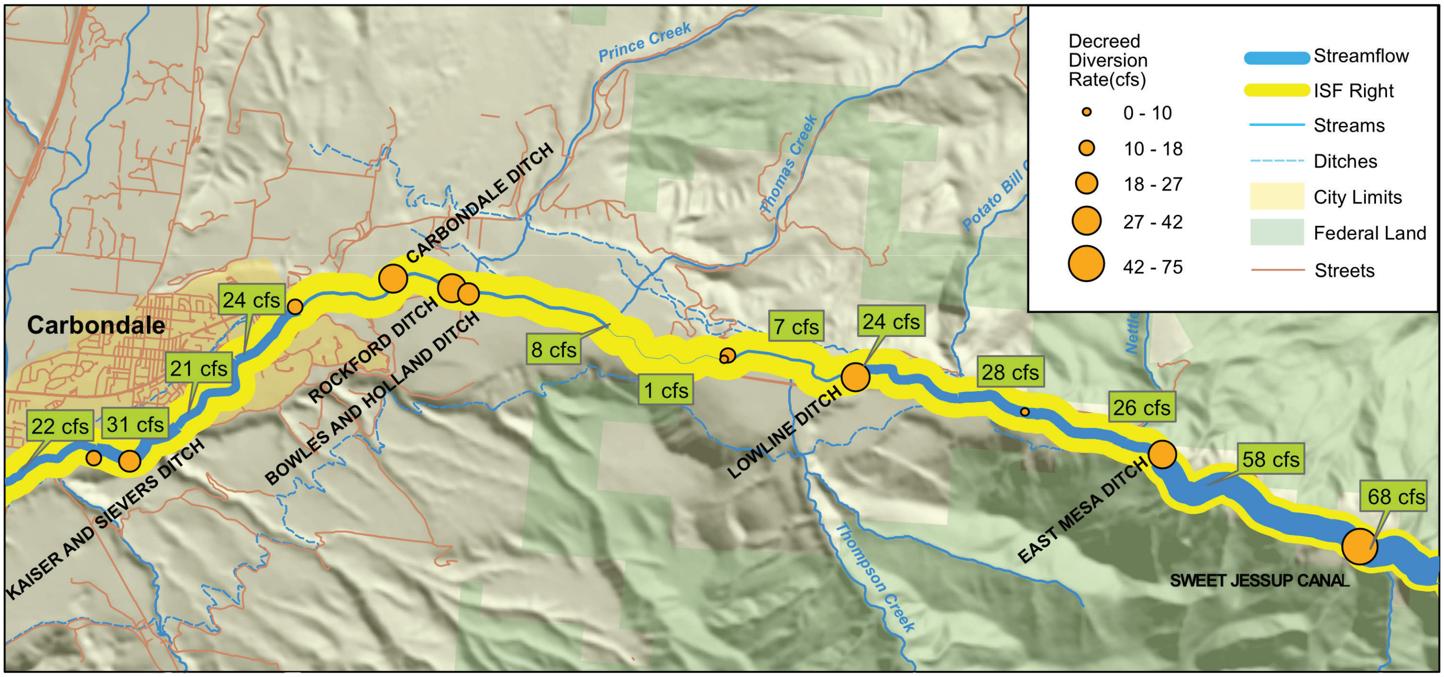


Figure 2-2: Late season streamflows observed on the Crystal River in the late summer of 2012. Green call-outs indicate measured flows. The thickness of the blue and yellow lines indicate the relative magnitudes of observed flows and the CWCB Instream Flow Right

surface water diversions switched "off" provided a simulation data set approximating natural or reference conditions on the Crystal. The EcoDSS quantitatively assessed the impact of resource management practices on total annual water yield, the magnitude and duration of peak and base flows, variability of peak flow frequency and timing, and rates of hydrograph recession. Management induced changes to the following metrics determined the functional condition of the flow regime:

- Mean Annual Flow
- Mean August Flow
- Mean September Flow
- 3-day Mean Annual Maximum Flow
- 7-day Mean Annual Minimum Flow
- Julian Date, 1-day Minimum Flow
- Julian Date, 1-day Maximum Flow

Functional Assessment

Flow regime is the most significantly constrained state variable on the Crystal River. Impairment is concentrated in the thirteen miles of the river upstream of the confluence with the Roaring Fork River. Moderate impairment beginning below Sweet Jessup Canal becomes increasingly severe downstream of Thomas Creek. Functional impairment begins to rebound somewhat below the Town of Carbondale (Figure 2-2).

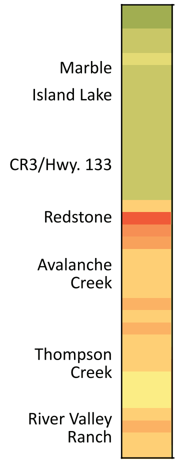
Several major surface water diversions in the lower watershed support agricultural production, drinking water supply, and non-potable irrigation water for the Town of Carbondale. Cumulatively, these withdrawals impact the flow regime most significantly during moderate (1 in 5 year) to severe drought (1 in 20 year) during late-summer low flow periods.

Field data collection campaigns executed in the summer of 2012 identified complete dewatering of Crystal River near the Thomas Road Bridge (Figure 2-3).[45] Quantitative metrics produced by the IHA assessment verify that mean August and September flows exhibit the greatest degree of departure from natural conditions (Table 2-4). Mean annual flow and variability in peak flow timing and magnitude appear less impacted; however, the onset of low flow conditions occurs somewhat earlier in the year under current management practices. Changes in flow regime frequently impact several other state variables. For example, total annual volume and peak flow characteristics influence channel stability, riparian vegetation, and floodplain connectivity. Base flow characteristics, in turn, influence patterns in water chemistry, physical and biological structure.

Management Response Opportunities

- Water conservation programs for treated and raw municipal water supply
- Irrigation application method and conveyance system efficiency upgrades
- Market-based streamflow bypass agreements
- Water leasing programs
- Off-channel reservoir construction

2.2.2 Sediment Regime



Sediment Regime

The production and transport of sediment within a stream system is a crucial determinant of stream form, habitat quality and general long-term stability. Functional condition considers the amount and timing of sediment production from the contributing watershed via surface and channel erosion, and sediment transport to and through the stream channel. Watershed-scale disruptions, such as deforestation, fire or dam construction, can alter sediment regime characteristics.

Assessment Methodology

Stakeholder conversations held during the initial scoping phases of the Plan indicated concerns about sediment dynamics among the highest concerns for diminished ecosystem function. The focus on sediment dynamics arose from extremely high sediment load observed on the Crystal River, Coal Creek, and other tributaries during late-summer precipitation events. Common knowledge held that historical road development and mining operations in Coal Basin contributed heavily to those sediment loads. Assessment of watershed-wide erosion and sediment supply dynamics relied initially on assessments of aerial imagery. Evidence of a highly dynamic system prompted reach-specific rapid assessments and, finally, a comprehensive modeling effort that quantified relative sediment yields throughout the watershed. Modeling characterized the impacts of surficial geology, topography, vegetative cover, road development, and other land-use disturbances on hillslope surface erosion, gullying, landslide activity, and road surface erosion (Appendix B). Both the timing and amount of sediment production via land and channel erosion, and sediment transport were considered in sediment regime evaluations.

Functional Assessment

The Crystal River's sediment regime appears relatively functional. The most significant impairments exist between Redstone and Avalanche Creek due to erosion from Coal Basin associated with road development and mining activity. Most sediment delivered to the Crystal from Coal Basin sources from highly erosive surficial geology, but past landslides and channel incision on Coal and Dutch Creeks evidences altered sediment yields in the past from historic Coal Basin mining practices. The bulk of these anthropogenic impacts in the Crystal River watershed is evidenced in Coal Basin itself (Figure 2-3). The Crystal River appears to transport elevated sediment loads from Coal Creek without the telltale signs of sediment transport functional degradation. Furthermore, bridge constrictions, levee construction and bank armoring near Redstone appear relatively innocuous in their impact on the continuity of sediment transport dynamics. A natural geological grade control north of Redstone causes the greatest disruption in transport dynamics in that part of the watershed. Impairments to sediment regime largely abate below Avalanche Creek where the influence of Coal Basin diminishes.

Management Response Opportunities

- Limited erosion control projects on historical mining and roadway surfaces in Coal Basin

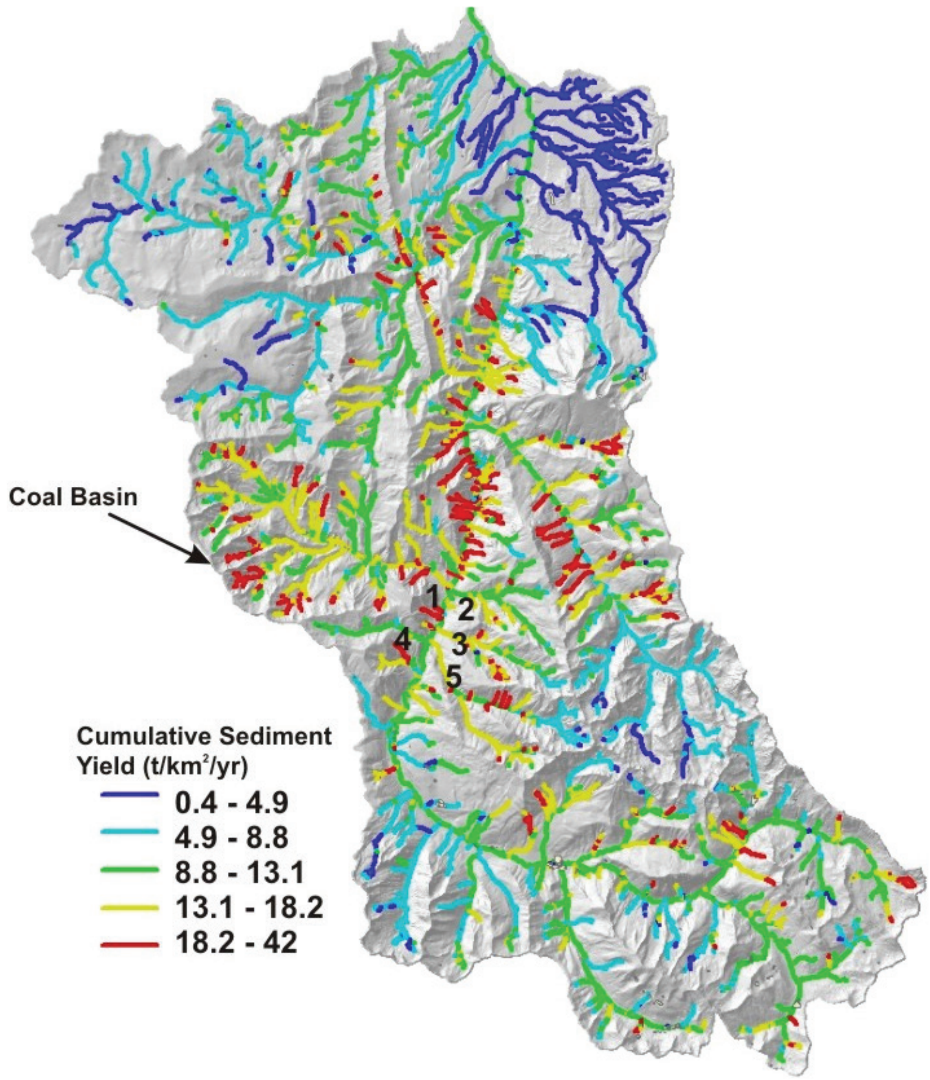
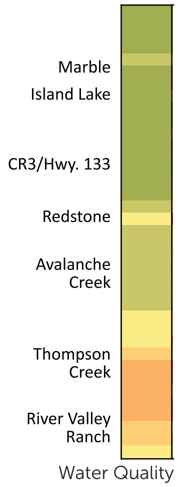


Figure 2-3: Shallow landslide and hillslope erosion modeling revealed that Coal Basin and the surrounding areas generate elevated sediment yields

2.2.3 Water Quality



Natural geological weathering and human activities occurring at the scale of the contributing watershed largely dictate the physicochemical properties apparent on a stream reach. Biogeochemical processing by stream organisms may alter local water quality conditions to a small degree.[24] Physical water quality conditions (e.g. water temperature), while somewhat influenced by local patterns of channel form and streamside vegetation, remain fundamentally rooted in upstream conditions.

Assessment Methodology

Assessment of water quality conditions relied on a review of relevant literature[28, 30, 45, 47] and on a statistical data analysis. To capture potential impacts associated with these practices, assessment of water quality conditions relied on comparison of available water quality data to Colorado Department of Health and Environment (CDPHE) WQCD standards (Appendix C). Limited data availability restricted assessments to 23 locations across the watershed for the following water quality parameter types:

- Metals
- Nutrients
- Physical Characteristics
- Inorganic Compounds

Functional Assessment

A wide variety of land uses expected to impact water quality occur in the Crystal River watershed. Activities in the upper watershed include road development, forestry, legacy hardrock mining, and limited underground quarrying. Activities in the lower watershed include riparian alteration, livestock production, roads and urbanization. Nonetheless, the mainstem Crystal River generally exhibits high levels of water quality (Table 2-4). When evaluated against Water Quality Control Division (WQCD) standards for aquatic life use protection, water chemistry data indicate no impairments exist. A relatively small number of parameters present as potential areas of concern when compared against standards for drinking water. However, natural geological processes likely contribute to observed elevated arsenic levels and the single elevated lead value may be an outlier produced by a contaminated sample or poor data collection practices.

Flow depletion from the cumulative surface water diversions on the lower Crystal contributes to elevated temperatures during drought conditions. Previous studies indicate exceedances of the daily maximum stream temperature standard for protection of fisheries on the Crystal River below Thomas Road Bridge. Although limited data is available to assess temperature patterns across a range of streamflows, these transient conditions likely exist between July and October in moderate to severe drought conditions at locations along the river where flow depletions are most pronounced. Data collected in 2012 and 2013 indicates a strong inverse relationship between water temperatures and discharge between Thompson Creek and the Roaring Fork River. Elevated water temperatures in the lower Crystal River contribute to limited habitat quality and availability during drought conditions.

Management Response Opportunities

- Water conservation programs for treated and raw municipal water supply
- Irrigation application method and conveyance system efficiency upgrades
- Market-based streamflow bypass agreements
- Water leasing programs
- Off-channel reservoir construction

USE PROTECTION ASSESSMENT RANKINGS: GOOD; ACCEPTABLE; CONCERN; POOR; LOW RESOLUTION; DATA GAP

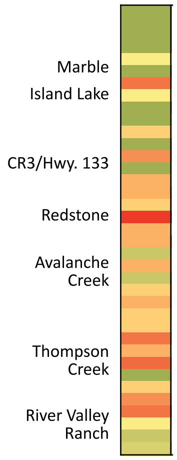
	Aquatic Life Use Protection Water Quality Standards																																	
	Biology					Physical					Nutrients			Inorganics					Metals															
	Algae	Dead Fish	Fish	Invertebrates	Macrophyton	Dissolved Oxygen	Specific Conductance	Suspended Solids	Temperature	pH	Chlorophyll	Total Nitrogen	Total Phosphorous	Ammonia	Chlorine	Cyanide	Nitrite	Sulfide	Aluminum	Arsenic	Cadmium	Chromium (III)	Chromium (VI)	Copper	Iron	Lead	Manganese	Mercury	Nickel	Selenium	Silver	Thallium	Uranium	Zinc
Crystal River	GOOD	GOOD	GOOD	GOOD	DATA GAP	GOOD	DATA GAP	DATA GAP	ACCEPTABLE	GOOD	DATA GAP	LOW RESOLUTION	LOW RESOLUTION	LOW RESOLUTION	DATA GAP	DATA GAP	LOW RESOLUTION	DATA GAP	GOOD	GOOD	GOOD	DATA GAP	DATA GAP	GOOD	GOOD	GOOD	GOOD	DATA GAP	LOW RESOLUTION	GOOD	LOW RESOLUTION	DATA GAP	LOW RESOLUTION	GOOD
Coal Creek	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	GOOD	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	GOOD	GOOD	GOOD	DATA GAP	DATA GAP	GOOD	GOOD	GOOD	GOOD	DATA GAP	DATA GAP	GOOD	DATA GAP	DATA GAP	DATA GAP	GOOD
Thompson Creek	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	ACCEPTABLE	GOOD	DATA GAP	DATA GAP	DATA GAP	LOW RESOLUTION	DATA GAP	DATA GAP	DATA GAP	DATA GAP	CONCERN	LOW RESOLUTION	GOOD	DATA GAP	DATA GAP	GOOD	GOOD	GOOD	GOOD	DATA GAP	LOW RESOLUTION	LOW RESOLUTION	LOW RESOLUTION	DATA GAP	DATA GAP	GOOD
North Thompson Creek	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	GOOD	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	DATA GAP	POOR	LOW RESOLUTION	LOW RESOLUTION	DATA GAP	DATA GAP	LOW RESOLUTION	GOOD	LOW RESOLUTION	GOOD	DATA GAP	DATA GAP	LOW RESOLUTION	DATA GAP	DATA GAP	DATA GAP	GOOD

Figure 2-4: Assessment of water quality data against WQCD standards for aquatic life use protection

2.3 REACH SCALE ASSESSMENTS

2.3.1 Floodplain Connectivity

The frequency, lateral extent, and duration of interactions between the channel and 5-year floodplain create a characteristic pattern of floodplain connectivity that determines the extent to which the river accesses and hydrates overbank areas. Overbank flows elevate the water table in the alluvial aquifer and produce favorable conditions for riparian vegetation. Typical floodplain connectivity impairments result from watershed-scale impacts to the flow regime or localized geomorphic impacts from artificial levees, ditches, channelization, or channel enlargement.[24]



Floodplain Connectivity

Assessment Methodology

Evaluations on the Crystal River relied on reviews of aerial imagery, rapid field assessments, and hydrological and hydraulic simulation modeling. Reviews of aerial imagery revealed locations of limited floodplain development along the river corridor. Rapid assessments utilized expert knowledge of geomorphological processes and riparian ecology to determine the extent to which modification of the flow regime or structural impediments limited connections between the channel and overbank areas. The EcoDSS supported a more quantitative assessment of connectivity by relating patterns in stream hydrology, channel hydraulics, and floodplain inundation by simulating two dimensional channel flow along the lower Crystal River on a daily timestep across a range of hydrological conditions (e.g. average flow, moderate flood, extreme flood). The degree of departure from reference conditions was evaluated by comparing the total inundated floodplain area for each reach under existing conditions and natural conditions (i.e. no surface water diversions) as simulated by the hydrological model in the EcoDSS (Appendix A).

Functional Assessment

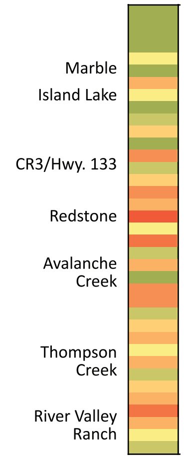
Widespread floodplain connectivity issues do not exist on the Crystal River. However, small pockets of considerable impairment occur at a few locations in the watershed. Pockets are concentrated around Island Lake, in the Redstone area, and near bridges in the lower Crystal. Observed impairment is generally attributable to roads, railroad grades, and bridges. Existing and abandoned transportation corridors bisect historical floodplains, diminishing the ability for bankfull flows to inundate the full lateral extent of the historical floodplain, fragmenting important off-channel habitat and reducing the extent of riparian zones. Roadfill and bridges impose artificial constriction in unconfined reaches, cutting off the stream's access to floodplain. Levees and berms protecting developments from floodwater, particularly around Redstone, limit access to undeveloped floodplain. These impairments limit effective floodplain width, and reduce the floodplain's ability to buffer against extreme changes in streamflow. Reduction in effective floodplain width further limits the quality and extent of important terrestrial and aquatic habitat.

Management Response Opportunities

- Culvert and or bridge installation through historical railroad grade at Red Wind Point
- Conservation and protection of limited high-quality floodplain habitats

2.3.2 Riparian Vegetation

Riparian vegetation performs several important functional roles for stream ecosystems. Root systems increase bank stabilization and the vegetative overstory provides detrital input and shading for aquatic species. Riparian forests supply the channel with woody debris, an important determinant in local physical structure. The functional condition of riparian vegetation considers species diversity and the structure of both the woody and herbaceous vegetation communities.[24] Impacts to riparian vegetation include deforestation or habitat degradation resulting from an altered hydrological regime or floodplain disconnections.



Riparian Vegetation

Assessment Methodology

Assessments of riparian condition consider the age class distributions and overall diversity of riparian species, total vegetative cover, root strength and depth, and above and belowground density of woody and herbaceous vegetation. Characterization of vegetative condition on the Crystal River relied primarily on literature reviews[9, 3, 19, 20] and rapid field assessments. Field assessments considered dominant valley form (e.g. confined vs. unconfined) and local floodplain size when assessing the degree of departure from reference conditions. In areas affected by hydrological impairment, the EcoDSS implemented the Recruitment Box methodology[31] to provide a quantitative understanding of constraints on cottonwood recruitment success (Figure 2-5). Simulation of one-dimensional channel hydraulics at representative cross sections throughout the lower Crystal River replicated rates of hydrograph recession and falling water surface elevations. Cottonwood saplings require a limited rate of water table decline to ensure that growing roots maintain contact with the free water surface. Comparing the number of days exhibiting optimal recruitment conditions under natural vs. existing conditions assessed the degree of departure from reference conditions.

Functional Assessment

Riparian areas exhibit high functional capacity in the upper Crystal River watershed. Pockets of moderate impairments exist around Marble, Redstone and below Avalanche Creek. Observed patterns of impairment on the mainstem of the Crystal River generally correspond to upland land use practices, rather than water resource management activities.

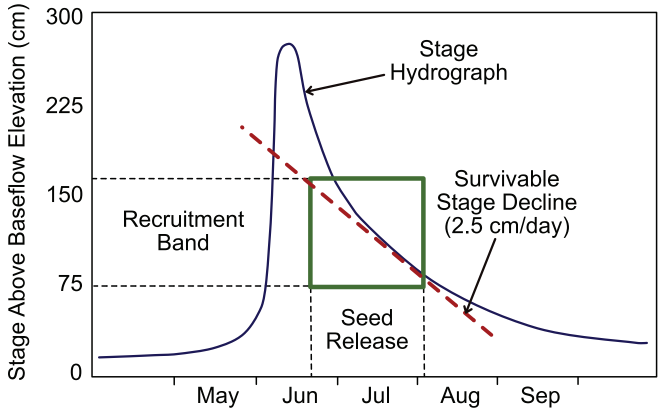


Figure 2-5: The Recruitment Box methodology compares rates of water table decline to average root growth rates for woody riparian vegetation to identify optimal and sub-optimal conditions for sapling growth

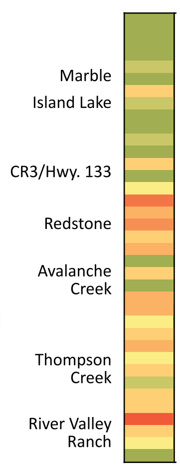
Floodplain development in the area around Redstone limits the extent of the riparian zone, impacting species diversity and wood vegetation structure. Riparian forest removal in several locations along the river corridor, particularly in the lower Crystal where grazing and haying production is more intensive, similarly limit the functionality of these zones. The most significant riparian forest degradation exists between the Bowles and Holland Ditch headgate and the River Valley Ranch (RVR) golf course. Limited invasion of Russian olive trees and tamarisk near the confluence with the Roaring Fork River likely produce limited effects on overall riparian function but could indicate a significant pathway for future degradation.

Management Response Opportunities

- Targeted removal of invasive species near the Roaring Fork River
- Moratorium on riparian forest removal practices
- Enhanced grazing enclosure buffer widths above the Carbondale Ditch headgate.
- Small-scale riparian restoration on Town of Carbondale stream tract.

2.3.3 Debris Supply

Debris supply encompasses the amount, timing, and type of large woody debris and small organic detritus reaching a stream channel from near stream areas. Large woody debris performs an important function as a component of structural heterogeneity on the streambed, altering channel hydraulics, patterns sediment transport, and habitat quality. Detritus represents a critical carbon and energy input to aquatic food webs. Impairment of debris supply typically follows degradation of riparian forests in response to active removal of vegetation, hydrological modification or floodplain dissection.



Debris Supply

Assessment Methodology

Assessment of debris supply relied exclusively on rapid field assessments that examined the types of debris present in the channel and the presence or absence of source areas supplying similar material throughout the river corridor.

Functional Assessment

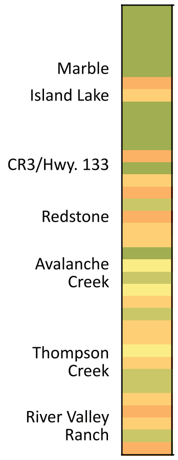
Organic debris is a structural building block and important energy source in stream ecosystems. Patterns of impaired debris supply mirrored that of riparian vegetation. Small isolated pockets of minor impairment exist near Redstone and between the Bowles and Holland Ditch headgate and the RVR golf course. Valley floor development activities affecting riparian vegetation represent the primary stressors on debris supply. Given the relatively high functionality of this variable, response opportunities are somewhat limited.

Management Response Opportunities

- Moratorium on riparian forest removal practices
- Enhanced grazing exclosure buffer widths above the Carbondale Ditch headgate.
- Small-scale riparian restoration on Town of Carbondale stream tract.

2.4 CHANNEL SCALE ASSESSMENTS

2.4.1 *Stream Morphology*



Morphology

A stream's morphological patterns reflect the interplay between hydrology, channel hydraulics, sediment supply, beaver activity, and streamside vegetation. Assessments of stream morphology consider the patterns of channel evolution, planform, cross-sectional dimensions, and channel profile. Impacts to stream morphology may arise from construction of roads and levees, extirpation of beavers, reduction of the active floodplain width, and disruption of sediment supplies due to dam construction. Stream's exhibiting morphological characteristics inappropriate for local valley forms and sediment regime may display elevated channel instability or a reduction in physical heterogeneity of the streambed.

Assessment Methodology

Evaluation of channel morphology began with windshield surveys and assessments of aerial imagery to determine the Rosgen stream classification of each reach. Subsequently, rapid field assessments investigated states of dynamic equilibrium and identified local impacts on cross-sectional geometry and planform structure.

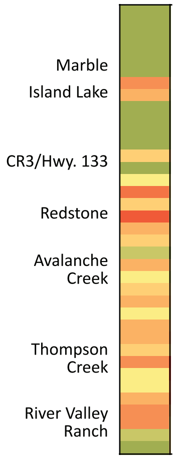
Functional Assessment

The majority of the Crystal River transports sediment effectively and exhibits very similar and stable channel types, planforms and dimensions. Minor morphological impairment results from local, structural instabilities due to development in near-stream areas. Levee construction and bank armoring near Redstone and Marble affect patterns of sediment scour and deposition, destabilizing natural morphology. Floodplain development in these areas also diminishes the extent and quality of riparian vegetation. Riparian forests help maintain stable channel forms by strengthening streambanks and contributing large woody debris to the stream channel. Impairments observed on the Crystal near Carbondale are mostly due to the interactive effects of water withdrawals and diversion infrastructure. Push-up dam creation near headgates somewhat disrupt sediment transport dynamics, contributing to aggrading bedforms, braiding, and increased rates channel avulsion. These effects are most pronounced near the headgates for the Carbondale, and Kaiser and Sievers ditches. Similar morphological patterns exist near the Lowline Ditch headgate. However, field assessment results suggest that aggradation at the terminus of the Crystal River Canyon is primarily due to a natural geological transition. A reduction in channel confinement and bed slope at this location diminish the River's ability to affectively convey the high bedloads common to the Crystal.

Management Response Opportunities

- Replacement of push-up dams with permanent grade control structures

2.4.2 *Channel Stability*



Channel Stability

Channel stability reflects the river's ability to balance sediment supply and transport in dynamic equilibrium. High channel stability typically equates to resiliency and the ability of the stream to recover after large disturbances. Morphological impairment on alluvial streams often emerges in the form of local channel instability. Stressors at the channel scale (e.g. bank hardening at a bridge crossing), reach-scale (e.g. bank failure due to riparian vegetation removal), or watershed-scale (e.g. sediment supply disruption due to dam construction) may, in turn, cause this instability.

Assessment Methodology

Characterization of channel stability relied heavily on prior assessments of flow regime, sediment regime, stream morphology, floodplain connectivity, and riparian vegetation. Process-based evaluations of fluvial geomorphic processes permitted prediction of unstable positions along the stream corridor. Follow-up field assessments at these locations verified the presence or absence of expected conditions. Where previous assessments indicated impacts to the hydrological regime, the EcoDSS employed two-dimensional hydraulic modeling and critical shear stress analysis to evaluate local sediment transport dynamics and the impacts of water management on channel maintenance flows (Appendix A). This approach assessed the degree of departure from natural conditions by comparing the fractional area of mobilized bed material for each reach under existing conditions and natural conditions (i.e. no surface water diversions) as simulated by the hydrological model in the EcoDSS (Figure 2-6).

Functional Assessment

Longitudinal patterns of channel stability on the Crystal River closely follow the functional condition of flow regime, sediment regime, floodplain connectivity, riparian vegetation, and channel morphology. Isolated pockets of minor to moderate impairment exist near Marble, Redstone, and in the vicinity of diversion infrastructure near Carbondale. Constrictions in the floodplain caused by push-up dams, levees, roads and bridges alter local patterns of sediment scour and deposition. These hardened structures are among the most stable channel forms in the river corridor, but may increase risk for chronic or catastrophic instabilities in the upstream and downstream direction. Little evidence of chronic instabilities exists; however, conditions may rapidly change following large magnitude flood or sediment mobilization events. Reconnection of disconnected floodplains and future realignment of levees and roadways can help mitigate for these risks. While impairments to channel stability are relatively minor on the Crystal, they are most pronounced near the headgates for the Carbondale, and Kaiser and Sievers ditches. Push-up dams created in the late summer at these locations frequently persist throughout the winter and spring months

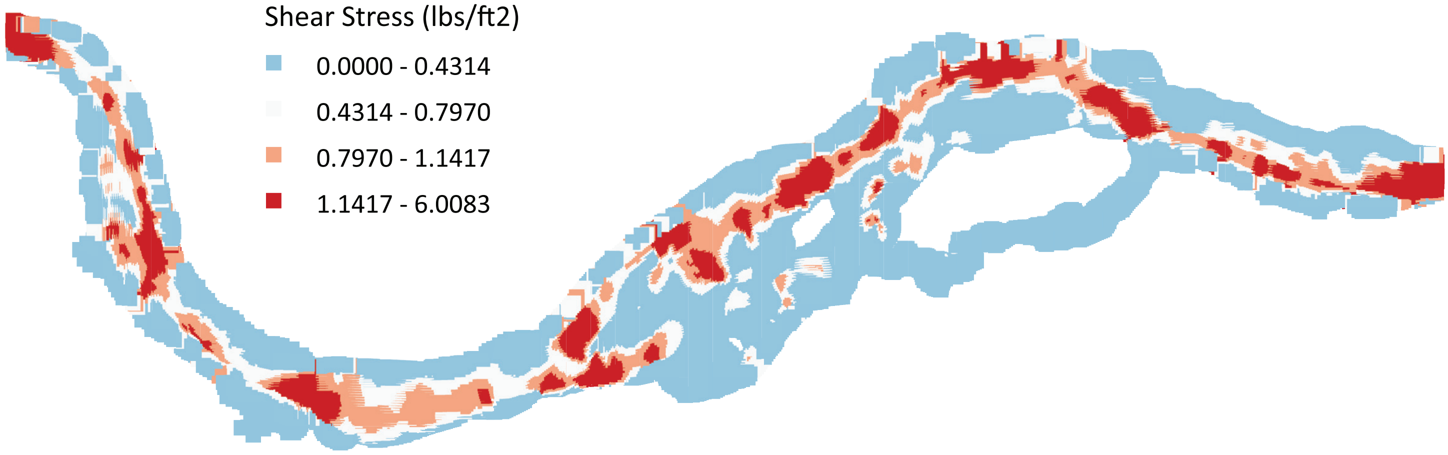


Figure 2-6: 2-dimensional hydraulic modeling simulated streambed shear stress conditions across a range of streamflows and allowed for assessment of sediment mobilization potential

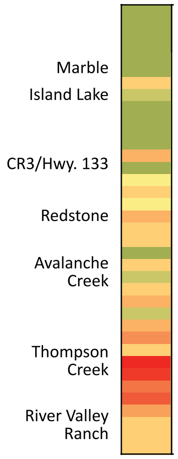
altering sediment dynamics and, where dams are large enough, contributing to elevated rates streambank avulsion and channel widening during peak flows. Similar instabilities noted near the Lowline Ditch headgate likely result from natural patterns in valley-scale landscape form.

Management Response Opportunities

- Replacement of push-up dams with permanent grade control structures
- Bridge span widening during future infrastructure replacement projects
- Culvert and or bridge installation through historical railroad grade during regional trail development at Red Wind Point

2.4.3 Physical Structure

Physical heterogeneity in the streambed and water column results from the complex interplay between the patterns of erosion, scour, and deposition that shape the streambed.24 As is the case for stream morphology, biological drivers, such as riparian vegetation, wood, and beavers, may also exert significant control over physical structure. Assessments of physical structure consider the hydraulic structure (water depth and velocity distributions), bed and bank features, and substrate material. Heterogeneity is a critical determinant of habitat quality for many aquatic organisms including macroinvertebrates and fish. Activities that physically alter the structure of the streambed, disrupt the sediment regime, or reduce large woody debris supplies to a reach frequently impact the physical structure and degree of heterogeneity present in the stream channel.



Physical Structure

Assessment Methodology

Characterization of the physical structure of stream habitat aggregated results from prior assessments of flow regime, stream morphology, debris supply, and biotic structure to identify positions throughout the river corridor expected to exhibit significant departure from natural conditions. Visual indication of stress to the hydraulic structure was observed during rapid field assessments. Where field assessments and results considering other state variables identified impairment, the EcoDSS employed two-dimensional modeling of channel hydraulics and habitat quality and availability (Figure: Habitat suitability curves) to assess management impacts on fine scale (feet to tens of feet) physical structure (Appendix A). This EcoDSS assessed the degree of departure from natural conditions by comparing the weighted usable area (WUA)[32] of critical fish habitat on each reach under existing conditions and natural conditions (i.e. no surface water diversions).

Functional Assessment

Physical Structure is not significantly impacted in the Crystal River headwaters. Pockets of mild to moderate impairments become increasingly concentrated in the lower part of the Crystal where water resource management activities alter patterns of streamflow. Relatively homogenous bed structures in reaches on the lower Crystal generally limit habitat quality and availability and makes them more vulnerable to physical impacts produced by modifications of the hydrological regime. Water depletions supporting agricultural and municipal uses diminish spatial heterogeneity in water velocity and depth, fragmenting high quality habitat. Impairments are most pronounced between the headgates for the Lowline Ditch and Carbondale Town ditch in moderate (1 in 5 year) to severe (1 in 20 year) drought conditions (Figure 2-7). Conditions abate somewhat in the downstream direction as surface and groundwater return flows contribute to increased flows (Appendix A).

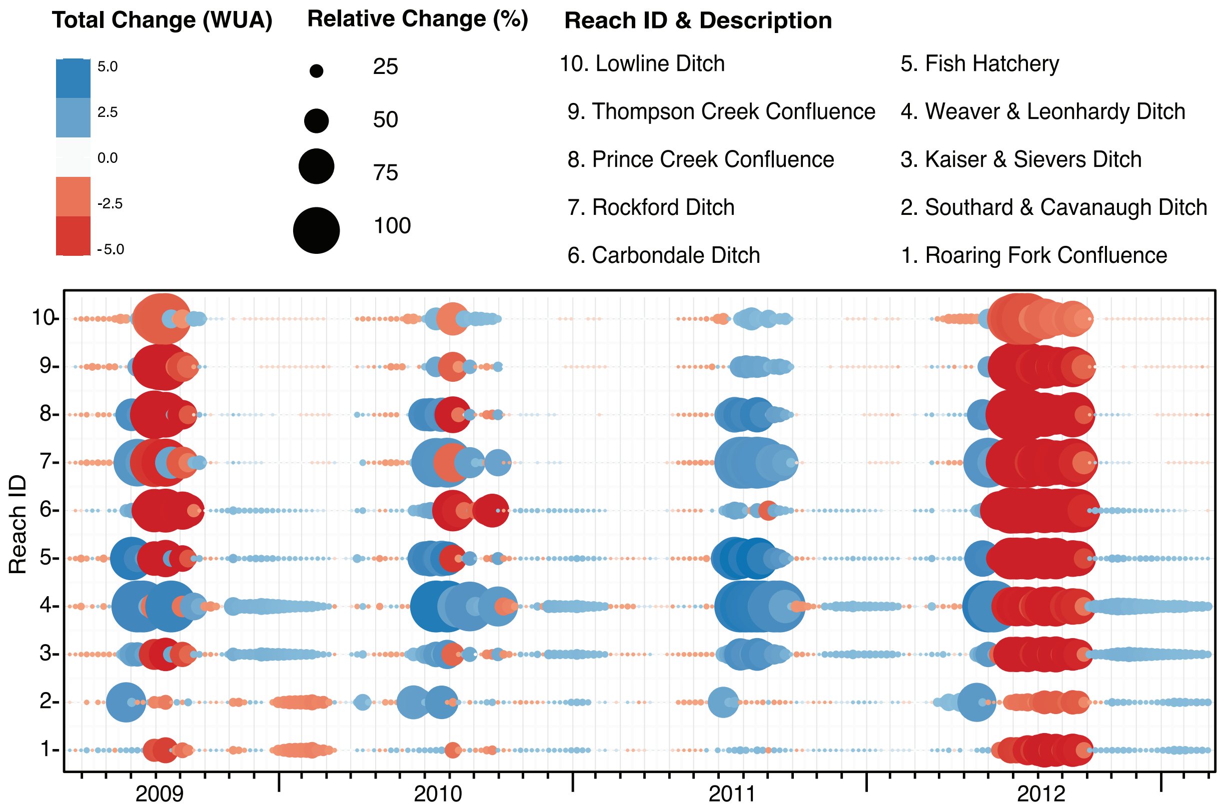


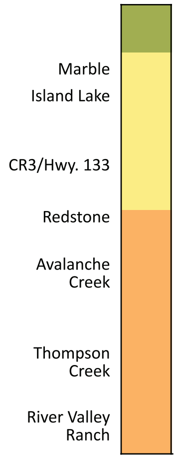
Figure 2-7: Changes in adult rainbow habitat availability due to water management and use on the lower Crystal River across a range of hydrological conditions. Larger, redder circles indicate a significant reduction in habitat quality and availability. Blue circles indicate a relative increase in habitat quality brought about by reductions in water velocity or by late season return flows that accompany agricultural water uses

Management Response Opportunities

- Water conservation programs for treated and raw municipal water supply
- Irrigation application method and conveyance system efficiency upgrades
- Market-based streamflow bypass agreements
- Water leasing programs
- Off-channel reservoir construction
- Stream habitat enhancement projects

2.4.4 Biotic Structure

Biotic structure considers the total biomass and species diversity of microbes, macrophytes, macroinvertebrates, fish and amphibians, and other animals. The degree to which a stream can support complex trophic structures when assessed against reference conditions is a prime indicator of overall ecosystem health. The living components of the stream system are the components most frequently recognized for their ties to EGS. The biotic makeup of a stream is impacted by all other ecosystem state variables. As a result, any activity that impairs other processes at the watershed, reach, or channel scale may similarly affect biotic structure. For example, disruptions in the hydrological regime impact the structural complexity of the streambed and water column. This complexity is an important control on habitat quality for fish and macroinvertebrates and, where it is reduced, a corresponding impairment of biotic structure may result.



Biotic Structure

Functional Assessment

The Crystal enjoys a healthy biotic structure above Redstone. Some moderate impairment is evident below this location. The condition of macrophytes and macroinvertebrates in most locations along the Crystal do not indicate impairment by human activities. Some exceptions exist for macroinvertebrates in Coal Basin where significant bed mobilization and sediment transport events likely produce local, short-lived extirpations. Evidence for impairments to biotic structure focus on fisheries. The lower Crystal does not support robust whitefish and sculpin populations, or sustainable rainbow trout fishery—despite active management and stocking by CPW in support of the latter. Comparison of historical rainbow trout, brown trout, and whitefish population data sets for the upper Crystal River, lower Crystal River, and lower Eagle River indicate fundamental differences in community structures (Figure 2-8). Assessing Crystal River fisheries data against available reference conditions and consideration of prior assessments of hydrological regime, water quality, channel morphology, and physical structure suggest that modification of local hydrology in support of municipal and agricultural water uses alters channel hydraulics and increases water temperature extremes—critical determinates of habitat quality and extent.

Assessment Methodology

Conversations with long-time residents in the Crystal River valley indicate that the absence of a robust fishery in the Crystal River near Carbondale is a long-recognized chronic condition. The Colorado Department of Parks and Wildlife (CPW), the United States Forest Service (USFS) and Roaring Fork Conservancy (RFC) provided data instrumental in assessing biological conditions on the Crystal. A comparative review of data collected by CPW at multiple points along the river corridor elucidated species diversity, total biomass, and age class distributions of the Crystal River fishery. Assessing the degree of departure of the fishery from natural conditions relied heavily on expert review and communication of resource management expectations by CPW staff. A direct comparison of data collected on the Crystal with nearby reference streams supported those discussions. Relevant literature [40,41] provided the basis for assessing macroinvertebrate community health. Data collected by USFS and RFC helped characterize the structure and health of benthic macroinvertebrate communities. Macroinvertebrate condition was assessed according methodologies outlined in the WQCD Aquatic Life Use Attainment Policy Statement.[12]

Management Response Opportunities

- Water conservation programs for treated and raw municipal water supply
- Irrigation application method and conveyance system efficiency upgrades
- Market-based streamflow bypass agreements
- Water leasing programs
- Off-channel reservoir construction
- Stream habitat enhancement projects

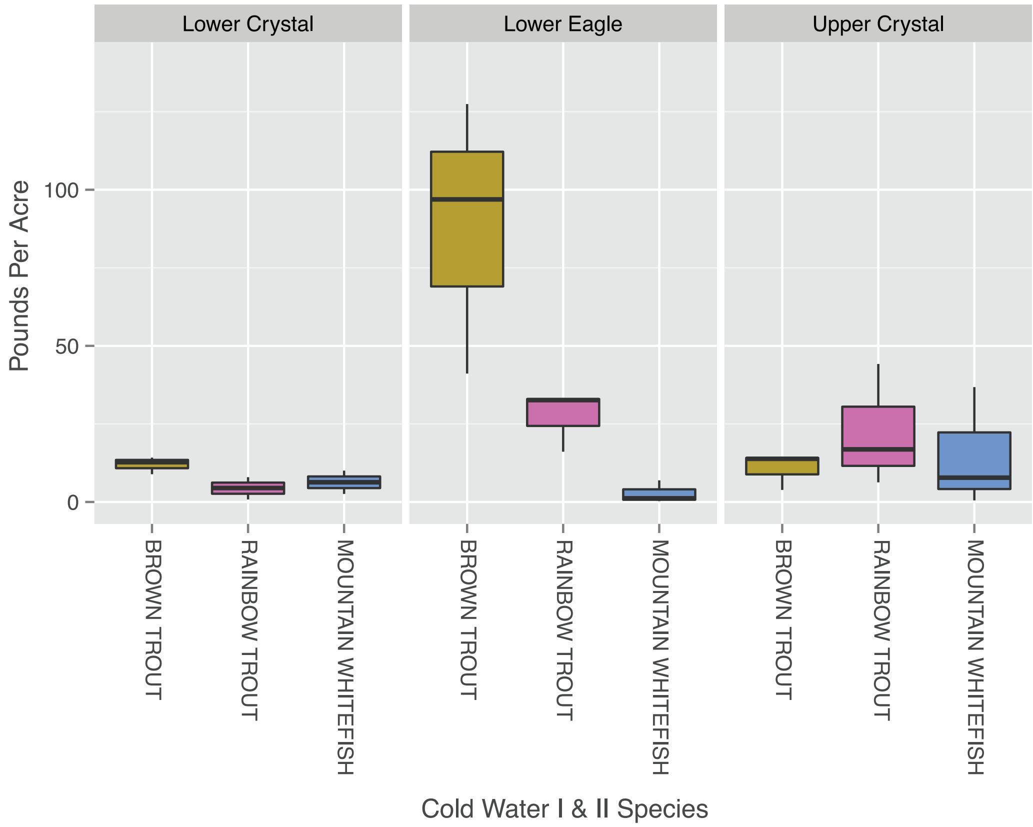


Figure 2-8: Differences in fish species biomass between the upper and lower Crystal River and the lower Eagle River

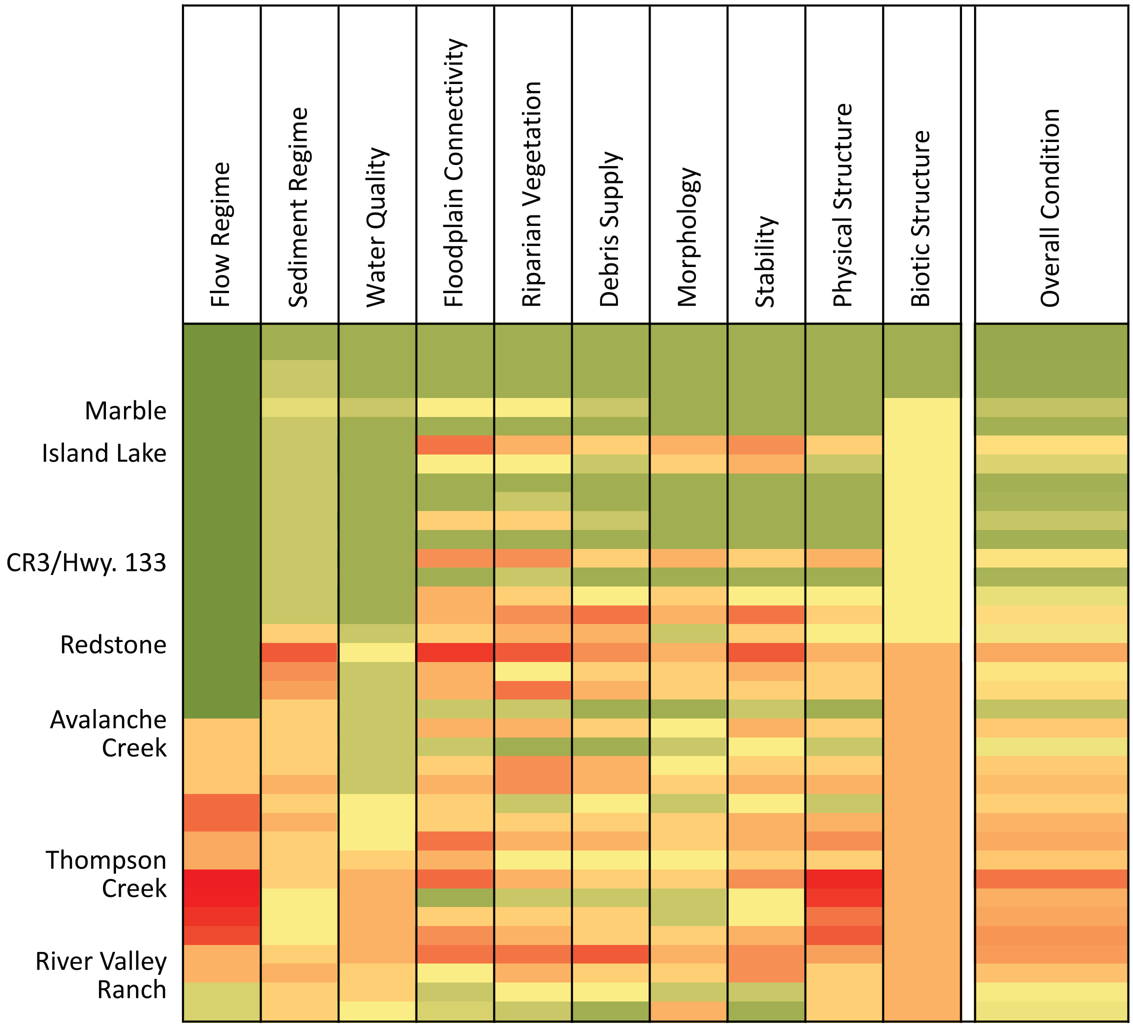
2.5 AGGREGATED FUNCTIONAL CONDITION

Functional assessment of the various components of the Crystal River ecosystem illuminated three important conclusions:

1. Flow regime alteration in the 7 miles of the Crystal River above its confluence with the Roaring Fork impairs physical structure, limits aquatic habitat quality, and may be responsible for observed impairments to local trout fisheries.
2. Moderate site-specific impacts to floodplain connectivity, riparian vegetation, debris supply, stream morphology and stability exist at several locations throughout the river corridor, particularly in the vicinity of Redstone.
3. The upper reaches of the Crystal River exhibit adequate functional condition.

The CRMP identifies a wide variety of management options to lessen observed impacts to ecosystem function at a range of spatial scales and at different locations in the watershed (Table 2-5). Few external stressors exist in the headwaters of the Crystal contributing to a generally healthy ecosystem above Redstone. Constraints on function slowly increase in the downstream direction due to the cumulative effects of floodplain development and surface water diversions. The reaches of Crystal River between Thompson Creek and the confluence with the Roaring Fork exhibit the most degraded overall functional condition. This pattern most strongly reflects late summer modifications to the hydrological regime and cascading impacts on channel hydraulics, water temperature, habitat quality and availability, and biotic structure. The dominant nature of the impacts to streamflow and habitat suggest that management strategies that focus on these two variables will yield the greatest overall benefit to the Crystal River.

Grade	Score	Level of Impairment
A	90-100	Negligable
B	80-90	Mild
C	70-80	Significant
D	60-70	Severe
F	50-60	Profound/Unsustainable



Management Response Opportunities	State Variable Addressed
Water conservation programs for treated and raw municipal water supply	Flow Regime, Water Quality, Physical Structure, Biotic Structure
Irrigation application and conveyance system efficiency upgrades	Flow Regime, Water Quality, Physical Structure, Biotic Structure
Market-based streamflow bypass agreements	Flow Regime, Water Quality, Physical Structure, Biotic Structure
Water leasing programs	Flow Regime, Water Quality, Physical Structure, Biotic Structure
Off-channel reservoir construction	Flow Regime, Water Quality, Physical Structure, Biotic Structure
Low flow channel modification/stream habitat enhancement projects	Physical Structure, Biotic Structure
Limited erosion control projects on historical mining and roadway surfaces in Coal Basin	Sediment Regime
Culvert and/or bridge installation through historical railroad grade at Red Wind Point	Floodplain Connectivity, Stability
Limited floodplain reconnection at the mouth of Coal Basin and Thompson Creek	Floodplain Connectivity
Conservation and protection of limited high-quality floodplain habitats	Floodplain Connectivity
Targeted removal of invasive species near the Roaring Fork River	Riparian Vegetation
Moratorium on riparian forest removal practices	Riparian Vegetation, Debris Supply
Enhanced grazing exclosure buffer widths above the Carbondale Ditch headgate.	Riparian Vegetation, Debris Supply
Small-scale riparian restoration below Bowles and Holland Ditch	Riparian Vegetation, Debris Supply
Replacement of push-up dams with permanent grade control structures	Morphology, Stability
Bridge span widening during future infrastructure replacement projects	Stability

Table 2-5. Management response opportunities on the Crystal River address observed constraints on state variables.

3 EXISTING WATER USES

Local resource management and water conservation organizations—the Roaring Fork Conservancy and Public Counsel of the Rockies—considered functional ecosystem assessment results and expressed concern that observed impairments to the hydrological regime push the Crystal River to a less-desirable state, reducing delivery of important ecosystem goods and services. This concern initiated a focused investigation of opportunities to mitigate impacts on late season streamflows and habitat structure in the lower seven miles of the watershed. Evaluation of projects and programs to address constraints on ecosystem function necessarily considered the social and economic systems reliant upon existing patterns of water use. The CRMP utilized a robust characterization and engineering analysis of existing water uses to provide an evidence-based foundation for recommendations that met stakeholder goals.

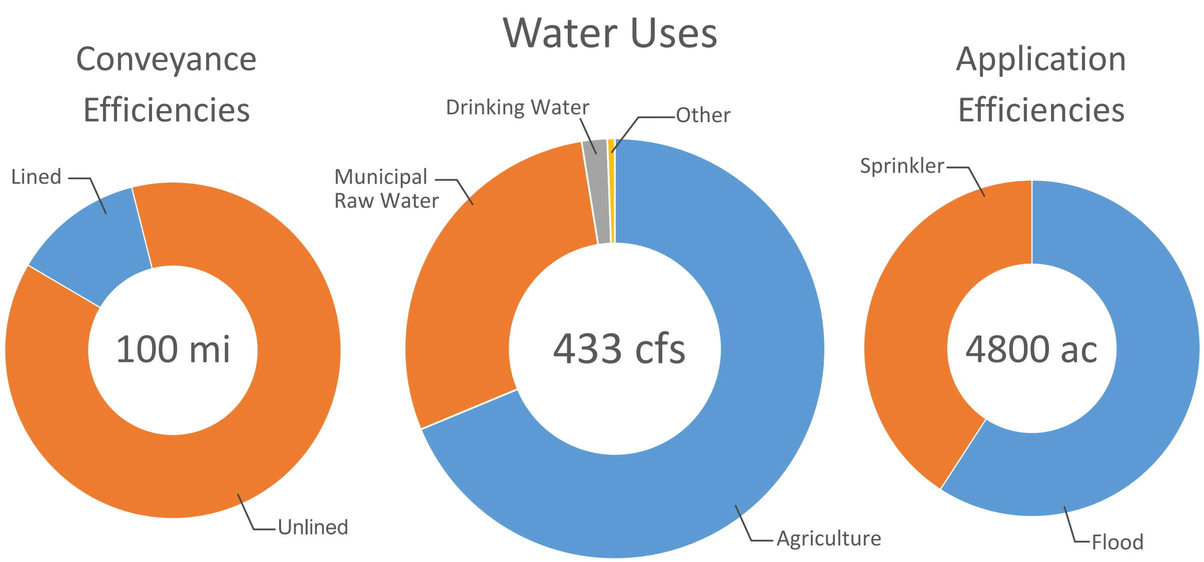


Figure 3-1: Summary of water uses and supporting infrastructure on the Crystal River and its tributaries. 433 cfs of surface water diversions are conveyed along approximately 100 miles of ditch and pipe to support municipal uses and about 4800 acres of irrigated land

3.1 WATER RIGHTS OVERVIEW

Legal and administrative frameworks governing the use of water on the Crystal River allocate water among multiple users according to the Prior Appropriation System. Water from the River supports agricultural production, municipal water use, operation of a Colorado Parks and Wildlife (CPW) fish hatchery, and a minimum instream flow right (Figure 3-1) according to a seniority system that places the oldest existing uses ('senior rights') in priority over other new uses ('junior rights').

3.1.1 Municipal Use Rights

The Town of Carbondale supplies local residents with treated drinking water from diversions on Nettle Creek. Backup sources include a well field near the CPW fish hatchery and another in the Roaring Fork River's alluvial aquifer. Existing water rights are generally considered adequate to accommodate future population growth in the Town and surrounding areas. The Town's adjudicated surface water diversion rate on Nettle Creek is 5.75 cfs.

3.1.2 Agricultural Use Rights

Agricultural production occupies a significant position in the history, culture, and economy of the Crystal River valley. Approximately 4,800 acres of productive irrigated agriculture49 occupy the terraces and benches around Carbondale, contributing to the vibrancy of the local economy and to the scenic attributes of the landscape cherished by local residents and visitors (Figure 3-2). Agricultural rights are among the most senior on the River. More than thirty agricultural diversion structures exist on the mainstem of the Crystal River below Avalanche Creek and adjoining tributaries. Agricultural production in the Crystal River Valley is supported by the approximately 300 cfs of adjudicated surface water rights.

The Town of Carbondale owns and operates several surface water diversions near the CPW fish hatchery. These diversions provide raw water for homes and gardens, municipal parks, and landscaping along roads and sidewalks. The private and public amenities this water supports provide important recreational opportunities for residents and visitors, and contribute to the character of downtown Carbondale by greening public and private spaces. The Bowles and Holland, Kaiser and Sievers Ditch and Southard and Cavanaugh Ditch provide raw water to the River Valley Ranch, Coryell Ranch and Aspen Glen subdivisions. This water supports turf grass on golf courses and provides water feature amenities to residents. Approximately 125 cfs of adjudicated agricultural water diversion rights on the Crystal River support these raw water municipal and recreational uses.

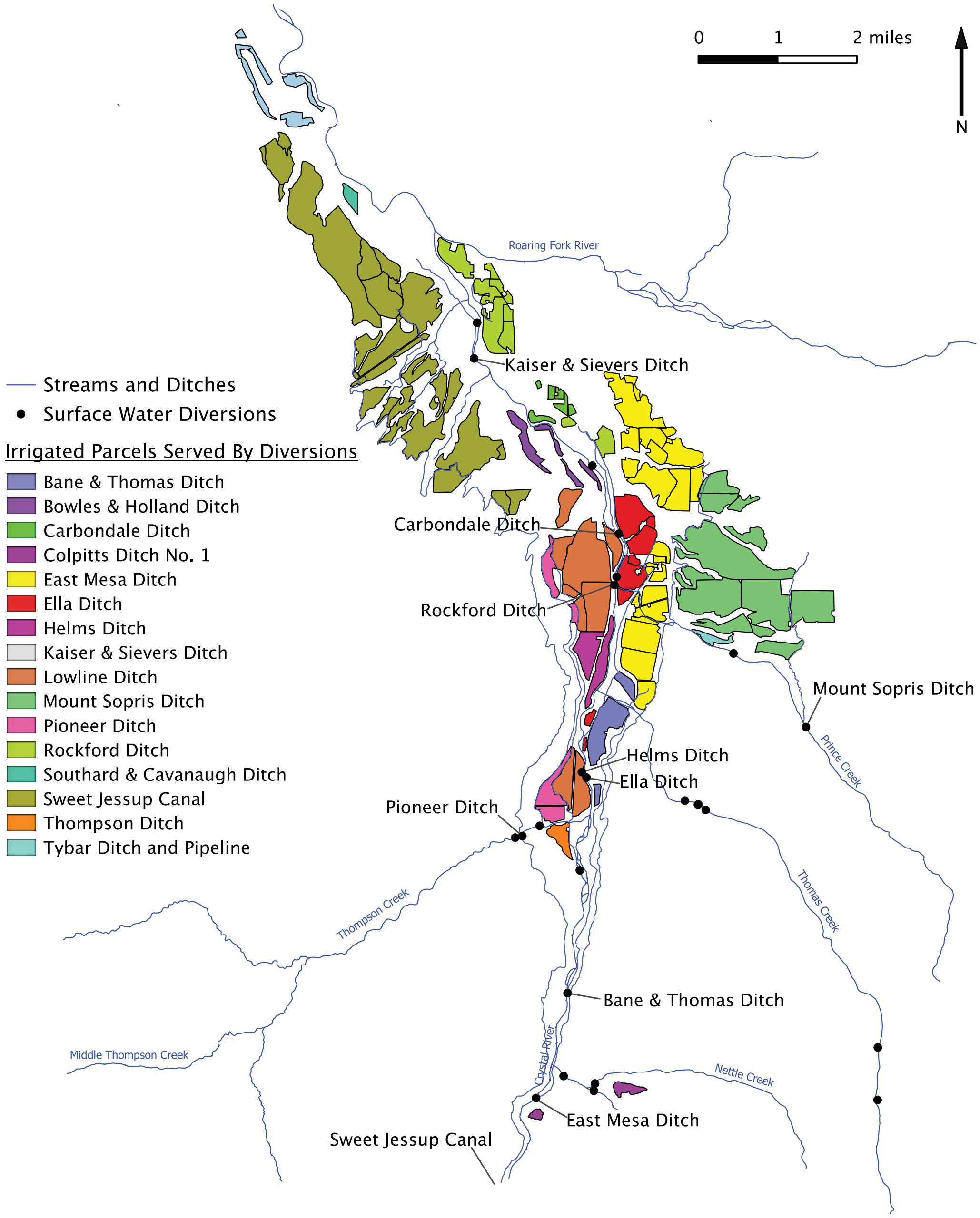


Figure 3-2: Irrigated lands in the Crystal River watershed

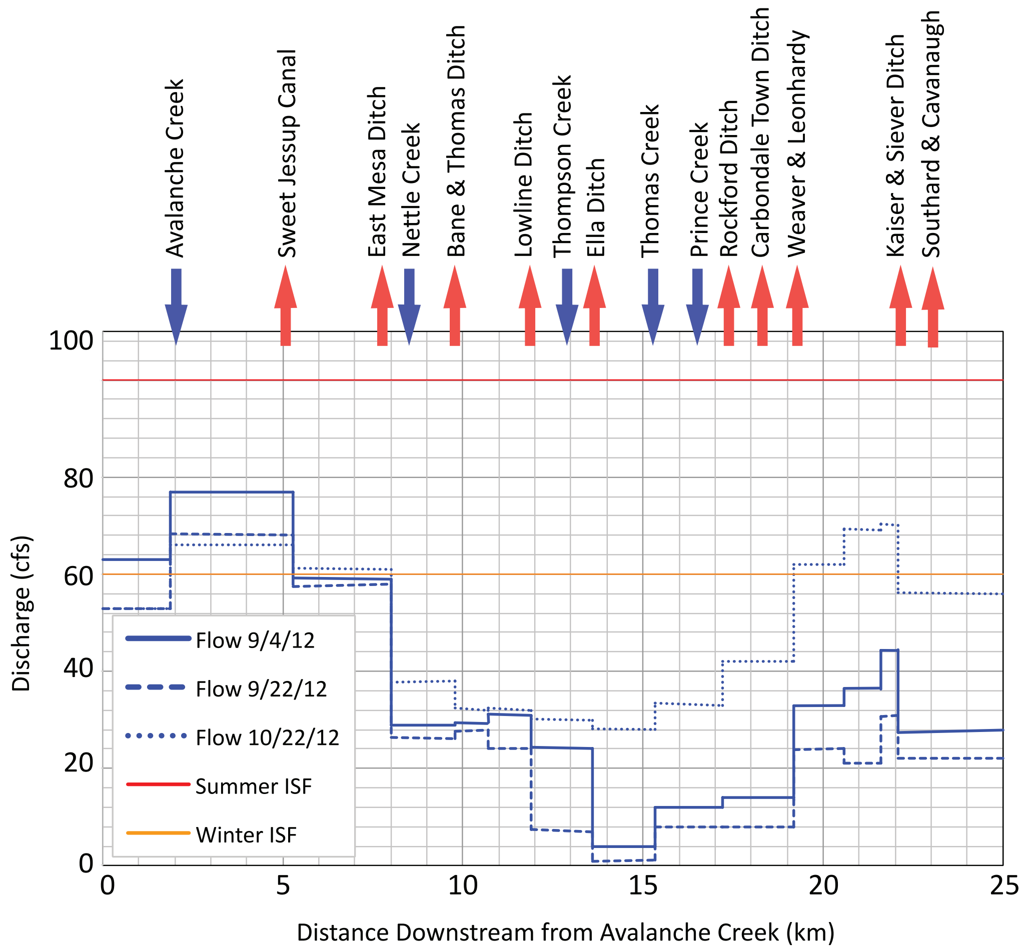


Figure 3-3: Longitudinal patterns in streamflow observed on the Crystal River in the late summer of 2012

3.1.3 CWCB Instream Flow Rights

The CWCB holds a junior instream flow (ISF) right on the Crystal River between its confluences with Avalanche Creek and the Roaring Fork River. ISF rights are intended to provide some measure of environmental use benefit under the Prior Appropriation System. The ISF right (100 cfs summer / 60 cfs winter) on the Crystal is frequently not met during moderate and severe drought conditions in late summer and early fall (Figure 3-3).

3.1.4 Trans-basin Diversions

A single, trans-basin diversion moves water out of the headwaters of Thompson Creek and into the Willow Creek drainage to the west. This 24 cfs junior surface water diversion right only diverts flow during spring runoff and generally does not affect water availability for other uses in the Crystal River watershed.

3.2 WATER USE ASSESSMENT

The balance of water flowing into the Crystal River and its tributaries from snowmelt and rainfall, moving out of the river into canal networks and onto fields, evaporating, and returning to the river via surface or groundwater constitute the primary components of a local water budget. The responses of physical and legal water demands to hydrological conditions determine the allocation of water among the various uses present in the system. In the case of individual agricultural users, the characteristics of the infrastructure used to convey water and the irrigation application method largely determine the timing and location of surface and groundwater return flows (Figure 3-4). Synergies between water availability and use efficiencies conspire to create demand shortages at different locations over the course of a water year. The water use assessment described in the CRMP characterized management and use of water on the Crystal River by integrating analyses of watershed hydrology and water rights administration under the Prior Appropriation System.

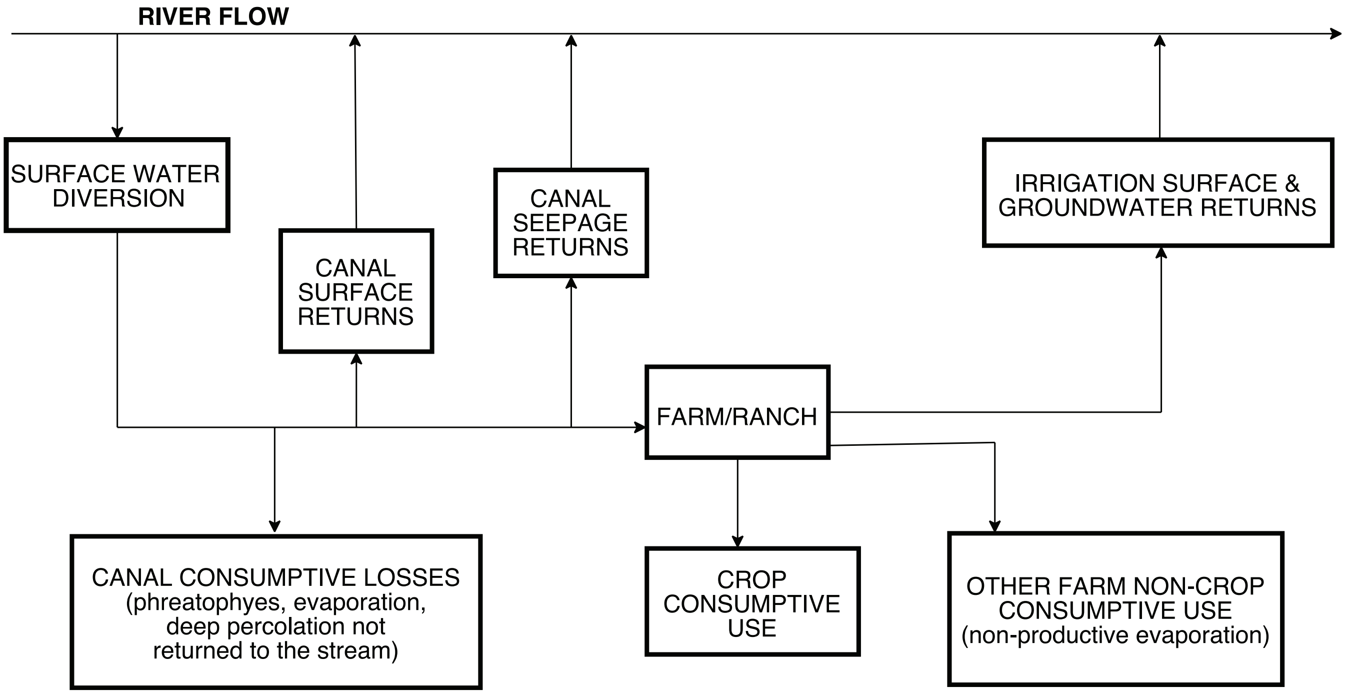


Figure 3-4: Irrigation system schematic indicating the various pathways water travels along between a point of diversion and a point of use.[10]

3.2.1 Hydrological Simulation Modeling

Water resource planning questions addressed in the CRMP regarding water availability, patterns of local use, and discrepancies between use needs and water supply relied heavily on hydrological simulations. The hydrological modeling component of the EcoDSS simulated tributary inflows, allocated surface water to diversions according to Colorado Water Law, and routed groundwater and surface water return flows from irrigated acreages back to the river on a daily timestep across a range of drought and flood conditions (Appendix A). The EcoDSS derived diversion information, including structure names, locations, decreed amounts, priority date, application type, and irrigated acres, from the Colorado Division of Water Resources water rights database, HydroBase. Calculation of lag response coefficients for groundwater returns from irrigated acreages required estimates of water application efficiency, aquifer transmissivity, specific yield, and the least-cost path distance between irrigated parcels and the Crystal River. Estimating return flow fractions for each water demand required investigation into the water application method used on each irrigated parcel. For each water right, return flow fractions and locations were modeled according to the distributed ownership amounts and spatial orientation of associated irrigated parcels. Where necessary, information communicated by the local Water Commissioner and several water users helped refine HydroBase data. Historical gauge records and hydrological predictions for ungauged basins generated streamflow boundary conditions. Published hydrogeological studies provided the necessary input information for groundwater simulations. The simulated river network extended from Avalanche Creek to the Roaring Fork River and included all significant agricultural and municipal water diversions on the Crystal River mainstem, Nettle Creek, Thompson Creek, Thomas Creek and Prince Creek (Figure 3-5).

3.2.2 System Efficiencies

Evaluating the relative efficiencies of water conveyance and application systems represented a critical planning step that helped identify conservation opportunities that can benefit ecosystems and reduce maintenance obligations for local users. In the Crystal River watershed, many water conveyance and irrigation water application systems look much as they did in the early 20th century. Most ditches are unlined and flood irrigation is the most typical water application method (Figure 3-1). Water diverted for irrigation satisfies crop needs only after accounting for ditch seepage, evaporative losses, surface runoff, and hydraulic push water requirements (Table 3-1). Reducing the amount of water "lost" to these inefficiencies by lining or piping ditches or switching to sprinkler irrigation will require diverting less water to satisfy existing crop demands (see Section 3.3). When and where efficiency upgrades lead to diversion reductions, they can benefit other junior users and, potentially, ecosystem needs present in the system.
For any given surface water demand, there exist several paths that diverted water moves along before being evaporated, consumed by vegetation, or returned to the river. Many of these paths do not directly reflect the intended use of the diverted water, but provide important secondary benefits, nonetheless. Seepage of water from unlined ditches supports vibrant riparian communities of willow and cottonwood on several benches and terraces in the lower Crystal River valley. These riparian zones provide important habitat to numerous

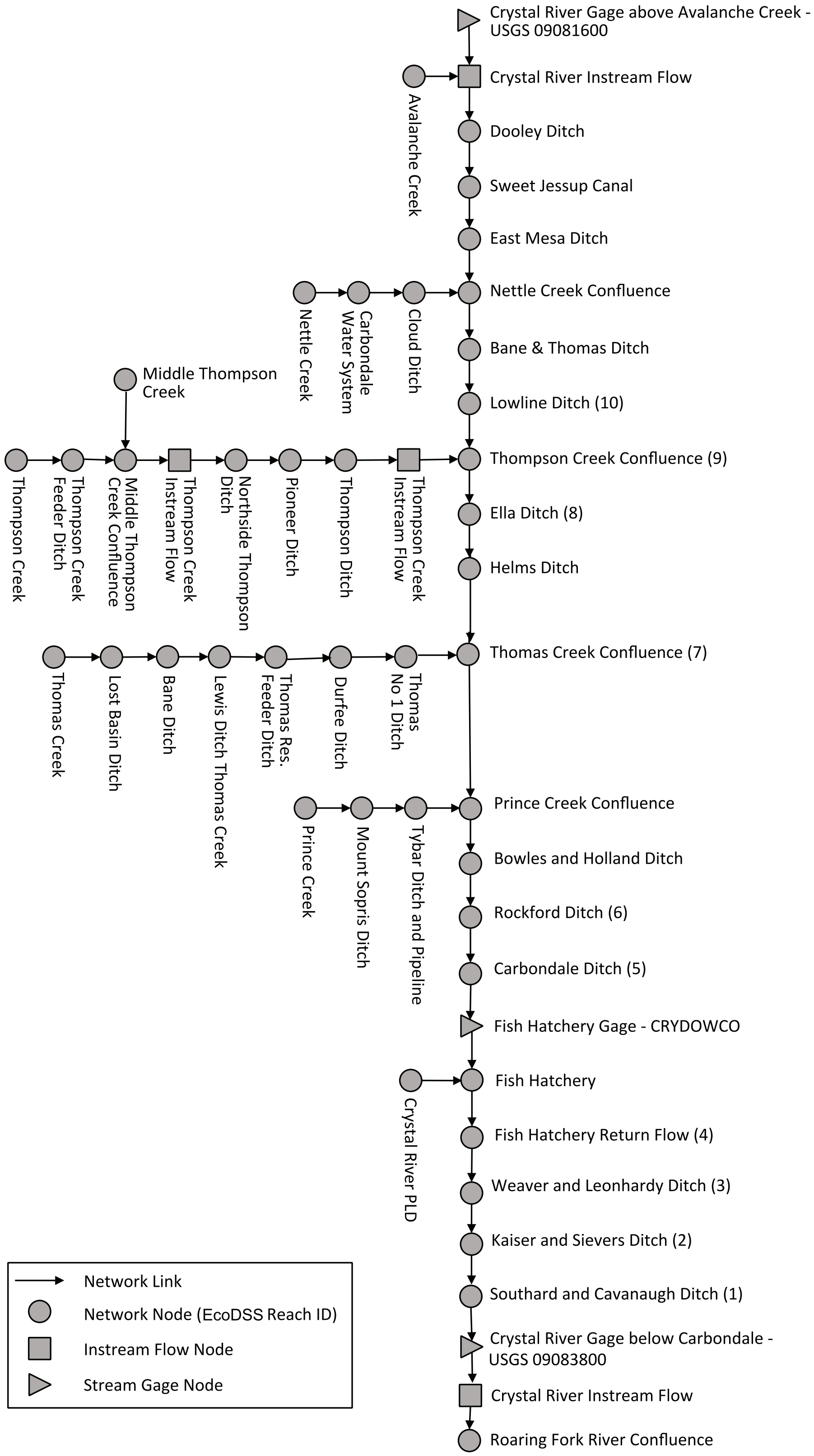


Figure 3-5: EcoDSS hydrological simulation network

System	Efficiency (%)
Primary Conveyance Efficiency	
Lined	95%
Unlined (200-2000m)	75%
Unlined (>2000m)	60%
On-farm Conveyance Efficiency	
Fields larger than 50 acres	
Unlined	80%
Lined or Piped	90%
Fields up to 50 acres	
Unlined	70%
Lined or Piped	80%
Application Efficiency	
Surface Irrigation Systems	
Wild Flood	30-50%
Graded Furrow	50-80%
Level Furrow	65-95%
Level Basins	80-95%
Sprinkler (non-center pivot)	
Side Roll	60-85%
Moving Big Gun	55-75%
Lateral Move	
Spray heads w/hose feed	75-95%
Spray heads w/canal feed	70-95%
Center Pivot Irrigation Systems	
Impact heads w/end gun	75-90%
Spray heads w/o end gun	75-95%
Microirrigation Systems	
Surface Drip	70-95%
Subsurface Drip Irrigation (SDI)	75-95%
Microsprinklers (microspray)	70-95%

Table 3-1: Estimated efficiency rates of water conveyance and application systems[2,26]

avian and terrestrial species. Critically, system inefficiencies that produce lagged groundwater returns from ditches and fields benefit streamflows and river ecology in late summer and early fall. The soil types and unconsolidated material present in the Crystal River valley and alluvial aquifer promote relatively rapid rates of infiltration and groundwater movement.[25] Anecdotal evidence provided by local residents, field data collection, and review of EcoDSS simulation results indicate that the influence of groundwater return flows on the Crystal River is strongest between the CPW fish hatchery and the Roaring Fork River. The modest increase in streamflows produced by these groundwater inputs is sufficient enough to produce measureable ecosystem benefit between the CPW fish hatchery and the Roaring Fork River during times of moderate or severe drought (Appendix A).

3.2.3 Demand Shortages

The convergence of priority system administration, hydrological conditions, and total system efficiency dictates the River's ability to meet the full array of existing uses. In places and times where a junior water right is "called out" by a senior user or where conveyance or application system inefficiencies exceed full agricultural use needs, shortages exist. Most demand shortages in the Crystal River Valley exist for agricultural users on tributaries where water supply is limited (Figure 3-6). However, agricultural users on the mainstem Crystal River also experience shortages in late summer. These shortages are particularly acute during moderate and severe drought conditions. The CWCB ISF right, the only water right reflecting ecosystem needs, is shorted in many reaches between the Sweet Jessup Canal and the Roaring Fork River in drought years. Resolution of this demand shortage represents a significant challenge due to the relatively large size of the ISF right and the significant use pressures on the Crystal during drought years when water supply is particularly constrained.

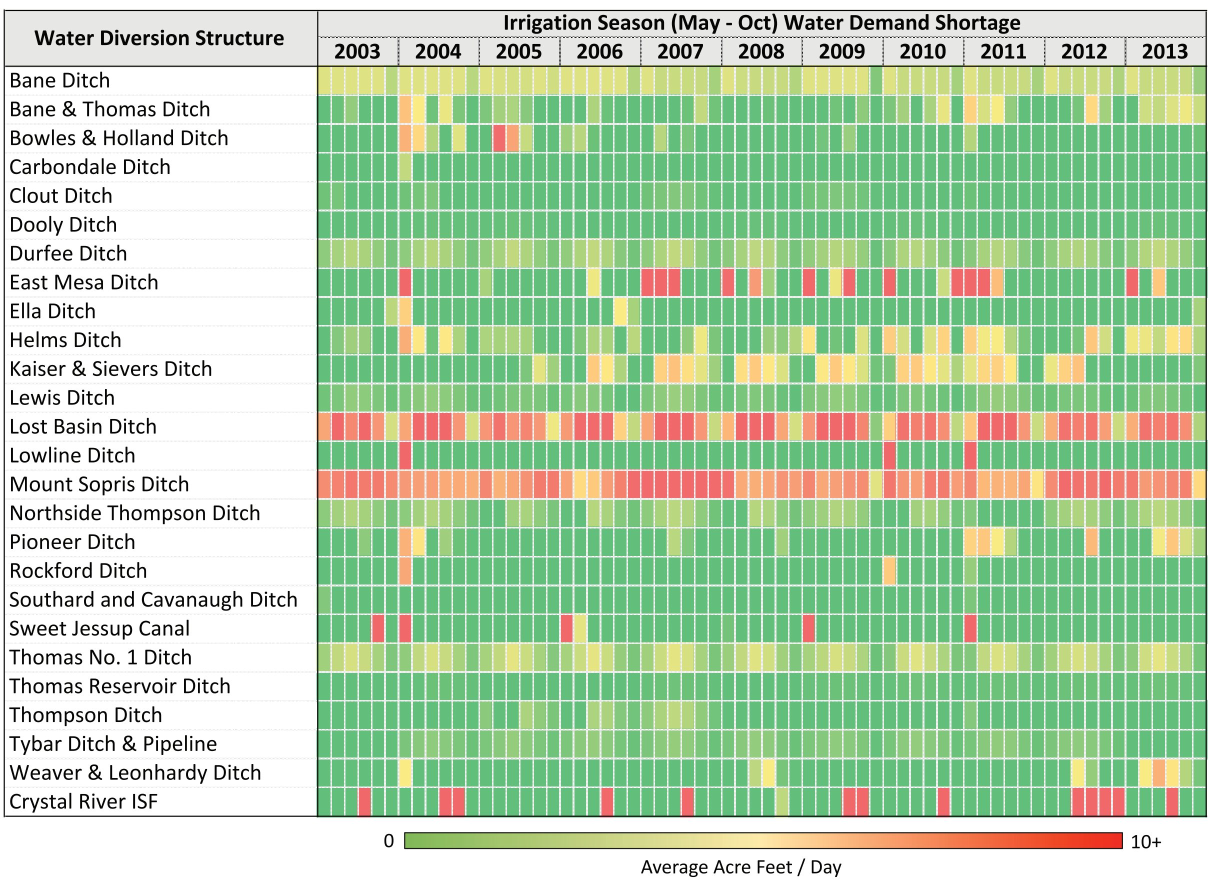


Figure 3-6: Monthly water use shortages during the irrigation season on the Crystal River and its tributaries

The State of Colorado supports use of established methods and criteria for calculating consumptive and non-consumptive demands and shortages. Approaches for evaluating irrigation demands consider geographic location, air temperature, irrigated acreage, system inefficiencies, and crop type. The State's adopted approach for determining ecosystem water demands relies on the R2Cross methodology.[56] This approach relies on hydraulic calculations that approximate baseflow habitat connectivity requirements for trout. Unfortunately, this relatively rigid approach does not adequately reflect ecosystem adaptations to natural variability in hydrological conditions or the Crystal River stakeholders' collective tolerance for water management strategies that impart some degree of ecosystem risk.

Assessments of ecosystem demand shortages presented in the CRMP are based on the Mean 7-Day Annual Minimum (7Q) flow, one of the most widely used low flow indices. Ecological research indicates the utility of the 7Q as: the minimum streamflow needed during drought conditions; the critical streamflow needed to protect and maintain aquatic habitat and ecosystem integrity; and the continuous chronic criterion for aquatic life.[18,34,39,46] The Sustainability Boundary Approach (SBA) and Presumptive Standard provide a framework for target flow ranges by defining allowable deviation of flow from the natural hydrograph in terms of degrees of ecosystem risk (Table 3-2).[27,36,38] Application of these methods to the 7Q brackets baseflow ranges corresponding to different hydrological conditions that reflect low, moderate, and high risk to ecosystem function (Figure 3-7). Existing management practices indicate an absence of ecosystem demands shortages in average years. However, moderate (1 in 5 year) and severe (1 in 20 year) drought conditions produce shortages between Thompson Creek and the CPW fish hatchery.

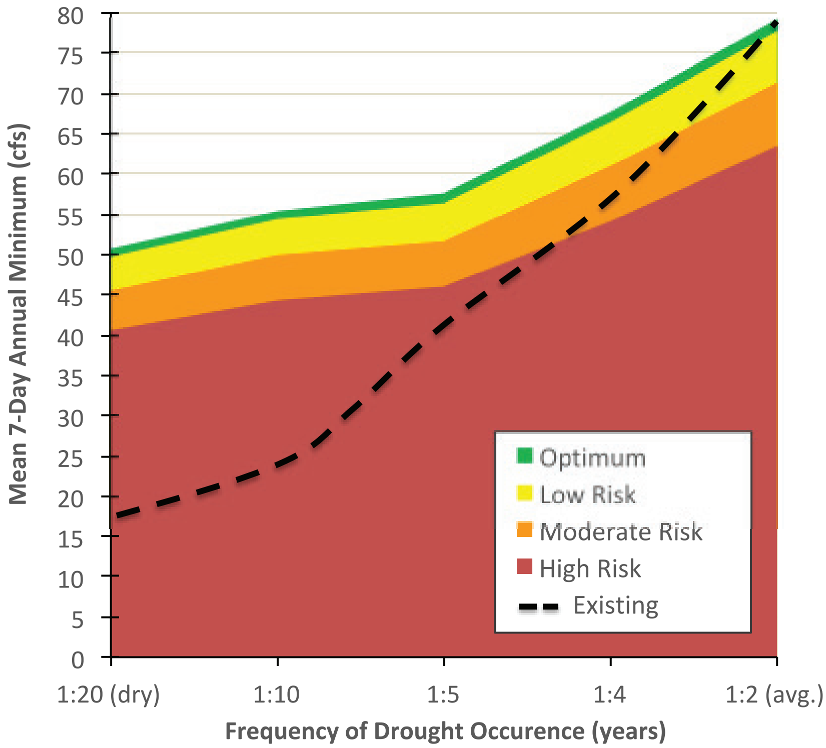


Figure 3-7: Ecosystem need shortages on the Crystal River below Thomas Road Bridge as described by application the SBA approach to the 7Q under different drought conditions.

3.3 OVERALL PATTERNS OF WATER USE

Assessments of ecosystem function, water management and use identified the prominent limiting conditions for consumptive and non-consumptive use needs on the Crystal River. Significantly, reduced late summer baseflows in moderate and severe drought conditions and the resultant impacts on physical structure and aquatic biota, particularly fish, constitute the most acute impairment of ecosystem function. Water use assessments conclude that agricultural use shortages impact users on tributaries more significantly than on the mainstem of the Crystal River. The most persistent shortages on the Crystal River mainstem are the CWCB ISF right, ecosystem needs computed as the 7Q, and the junior diversions on the Kaiser and Sievers and Bane and Thomas ditches. The alternative management strategies detailed in Section 4 respond to the overlapping themes and management prospects that emerged from reviews of water use patterns, legal and administrative considerations, and evaluations of ecosystem function.

4 ALTERNATIVE MANAGEMENT STRATEGY EFFECTIVENESS

Water is a limited resource, and balancing consumptive and non-consumptive use needs generally involves tradeoffs. This is certainly the case on the Crystal River where the most acute impacts on the ecosystem are tied to municipal raw water supplies and agricultural production. Identifying feasible management alternatives that respond to hydrological regime modifications and aquatic habitat quality required explicit consideration of the types and locations of existing water uses, and the frequency at which they experience shortages (Figure 4-1). Ecosystem and agricultural water demand shortages and irrigation system inefficiencies represent important opportunities and constraints for future actions designed to enhance support of ecosystem function without negatively impacting existing water users. In this vein, the CRMP considered the relative effectiveness of the following management strategies for meeting the stated planning Goal:

- Market-based incentives for water conservation or bypass flows
- Infrastructure improvements and efficiency upgrades
- Reservoir construction
- Habitat enhancements and channel modification projects

Effectiveness characterization for each of the above management strategies relied heavily on application of the EcoDSS to evaluate two primary assessment criteria: 1) the magnitude, frequency, and duration of ecological lift brought about by a given change in management, and 2) the severity and frequency of water use shortages that result from strategies that support or enhance ecosystem function.

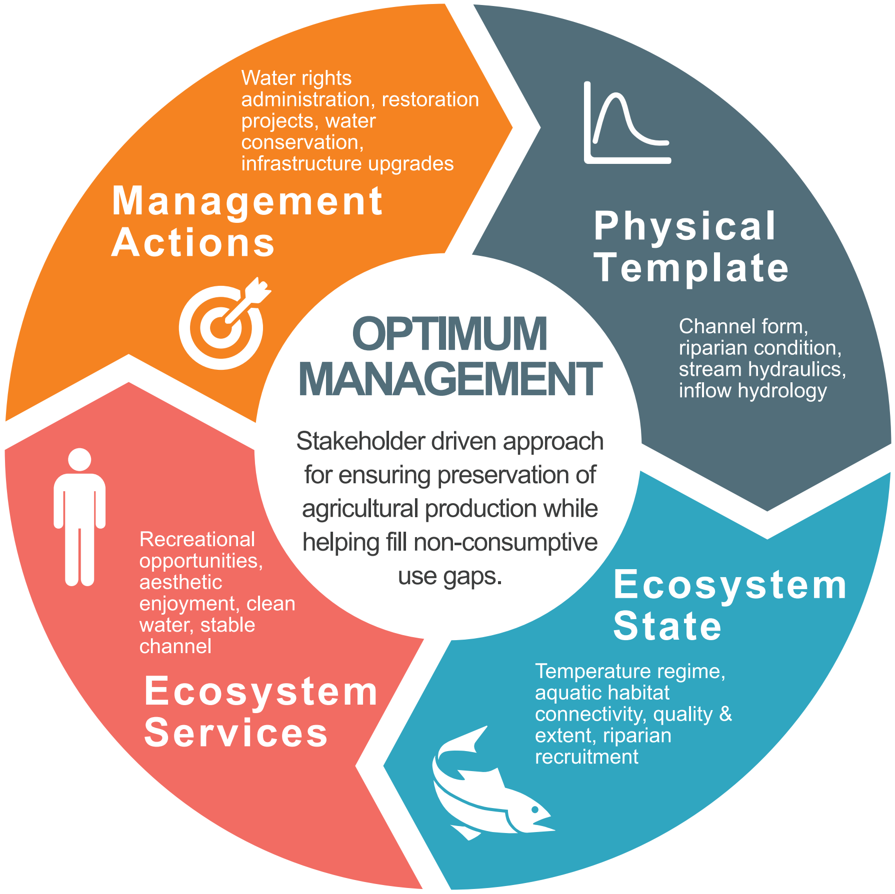


Figure 4-1: Changes to the physical components of river systems alters ecosystem dynamics associated with the delivery of EGS. Where the community perceives diminished EGS, consideration of alternative management strategies is necessary to affect physical conditions in a manner that promotes more desirable ecosystem behavior

An Ecological Decision Support System (EcoDSS) evaluated the impact of alternative management strategies on consumptive and non-consumptive use needs by examining the interaction between hydrological inputs, exercise and administration of water rights, changes in channel structure, stream hydraulics, and the responses of aquatic biota. The EcoDSS used a series of loosely-coupled hydrologic, hydraulic and statistical models to 1) predict and simulate rainfall-runoff processes contributing streamflow to the lower Crystal River watershed, 2) allocate and account for water along the lower Crystal River according to Colorado Water Law, 3) estimate spatially distributed water surface elevations, stream depths, and velocity profiles corresponding to a range of hydrological conditions, water conservation scenarios, or physical channel modifications, and 4) quantify the ecological effects of alteration of streambed topography or incremental increases/decreases in streamflow on adjoining reaches of the river. In this way, the EcoDSS functioned as a descriptive tool, rather than a prescriptive tool, for guiding local water management decisions.

The EcoDSS gauged effectiveness based on each strategy's ability to enhance physical structure and provide important aquatic habitat benefits without causing or exacerbating shortages experienced by other water users. Computing the relative and absolute magnitude of changes in the hydrological regime behavior (e.g. 7Q), physical complexity and aquatic habitat availability for various fish species and life stages brought about by a management change revealed its ecological effectiveness. Computations and predictions for hydrological regime behavior occurred on the ten stream segments (the "Management Reaches") most impacted by surface water diversions (Figure 3-3) across a range of hydrological conditions on a daily time step. The EcoDSS utilized an extensive 2-dimensional hydraulic modeling effort to characterize changes in physical complexity and habitat quality on a five-foot grid throughout the lower seven miles of the Crystal River. Ecological effectiveness results were aggregated across Management Reaches on a weekly time step to ease interpretation. Assessments of effectiveness from the perspective of existing water users relied on calculations of water use shortages brought on or relieved by a given strategy. Water use effectiveness assessments aggregated water shortage results to each surface water diversion location on a monthly time step.

4.1 MARKET BASED STRATEGIES

4.1.1 Non-Diversion Agreements

Non-diversion agreements compensate agricultural water users for bypassing varying quantities of water otherwise destined for fields and pastures. This approach assumed no formal water leasing through the CWCB instream flow program or shepherding of water downstream past junior users. **Bypass terms approximated a "gentleman's agreement" where leased water remained instream and was available to junior water users both upstream and downstream from the point of diversion**. Depending on the efficiency of a given diversion system and the size of the bypass, voluntary diversion reductions can negatively impact the productivity of irrigated agriculture. Therefore, appropriate compensation terms must be reached to ensure a net benefit to participating agricultural users. The fact that bypassed water is available to junior water rights in the system constitutes a net benefit to other agricultural or municipal users. Depending on the orientation of bypass flows and the junior users that consume them, ecosystem use needs may incur some benefit or see further impairment.

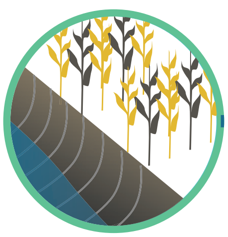
The most effective application of this simulated approach on the Crystal River bypassed water from large senior and junior water users between the Sweet Jessup Canal and the Rockford Ditch. Bypass flows on the order of 10-18% of average diversion rate from several of the larger diversions in this focus area (e.g. Sweet Jessup Canal, East Mesa Ditch, Ella Ditch, and Lowline Ditch) generated significant benefits to aquatic habitat availability during moderate drought in the most heavily impacted sections of River (Figure 4-2). Simulated diversion bypasses did increase shortages for some producers. Unfortunately, the assessment could not evaluate terms of an Agreement that would compensate users for participation (because those terms have not been worked out), prohibiting a complete evaluation of agricultural effectiveness.

4.1.2 Short-Term Water Leasing

The Colorado Water Trust (CWT) works with the CWCB Instream Flow Program to implement short-term water leasing contracts that temporarily transfer part or all of a water right to an adjudicated instream flow. Water leasing programs aim to benefit ecosystem function by shepherding leased water past junior users to the point of historical groundwater return flow. Lease contracts require agricultural producers to fallow a portion of irrigated land commensurate with the quantity of leased water. Therefore, appropriate compensation terms ensure a net benefit to both ecosystem needs and agricultural users.

Modeling investigations assessed outcomes associated with full-season and split-season leasing arrangements with large senior water rights holders on the Crystal River. The most effective leasing opportunities simulated on the Crystal existed upstream of the Carbondale and Rockford ditches in the late summer. Split season leasing arrangements with one or more users that cumulatively contributed between 15-30 cfs to river baseflows in August and September significantly improved aquatic habitat quality and reduced ecosystem risk associated with hydrological regime modifications during moderate (1-in-5 to 1-in-10 year) drought conditions. The fact that leased water was unavailable to junior water rights in the system produced no net benefit or loss to other agricultural or municipal users. These users continued to operate within the system as they otherwise would have in the absence of the leasing arrangement. Due to their voluntary nature, leasing contracts will only occur where water rights holders receive some net benefit (financial, emotional, etc.).

4.2 CONSERVATION BASED STRATEGIES



4.2.1 Ditch Lining

Ditch lining or piping increases conveyance system efficiency by reducing seepage loss, evaporation, and transpiration by phreatophytes. Converting an earthen ditch to a concrete ditch or pipeline conserves up to 30% of diverted water, depending on soil type, ditch length, and canal geometry (Table 3-1).[6] This type of infrastructure upgrade represents a relatively permanent conservation measure. Benefits of conservation accrue mainly to water users served by a ditch system by reducing the likelihood that they are affected by shortages. If users choose to leave conserved water in the stream (e.g. under a Non-Diversion Agreement) it can additionally benefit junior water users and ecosystem function. A notable ecosystem impact to ditch lining or piping includes the desiccation of cottonwood galleries and wetlands supported by seepage.

The EcoDSS approximated reductions in conveyance system incidental losses based on the length of ditch between the headgate and the turnout to the receiving farm or ranch. Modeling did not assess the effects of on-farm conveyance system improvements. All conservation gains accrued back to the river at the point of the surface water diversion. Simulations showed that non-consumptive water uses benefit little if lining or piping occurs on ditches low in the watershed or those with large senior rights because upstream junior users consume the conserved water to alleviate demand shortages. Ditch system upgrades yield the largest ecosystem benefit when applied to large diversions that convey junior water rights. Most of these are not positioned appropriately in the watershed to produce benefits in the most impacted reaches of Crystal River. Lining or piping all ditches in the watershed did provide widespread ecosystem benefits in the most critical time period (August-September) under moderate or severe drought (Figure 4-2). Widespread infrastructure upgrades also tended reduce agricultural use demand shortages experienced by junior users

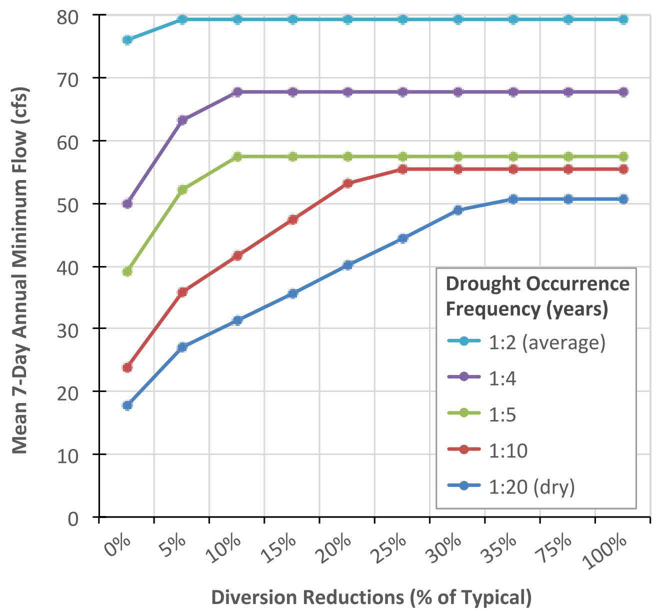


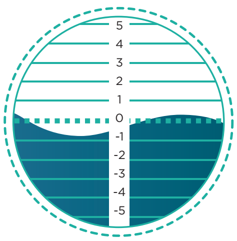
Figure 4-2: Changes in 7Q at the Thomas Road Bridge as a function of diversion reductions. Diversion reduction may be achieved through Non-Diversion Agreements, conservation gains resulting from ditch lining or sprinkler irrigation, or a combination of the two. Upper inflection points on the 7Q curves indicate a transition to optimal hydrological regime behavior

on the mainstem of the Crystal River. The EcoDSS predicted modest reductions in late season return flows below the CPW fish hatchery in the fall and winter months as a result of lining all earthen ditches in the watershed.

4.2.2 Sprinkler Irrigation

Conversion from flood irrigation to sprinklers reduces seepage loss, evaporation from ponding, and surface water runoff. Shifting to more efficient water application methods conserves up to 50% of diverted water, depending on soil type, irrigated acreage, crop type, and local topography (Table 3-1).6 Benefits of conservation accrue mainly to water users implementing sprinkler irrigation on their property. Water conservation reduces the likelihood that a user is affected by water shortages, but does come with increased maintenance and energy costs in many cases. If users choose to leave conserved water in the stream it can benefit junior water users and ecosystem function.

The EcoDSS approximated reductions in groundwater infiltration and hydraulic push-water requirements achieved by conversion to sprinkler irrigation. All conservation gains accrued back to the river at the point of surface water diversion. Similar to ditch lining, this scenario yielded little benefit to non-consumptive water uses when conversion to sprinkler irrigation occurred on parcels served by ditches low in the watershed or those served by large senior rights. Water application method upgrades yielded the largest ecosystem benefit when either applied to large irrigated parcels served by junior diversion rights high in the watershed or when applied to all parcels currently utilizing flood irrigation. Simulation of widespread conversion to sprinkler did predict widespread ecosystem benefits in the most critical time period (August-September) under moderate or severe drought (Figure 4-2). Reductions in late season return flows that negatively impact ecosystem needs in the fall and winter months are modest in comparison to the gains achieved through conservation.



4.2.3 Irrigation Scheduling

Irrigation scheduling refers to the practice of calculating and applying only the amount of water required by a crop. This approach can reduce surface water diversion requirements by: 1) reducing surface water runoff, 2) limiting deep percolation below the root zone, 3) decreasing evaporation and ponding, and 4) reducing crop evapotranspiration during non-sensitive life stages by controlling soil water depletion.2 Several manual or modeling based approaches exist for calculating the quantity and timing of irrigation needs for various crop types in Colorado. Agricultural producers use this approach as a means for reducing water requirements without decreasing yields.2 Successful implementation requires measurement devices for ascertaining water application quantities and/or infiltration depths. The wide variety of techniques available for assessing soil and crop water needs produces substantial variability in the water savings produced by this approach. If users choose to leave conserved water in the stream it can benefit junior water rights and ecosystem function. If applied broadly throughout a watershed, irrigation scheduling can reduce the occurrence frequency of water shortages.

Simulation of irrigation scheduling in the EcoDSS indicated opportunity for modest reductions in the frequency and magnitude of shortages experienced by junior water users and the CWCB ISF in the Crystal River. Of course, this was only the case when simulations allocated conserved water back to the point of surface water diversion to make it available to other users in the watershed. Use of conserved water to two large upstream diversions (e.g. Sweet Jessup Canal and East Mesa Ditch) to compensate for shortages in dry years negated any ecosystem benefit realized by this management strategy (Figure 4-3).

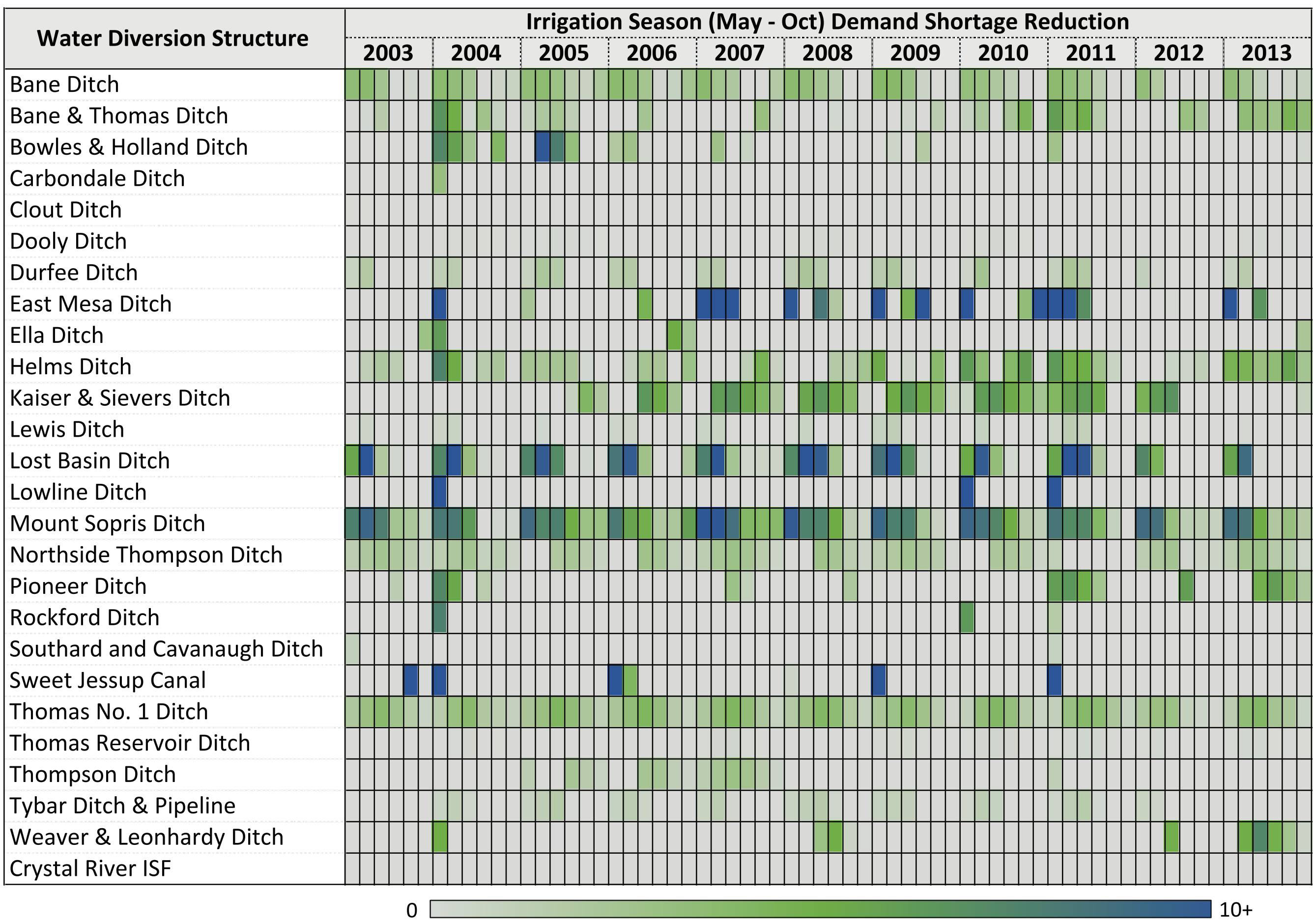


Figure 4-3: Use shortage reductions brought about by irrigation scheduling

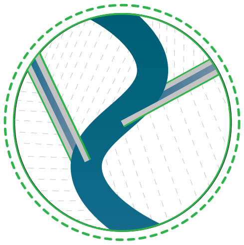
4.3 SUPPLY BASED STRATEGIES

4.3.1 Off-Channel Reservoir

Reservoir development is a typical management response to resolving water demand shortages. Reservoirs impound water during snowmelt runoff when peaking streamflows constitute an abundant water supply for downstream users. During late-summer baseflow periods when hydrological conditions and use pressures create consumptive and non-consumptive use need shortages, reservoirs release stored water back into the system to partially or fully satisfy those demands. The transiting of water from the reservoir site to downstream user may provide incidental ecosystem benefits on intermediate stream reaches. The benefit of water storage to consumptive uses is generally a function of a reservoir's position in the stream network, the seniority of the storage right, and the projected water yield. Non-consumptive use benefits produced by reservoirs are less straightforward. Dams create longitudinal discontinuities in a river network that disrupt the flow of organisms, sediment, and energy that may negatively impact channel evolution, morphology, and the distribution of aquatic biota. These impacts may be offset where the most significant downstream ecosystem impairments occur due to late-summer water depletions. Notably, small water storage projects are listed as a priority in the 2015 Colorado Water Plan and, therefore, may enjoy a broad base of support among water planning and administration agencies/organizations at the regional and state level.

A water supply alternative tested by the EcoDSS simulated the development of a reservoir on North Thompson Creek. The reservoir's firm yield was estimated at 3,000 AF in keeping with previous planning and water availability studies.[4,5] The reservoir provided 25 cfs to downstream users for 60 days during the late-summer period (August-September) where the most acute non-consumptive use need appear. Shepherding the released flows to the DWR streamgauge at the CPW fish hatchery provided significant benefit to aquatic habitat quality and extent. Alternatively, if some or all of the released water was allocated to users on Thompson Creek or as augmentation supply to support out-of-priority diversions by a junior user in the Crystal River above the confluence with Thompson Creek, the benefits to ecosystem function rapidly declined.

4.4 CHANNEL MODIFICATION STRATEGIES



4.4.1 Grade Control Structures

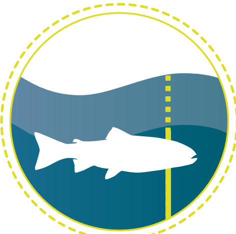
In places where water users rely on temporary push-up dams to force water toward surface water diversions, some localized impacts to habitat connectivity occur. Construction of push-up dams also requires significant investments of time and energy to create and maintain them throughout an irrigation season. Installation of permanent grade control structures may reduce impacts to aquatic habitat and simultaneously decrease work requirements by water users to maintain headgate effectiveness.

Evaluations of grade control structure designs through application of the EcoDSS confirmed moderate benefits to aquatic habitat quality and availability at late-summer streamflows experienced during moderate and severe drought (Appendix A, E). The Carbondale Ditch and Kaiser and Sievers headgate locations are most amenable to construction of grade control structures. Aggrading bedforms in the vicinity of the Lowline Ditch headgate mean installation of a grade control at this location will likely require significant maintenance.

4.4.2 Inset Channel

Modifications of river channel structure represents an appealing and often-contemplated method for resolving ecosystem needs on rivers where alternative water management solutions are either infeasible or unpalatable to local water users. Inset channel design represents one approach for "fitting" the river to the modified hydrological regime where the greatest constraints on ecosystem function occur during late-summer baseflows. Inset channels create a preferential pathway for water to move along during periods of low flow. This pathway is narrower and deeper than the main channel. Inset channels are designed to maintain habitat quality and availability by creating deeper pools, runs and glides and limiting extreme temperature variability caused by large width-depth ratios.

Assessment of inset channels through the EcoDSS indicated limited benefits to ecosystem function. The Crystal River has a relatively steep grade. Simulation of inset channels indicated a significant increase in channel velocities and subsequent degradation of aquatic habitat. Furthermore, the high bedload transport regime present on the River will likely result in significant ongoing maintenance requirements for designed channels.



4.4.3 Fish Habitat Enhancements

An alternative to inset channel design exists in the form of fish habitat enhancements. Artificial, hardened structures aim to create deep scour pools and eddies—important holding habitat for adult trout—on reaches where a modified hydrological regime reduces the physical complexity of the channel. The enhancement of fish habitat quality can help mitigate the impacts of reduced streamflows during low flow periods. Habitat enhancement projects must pay special attention to the background bedload sediment transport regime and the hydraulic characteristics of the designed channel to ensure adequate conveyance of sediment through the project area and anticipate ongoing maintenance requirements. Hardened structures may also produce unintended consequences for channel evolution and morphology—important functional components of the ecosystem.

Predictive modeling of the impact of fish habitat enhancement projects on the Crystal River indicates a two to three-fold gain in high quality habitat availability at flows below 20 cfs. The benefit decreases to approximately a 1-fold gain in habitat as flows approach 100 cfs. This pattern indicates that structural modification of the stream channel may represent a practical management approach for resolving non-consumptive use shortages on the lower Crystal River. Fishery habitat enhancement may be used alone or in concert with other water management approaches to alleviate impairments to hydrological regime and physical structure that may represent important bottlenecks for ecosystem function. To achieve the largest gains in aquatic habitat, structures on the Crystal River need to be closely spaced. As is the case with inset channels, high bedload transport rates may result in significant ongoing maintenance requirements for designed channels.

5 IDENTIFIED MANAGEMENT PRIORITIES

The CRMP considered the relative effectiveness of a wide array of market-based programs, efficiency measures, water supply projects, and channel modifications for achieving the project Goal. Unfortunately, no single option represented a panacea for meeting all existing needs and addressing observed ecosystem impairments. Each alternative was associated with a unique set of environmental, capital, and social costs and benefits. In order to align planning recommendations with local preferences, the CRMP relied on a facilitated stakeholder process to consider the relative effectiveness and feasibility of the various management alternatives. Resource experts and stakeholders that participated in this process included representatives from the following:

- Crystal River Valley Water Rights Holders/Agricultural Producers
- Colorado Division of Water Resources
- Town of Carbondale
- United States Forest Service
- River Valley Ranch
- Coryell Ranch
- Crystal Valley Environmental Protection Association
- Colorado River Water Conservation District
- Natural Resources Conservation Service
- Pitkin County Open Space and Trails
- American Rivers
- Colorado Parks and Wildlife
- Trout Unlimited

Stakeholders considered alternative management strategies in the context of the overarching Goal. Characterization of management alternative effectiveness considered the relative and absolute gains in aquatic habitat quality on the Crystal River between the Sweet Jessup Canal and the Roaring Fork River in moderate and severe droughts between July and October. Considerations of feasibility explored political will, capital and ongoing maintenance costs, administrative and legal constraints, community expectations for water use, and the potential for leveraging existing projects or plans (Figure 5-1). Final assessment and prioritization of management actions factored in the degree to which each action balanced agricultural production, existing water use needs, and the ecological integrity of the River. From this process, two alternatives emerged as the most viable short-term strategies for managing consumptive and non-consumptive use needs:

- A market-based solution promoting bypass flows between Sweet Jessup Canal and Carbondale Ditch
- A combination of ditch-lining and short-term water leasing by the Town of Carbondale on the Carbondale Ditch and Weaver and Leonhardy Ditch.

These flexible alternatives maximize ecological lift, ensure positive benefit to affected water users, and rely on realistic funding mechanisms for implementation. The discussion below represents a consensus-based prioritization of short-term management actions for the Crystal River.

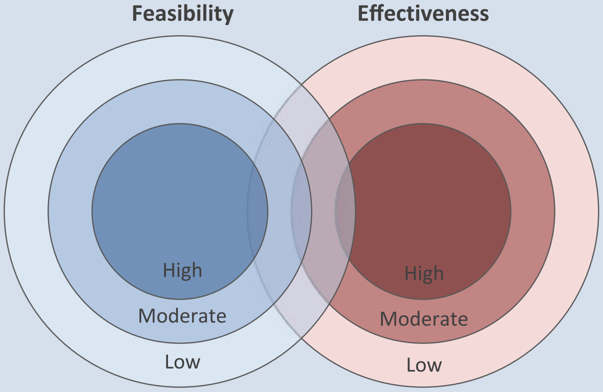


Figure 5-1: The most effective management options are rarely the most feasible. Optimization of management generally reflects some degree of compromise between the two

5.1 NON-DIVERSION AGREEMENTS FOR AGRICULTURAL USERS

Market-based solutions for water management exhibit a high degree of flexibility both in their structure and implementation. The ability to implement market-based solutions periodically and only during times of acute need make them ideally suited to resolving late-season low flow issues on the Crystal River. Stakeholders indicated strong preference for informal market-based strategies that do not require filings in Water Court. In response to this local interest, the Colorado Water Trust (CWT) developed a Non-Diversion Agreement framework to bypass flows past headgates located between the Sweet Jessup Canal and the Carbondale Ditch. The framework intends to maintain streamflow in critical reaches at, or above, a target streamflow during July, August and September in moderate (e.g. 1-in-5 or 1-in-10 year) droughts. CWT proposes compensation for willing water users who reduce diversion amounts in order to meet the target flow. Market-value compensation will reimburse water users for each 1 cfs of verified diversion reduction per day. The framework caps payments to individual water users relative to their total diversion right such that a single user does not deplete the total funding allocated to the program. This feature is meant to encourage the broad participation necessary to maximize ecological lift. The framework reimburses users for new diversion reductions until one of the following occurs: a) the program fund is exhausted, b) the target flow is met, or c) the month of September ends.

CWT's framework for Non-Diversion Agreements is neither a water transfer, nor a water lease, and does not require a Water Court filing or Division of Water Resources (DWR) administrative approval. To protect water rights from future challenge, participants will be enrolled in a Senate Bill 13-019 regional water conservation program through the Colorado River Water Conservation District. Any water rights holder upstream of Thomas Creek may voluntarily participate in the program. However, the most effective implementation requires broad participation by senior and junior rights in the target area. As noted previously, without participation of junior users, implementation of a non-diversion agreement on a senior water right may result in use of that water by an upstream junior user. This undesirable scenario may actually work to intensify constraints on ecosystem function on critical reaches of the Crystal River during low flow periods.

As a practical matter, Non-Diversion Agreements require a threshold condition to trigger their implantation. Typically, setting environmental flow targets involves integrating a river's physical processes and specific biological, physical, hydrological, and geomorphological requirements with the water use needs and values of the stakeholder group. The environmental flow setting approach utilized by stakeholders during development of the CRMP considered hydrologic metrics relevant to aquatic habitat quality during periods of low flows. Stakeholders accepted the 7Q as the hydrological metric of interest and indicated tolerance for moderate ecosystem risk under average to moderate drought conditions (Figure 5-1). In the driest years, this management target seeks flow augmentation through Non-Diversion Agreements of approximately 25 cfs. In moderate drought, Agreements will target bypasses on the order of 10-15 cfs. Reaching these targets will require diversion reductions between 5-18% (depending on drought severity) by a majority of the water users on the Crystal River mainstem above the Carbondale Ditch. Critically, any quantity of diversion reduction that elevates the 7Q above 15 cfs produces measureable benefit to the Crystal. Therefore, the success of Non-Diversion Agreements is not contingent upon attaining the full target bypass rate. Historical and simulated hydrological conditions indicate that diversion reductions for a period of thirty or more days may be required to completely satisfy program goals.

5.1.1 Examples of Similar Programs

Non-Diversion Agreements and water leasing programs are currently used in other Colorado basins for supporting critical water use demands that otherwise experience shortage under normal administration. While these examples fail to provide perfect examples of the program developed for the Crystal River, they are instructive in their details and successes.

1. The North Sterling Irrigation District (NSID) maintains a 25 year agreement with Xcel Energy to lease agricultural water on an as-needed basis for the Pawnee Power Plant in Brush, CO.56 Landowners within the District willing to lease water formed the Point of Rocks Water Company, LLC to facilitate the agreement. As part of the agreement, Xcel Energy may request up to 3,000 AF of consumptive use water between November and March each year. In exchange, landowners receive an annual base payment for participation in the program, regardless of whether water is requested. Xcel provides additional payment to the NSID and Point of Rocks Water Company members if water is delivered to the Pawnee Power Plant.

2. Landowners on Ohio Creek in the Gunnison River Basin partnered with Trout Unlimited, the Natural Resources Conservation Service, the Colorado River Water Conservation District, Gunnison River Water Conservation District, and the CWCB to improve the existing irrigation delivery system and water management in the Upper Ohio Creek Valley. Water users installed remote headgate monitoring equipment, converted a remote parcel from flood to sprinkler irrigation, developed and coordinated irrigation management plans to better match diversions and water delivery with crop demands during drought periods. Voluntary diversions reductions of up to 25% bypass water to support environmental uses. The project aims to increase minimum streamflows, improve water quality, and protect aquatic habitat in Castle and Ohio Creeks below the Acme Ditch.

5.1.2 Feasibility and Next Steps

CWT's proposed diversion reduction program is amenable to key agricultural interests in the Crystal River Valley insomuch as it provides financial incentive for participation and legal protections for water rights holders. In September 2013, CWT made a temporary agreement with seven landowners to test the management outcomes of voluntary diversion reductions on flows in the Crystal River. The framework agreement presented here builds on that initial work. The approach capitalizes on the effectiveness of market-based solutions to successfully respond to competing stakeholder interests. It also provides the necessary legal protections to water rights holders in the form of enrollment in a regional water conservation plan to ensure existing rights are not diminished in Water Court due to periods of reduced use. Appropriate pricing of water for reimbursements to agricultural producers is critical to ensuring no net loss to those water users. The impact of diversion reductions on agricultural production is a function of the water conveyance application inefficiencies present on a given ditch. Large diversion rights or high efficiencies promote large tailwater return flows from some ditch systems. Diversion reductions implemented on these systems may decrease total water deliveries in a way that diminishes tailwater returns without significantly impacting the quantity of water applied to a field to meet crop needs. Where users elect to implement efficiency upgrades and participate in Non-Diversion Agreements, compensation provided by the CWT program may be used to offset capital expenditures on those infrastructure improvements.

Successful implementation of this high-priority management alternative relies on the following actions:

- Enrollment of a significant number of water rights holders with diversion rights between the Sweet Jessup Canal and the Carbondale Ditch.
- Identification of appropriate water pricing strategies for the Crystal River.
- Development of a method to verify diversion reductions at the headgate on a daily or weekly basis.
- Development of methods and models to compute expected daily diversion rates based on a wide range of historical conditions and administration under Colorado Water Law.
- Development of methods and models to verify that diversion reductions are not an artifact of standard agricultural practices (e.g. cutting hay).
- Development of appropriate stream gauging infrastructure to identify important management triggers and thresholds

If CWT cannot implement the above actions or secure widespread participation in non-diversion agreements, short-term split season leasing of senior water rights under the CWCB Instream Flow Program represents a viable market-based alternative. Short term leasing of water from the Sweet Jessup Canal or the East Mesa Ditch would yield the largest ecosystem benefits. Return flows from these ditch systems accrue to the Roaring Fork River. Therefore, any leased water on the Crystal would be shepherded along the entire length of the river to its confluence with the Roaring Fork. Leasing monies transferred to water users can be used to support infrastructure maintenance and upgrades or compensate for any drop in agricultural yield caused by diversion reductions.

5.2 TOWN OF CARBONDALE CONSERVATION AND EFFICIENCY PLANNING

The Town of Carbondale must work to match conservation and management measures implemented by the agricultural community. Doing so will leverage stakeholder investment in the planning processes and demonstrate the community's willingness to participate in important local environmental issues. According to Carbondale's Municipal Water Efficiency Plan,17 the Town's total water rights are sufficient to meet future water demand forecasts if no conservation occurs. Regardless of sufficient supply, Carbondale set a potable water efficiency goal of 2% savings per year until 2050, demonstrating commitment to efficient resource use. While this represents an admirable conservation goal, it does not apply to the majority of surface water diverted by the Town and used to support trees, green lawns and landscaping in parks and along transportation corridors. The Municipal Water Efficiency Plan does identify the need for improved infrastructure and efficiency in raw water conveyance systems. The Town commonly lines portions of ditches and laterals when they are impacted by a development project. The CRMP recommends that the Town make lining a considerable portion of the remaining earthen ditch sections a high priority action item. This can best be achieved by ensuring that ditch lining is considered in all future relevant development review processes or during design and planning for sidewalks, parks, and other public spaces.

Currently, the Town does not charge residential customers for raw water usage from the ditch system. This makes incentivizing water conservation in times of shortage difficult. Metering use from ditches throughout Town is likely cost-prohibitive. Therefore, a more promising avenue for bringing market forces to guide water use by residents is to curtail raw water supplies during times of drought. Surface water diversion reductions by the Town of Carbondale in drought years would force more residents to water lawns and gardens with treated water, which is subject to tiered rate structures that disincentivize wasteful or inappropriate use. Bypass of water past the Town's surface water diversions should be formalized through short-term leasing agreements under the CWCB Instream Flow Program. Without leases in place, conserved water would be used by upstream junior users, exacerbating low flow conditions in the critical reaches of the Crystal River.

5.2.1 Feasibility and Next Steps

Town of Carbondale planning documents indicate political will exists to implement recommended water conservation actions. Reducing raw water supply in drought years, thereby forcing more residents to use treated water, will increase awareness of water supply issues in times of scarcity. Shifting users to a metered system will also generate revenue for the Town's utility department, which can be used to fund water conservation measures in other parts of the ditch system. Lining ditches should decrease ongoing maintenance costs for water conveyances, yielding additional financial benefit to the Town over the long run. Carbondale's support of strategic conservation projects and partnerships is critical to comprehensive efforts to optimize use of limited water supplies in the Crystal River Watershed.

Successful implementation of this high-priority management alternative requires Town staff and elected officials to complete the following actions:

- Develop short-term leasing arrangements under the CWCB Instream Flow Program with groups like the Colorado Water Trust.
- Consider the methods available to quantify crop "dry-up" in municipal spaces and private properties affected by water leasing terms.
- Characterize of the potable water supply's ability to support additional outdoor irrigation use in times of drought.
- Consider the revenue implications of increased potable water use in dry years.
- Consider an equitable cost sharing programs for raw water users to help support conservation upgrades and of the Town's ditch system.

5.3 FUTURE CONSIDERATIONS

The high-priority management actions identified above are favorable and appear feasible on relatively short planning horizons. Additional management solutions may play important roles in optimizing water uses to support agricultural, municipal, and environmental needs over the long term. Their consideration on the Crystal River largely depends on identification of appropriate funding mechanisms to support their implementation.

5.3.1 Channel Modification Projects

Structural enhancement projects on the River can improve adult trout habitat quality during low flow periods. This type of project would be most effective in the area between Thompson Creek and the CPW Fish Hatchery, and would be somewhat beneficial between the hatchery and the Kaiser and Sievers Ditch headgate (Figure 5-2). Recent cost estimates for constructing artificial fishery habitat on the Crystal River ranged from $215-245 per linear foot.42 The relatively high cost of this project type represents a barrier to implementation; although, granting programs like Great Outdoors Coloraodo (GOCO) may present a viable funding option for channel modifications completed on public property. Characteristics of the natural sediment regime also necessitate careful planning and design to minimize long-term maintenance costs and ensure that changes in channel hydraulics do not negatively impact riparian communities, channel morphology, and channel evolution.

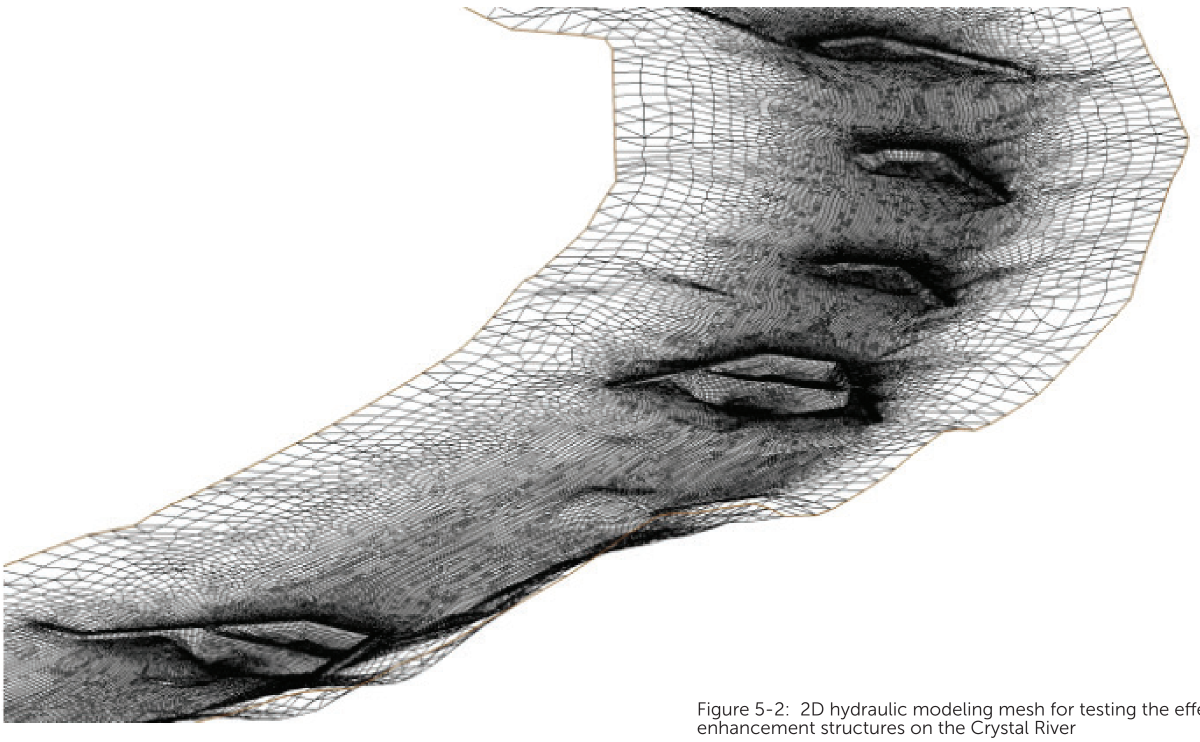


Figure 5-2: 2D hydraulic modeling mesh for testing the effectiveness of artificial habitat enhancement structures on the Crystal River

Installation of grade control structures at the headgates for the Carbondale Ditch and Kaiser and Sievers Ditch will reduce annual maintenance costs by limiting the need for push-up dams at these locations. When designed properly, grade-control structures also reduce aquatic habitat fragmentation and improve aquatic organism passage, yielding a net benefit to ecosystem function. Depending on site conditions and design elements, development of grade controls may approach $100,000.52 High bedload transport on the Crystal River may necessitate some ongoing maintenance of these structures to ensure they continue to function as originally designed. Future consideration of grade control structure development should focus on funding sources. The Colorado River Water Conservation District (CRWCD) and the Natural Resource Conservation Service (NRCS) both offer granting programs to support this type of agricultural infrastructure development. Design and installation of a grade control structure at the Carbondale Ditch may necessitate complex permitting and contracting arrangements due to the fact that the Town's headgate is located on private property. The NRCS is a logical source of funding for a project of this scale, but that agency cannot contract with municipal entities. Therefore, the property owner where the headgate is located would need to act as the fiscal agent and contractee for the project.

5.3.2 Off-Channel Reservoir

Development of a 3,000-5,000 AF reservoir on Thompson Creek may provide opportunity to alleviate existing consumptive use shortages and, simultaneously, improve ecosystem condition. Late season releases could significantly improve ecosystem impairment caused by severe flow depletion on Thompson Creek. Depending on the location of the downstream use, water from the reservoir could help meet identified late-season low flow targets on the Crystal River mainstem. Reservoir development requires overcoming several financial, administration, legal, and public interest barriers. Capital costs for a project of this size in the Thompson Creek watershed are estimated at $9.75 million.35 Due to possible reservoir siting on public lands, the permitting and approval process for a potential reservoir could be lengthy and may face opposition from groups concerned with associated environmental impacts. Additional costs may come in the form of private land purchases, water rights acquisitions, and planning study updates. Water from this reservoir could cost as much as $3,200 per acre-foot. Annual dam operations, inspections, and maintenance/repair costs may serve to increase this figure. During development of the Plan, no user in the Crystal River watershed indicated that these costs were reasonable for local agricultural producers. It is also likely that costs would prohibit securing reservoir releases exclusively for environmental uses. However, downstream junior users in the Colorado River basin may see its benefits as an augmentation supply. Future consideration of off-channel reservoir development in the Crystal River watershed should begin with conversations between local agricultural producers, conservation groups, representatives from the CRWCD, and the owner(s) of conditional storage water rights in the Thompson Creek watershed. These conversations should focus on estimated costs and timelines for reservoir development, anticipated or expected water use demands on the Crystal River and elsewhere that might benefit from water storage, and the willingness of various parties to pay for that stored water.

5.3.3 Ditch Lining and Sprinkler Irrigation

Despite the predicted benefits that water efficiency upgrades can provide to agricultural producers in the form of reduced severity and frequency of shortages in dry years, the high costs associated with these upgrades makes them difficult for individual water users or small ditch companies to implement. The NRCS estimates capital costs of sprinkler system installation to be $17 to $75 per linear foot. Ditch lining estimates range from $5-100 per linear foot for HDPE or flexible piping, materials commonly used in this area in projects attempting to eliminate water conveyance losses. Actual costs can vary widely based on materials, labor, and installation, and specialized additional requirements or engineering.52 A recent piping project on the Bowles and Holland Ditch cost approximately $100/ft, while a more complex piping effort on the East Mesa Ditch approached $400/ft. Capital expenditures may be offset by the reductions in ongoing maintenance and operation costs accrued to a water user or ditch company. To make widespread water infrastructure improvements a viable option for improving ecosystem function on the Crystal River, local water users must have access to a reliable funding source. During development of the Plan, local water users expressed interest in exploring the possibility, desirability, and feasibility of securing a dedicated fund for financing infrastructure improvements. Local conservation organizations promoting alternative water management on the Crystal River should investigate how such a fund could be managed, supported by grants and/or philanthropic gifts, and distributed among local users. Water conservation groups may need to further incentivize infrastructure projects by acting as the fiscal agent for infrastructure project contracts.

In order for efficiency upgrades to benefit the ecosystem and other users, conserved water must be left in the stream. Widespread perceptions regarding risk of water right abandonment and a general lack of appropriate incentives limit the likelihood that users bypass conserved water past headgates. Rather, efficiency upgrades typically benefit only the users they serve. Implementation of conservation measures under a regional water conservation plan created under Colorado Senate Bill 13-019 provides water users with the legal protections necessary to leave conserved water in the stream, consequence free. In this way, conservation gains can be shared among many local use needs. Conservation groups should actively work with the CRWCD to sign interested water users into the conservation plan. Before implementing infrastructure projects, attention should be given to the value the community places on cottonwood galleries, riparian zones, and wetlands created by ditch seepage that would otherwise be dried out by ditch lining or piping. Finally, strategies for bypassing conserved water past headgates must be carefully considered to ensure that potential use of conserved water by upstream junior users does not exacerbate existing impairments to the hydrological regime on critical reaches.

5.4 MOVING FORWARD

Changing demographics and local economies place increasing value on the Crystal River's aesthetic, environmental and recreational attributes while retaining important cultural ties to a strong heritage of agricultural production. Residents in the Town of Carbondale enjoy large shade trees, verdant gardens, and green open spaces supported by a free raw-water supply sourced from the River. Agricultural producers, in turn, depend on use of the Crystal River to support their livelihoods and maintain vast open spaces terraced along the flanks of Mount Sopris and across the valley floor. The convergence of multiple water use needs and water scarcity on the Crystal River during periods of drought leads to demand shortages for junior water users and impairment of various measures of ecosystem function.

Local recognition of these issues led to development of the Crystal River Management Plan as a tool for optimizing management decisions to support this wide array of community needs and environmental concerns. The findings and recommendations presented in the various sections of the Plan are summarized below:

- Few external stressors exist in the headwaters of the Crystal contributing to a generally healthy ecosystem above Redstone.
- Constraints on ecosystem function slowly increase in the downstream direction due to the cumulative effects of floodplain development and surface water diversions.
- The reaches of Crystal River between Thompson Creek and the confluence with the Roaring Fork exhibit the most degraded overall functional condition.
- Reductions in late summer baseflows produce cascading impacts on channel hydraulics, water temperature, and physical habitat quality and availability.
- Supply shortages on water-limited tributaries are common. Demand shortages on the Crystal River exist for the junior rights on the East Mesa Ditch, Sweet Jessup Canal, Helms Ditch, and Kaiser & Sievers Ditch. The CWCB ISF right is frequently short in late summer.
- Water efficiency upgrades (e.g. sprinkler irrigation and ditch lining) can significantly reduce the frequency and magnitude of demand shortages experienced by agricultural producers.
- The most feasible and effective management options for meeting planning goals include 1) Non-Diversion Agreements between the Sweet Jessup Canal and Carbondale Ditch, and 2) ditch lining and short term water leasing by the Town of Carbondale on the Carbondale Ditch and Weaver and Leonhardy Ditch.
- Non-Diversion Agreements of approximately 25 cfs in severe drought and 10-15 cfs during moderate drought will meet management goals for maintaining moderate risk to ecosystem function. Current conditions place the ecosystem at high risk for unfavorable change.
- Reaching management targets will require diversion reductions between 5-18% (depending on drought severity) between the Sweet Jessup Canal and the Carbondale Ditch.
- Stakeholders should continue to investigate the feasibility of stand-alone water efficiency infrastructure projects, off-channel reservoir development, and channel modifications to simultaneously promote ecosystem function and the long-term sustainability of local agricultural production.

Population growth trends indicate that the Town of Carbondale will experience a doubling in size in the coming decades. Projections from climate data indicate that climbing temperatures will shift the timing of snowmelt runoff and increase the frequency and severity of hot and dry summer conditions. These changes will place increasing strain on the riverine environment at the same time that demand shortages for existing uses become more common. Without tools and structured plans for responding to these challenges, tensions between stakeholders will continue to mount. This Plan recommends several high-priority actions for ensuring that the local community is adequately equipped to deal with shifting community values, economic foundations, and climate realities in a way that minimizes conflict between users groups and achieves high levels of environmental resiliency.

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