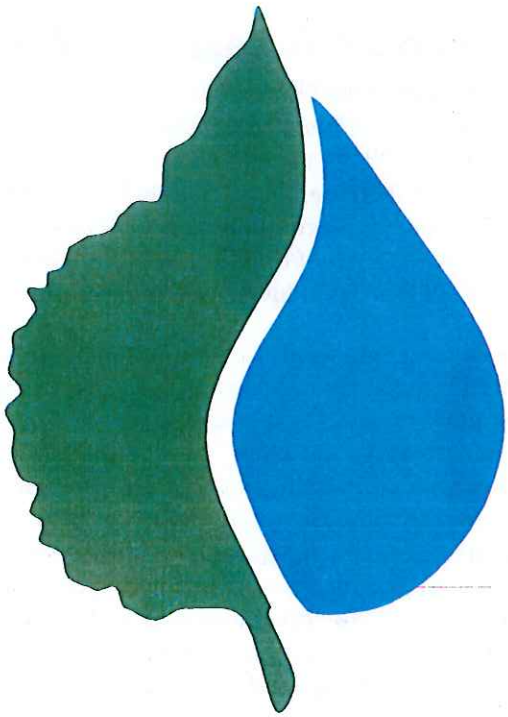
Upper Roaring Fork River Management Plan



Riverine Needs Assessment

City of Aspen | Pitkin County

May, 2017

Purpose

In recent years, the City of Aspen, Pitkin County, the Roaring Fork Conservancy, Colorado Basin Roundtable, and other organizations spent significant time, energy and money collecting information on the condition of aquatic resources in the Roaring Fork River. These efforts resulted in a wealth of scientific studies and reports useful for understanding the impacts of land and water management on riverine conditions. The following summary intends to assist the City, the County, and members of the Community to arrive at a common understanding regarding the prioritization of issues—both in type and location—that represent the greatest constraints on the healthy functioning of the stream ecosystem on the Roaring Fork River and its tributaries near Aspen. This assessment effort did not collect new data or perform any new analyses. Rather, synthesis of the information contained in the body of literature and organized by stream reach provides an intuitive framework for considering land use and water management recommendations for streams throughout the upper Roaring Fork watershed.

Functional Assessment Approach

The complex interplay between the human, physical, chemical, and biological components of the Roaring Fork River and its tributaries complicates the task of identifying appropriate management strategies that respond to local concerns about one or more environmental attributes of interest. Each environmental attribute, such as channel dynamics or aquatic habitat, is made up of many interconnected components, such as stream flow, weather conditions, temperature, and season of the year. Each of these many components must be identified and evaluated in order to develop an overall management plan for the riverine ecosystem.

This effort employed a modified version of the Functional Assessment of Colorado Streams (FACStream) framework to organize the body of research and studies that previously assessed the functional condition of streams and rivers in the upper Roaring Fork watershed based on a suite of physiochemical, biologic, geomorphic, hydrologic and hydraulic state variables. FACStream organizes information about stream function in a way that simultaneously recognizes the existence of complex interactions between the physical and biological components of riverine ecosystems and disaggregates the system into a collection of more easily understood ecosystem attributes and behaviors. Attributes and behaviors considered here include: flow regime, sediment dynamics, water quality, floodplain connectivity, riparian vegetation, debris supply, channel morphology, aquatic habitat, and aquatic biota. Together, they describe fundamental ecosystem processes and provide a relatively straightforward basis for characterization of individual reaches of stream that can facilitate comparative assessments across the upper Roaring Fork watershed.

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. In a similar manner, reach scale processes generally influence channel scale characteristics and dynamics. Thus, the consideration of scale is critical for ensuring the correct identification of stressors, and also for identifying appropriate management response opportunities.

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. Water quality may be impacted as flows decrease due to reduced dilution capacity or increases in stream temperature that alter rates of transformation of metals and nutrients in the water column. The quality and availability of stream habitat may also change as flows decrease. Fish and other aquatic species prefer specific habitat types defined by water depth, velocity, cover type, temperature ranges, and substrate type. Reduced flows frequently alter velocity and depth distributions and may result in increased average and maximum daily temperatures. Alterations to natural patterns of flow variability, including the frequency and timing of floods, may impact fish, aquatic insects and other biota whose life cycles are tied to predictable rates of occurrence or change.[24]

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. A functional analysis 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, wildfire, avalanche, mudslides, large scale development or road construction can alter the sediment regime by elevating sediment loads to transport limited channels. These changes may lead to channel aggradation and elevated rates of bank erosion and lateral channel movement. Sediment transport at local or regional scales may also be impacted by physical infrastructure like dams and weirs. These structures may trap sediment in supply limited reaches, resulting in channel down-cutting.

Water Quality

Natural geological weathering and human activities occurring at the scale of the contributing watershed largely dictate the physical and chemical characteristics of the water column. Streamside development of commercial, residential, and industrial land uses often contribute non-point source loads of various chemical constituents (e.g. solvents, pesticides, fertilizers). Wastewater treatment plants discharge point loads that frequently exhibit nutrient concentrations and temperatures that are elevated above instream concentrations. Biogeochemical processing (e.g. nutrient uptake) by stream organisms may alter local water quality conditions to some degree depending on carbon availability, temperature, and resulting rates of gross primary productivity.[24] Physical water quality conditions (e.g. water temperature), while somewhat influenced by local patterns of channel form and streamside vegetation, remain fundamentally controlled by watershed scale variables like latitude, elevation, and drainage aspect,

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. The overbank flows that elevate the water table in the alluvial aquifer and produce favorable conditions for riparian vegetation in the Upper Roaring Fork watershed are driving by snowmelt runoff, with peak flows typically occurring in late May or early June. Typical floodplain connectivity impairments result from watershed-scale impacts to the flow regime or localized geomorphic impacts resulting from construction of artificial levees, ditches, channelization, or channel enlargement.[24]

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.

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.

Channel 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 characteristics inappropriate for local valley setting and sediment regime may display elevated channel instability or a reduction in physical complexity of the streambed.

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.

Aquatic Biota

Assessments of biotic structure frequently consider the total biomass, community composition, and species interactions of and between microbes, macrophytes, macroinvertebrates, fish and amphibians, and other animals. Measures of productivity and 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 ecosystem goods and services. 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.

Table 1. Studies used to evaluate ecosystem state variables on the Roaring Fork River and its tributaries.

Indicator	Example Metrics	Assessments and Studies
Flow Regime	Peak Flow, Base Flow, Annual Yield	Roaring Fork Watershed Streamflow Survey Report (Clarke, 2006) Review of City of Aspen's Castle Creek Hydroelectric Project Aquatic Resource Documents (Espegren, 2011) Snapshot Assessment of the Roaring Fork Watershed (Mason, 2012) Preliminary Hydrologic and Biological Characterization of the North Star Nature Preserve (Hickey et al. 2000)
Sediment Dynamics	Land Erosion, Channel Erosion, Hydraulic Transport	Geomorphic Assessment of the Stability of the Roaring Fork River through the City of Aspen (Ayres Associates, 2011) Preliminary Hydrologic and Biological Characterization of the North Star Nature Preserve (Hickey et al. 2000) Geomorphic Assessment, North Star Nature Preserve (Goulder Associates, 2014)
Water Quality	Physical Params, Nutrients, Metals, Organic Compounds	Integrated Water Quality Monitoring and Assessment Report (CDPHE, 2014) Roaring Fork Watershed Water Quality Report (Roaring Fork Conservancy, 2006)
Floodplain Connectivity	Extent, Saturation Duration, Fragmentation	Geomorphic Assessment of the Stability of the Roaring Fork River through the City of Aspen (Ayres Associates, 2011) Preliminary Hydrologic and Biological Characterization of the North Star Nature Preserve (Hickey et al. 2000)
Riparian Vegetation	Structure and Complexity, Fragmentation, Extent	Preliminary Hydrologic and Biological Characterization of the North Star Nature Preserve (Hickey et al. 2000) Castle Creek Hydroelectric Plant Environmental Report (Miller and Swaim, 2010) Geomorphic Assessment of the Roaring Fork River and Impacts of Groundwater Changes on Wetlands, North Star Nature Preserve (MEC and Ayres Associates, 2011)
Debris Supply	Large Wood, Organic Matter	Geomorphic Assessment, North Star Nature Preserve (Goulder Associates, 2014)
Channel Morphology	Planform, Dimension, Profile, Rate of Change	Geomorphic Assessment of the Stability of the Roaring Fork River through the City of Aspen (Ayres Associates, 2011) Preliminary Hydrologic and Biological Characterization of the North Star Nature Preserve (Hickey et al. 2000) Geomorphic Assessment, North Star Nature Preserve (Goulder Associates, 2014)
Aquatic Habitat	Complexity, Connectivity, Quality	Review of City of Aspen's Castle Creek Hydroelectric Project Aquatic Resource Documents (Espegren, 2011) Castle and Maroon Creeks 2012 Aquatic Monitoring Reports (Miller and Swaim, 2011-2013) Castle Creek Hydroelectric Plant Environmental Report (Miller and Swaim, 2010) Final Report Evaluation of River Health: Roaring Fork River near Aspen, Colorado (Miller, 2011)
Aquatic Biota	Macroinvertebrates, Trout, Amphibians, Algae	Upper Roaring Fork River Aquatic Life Use Assessment (Mason, 2012) Preliminary Hydrologic and Biological Characterization of the North Star Nature Preserve (Hickey et al. 2000)

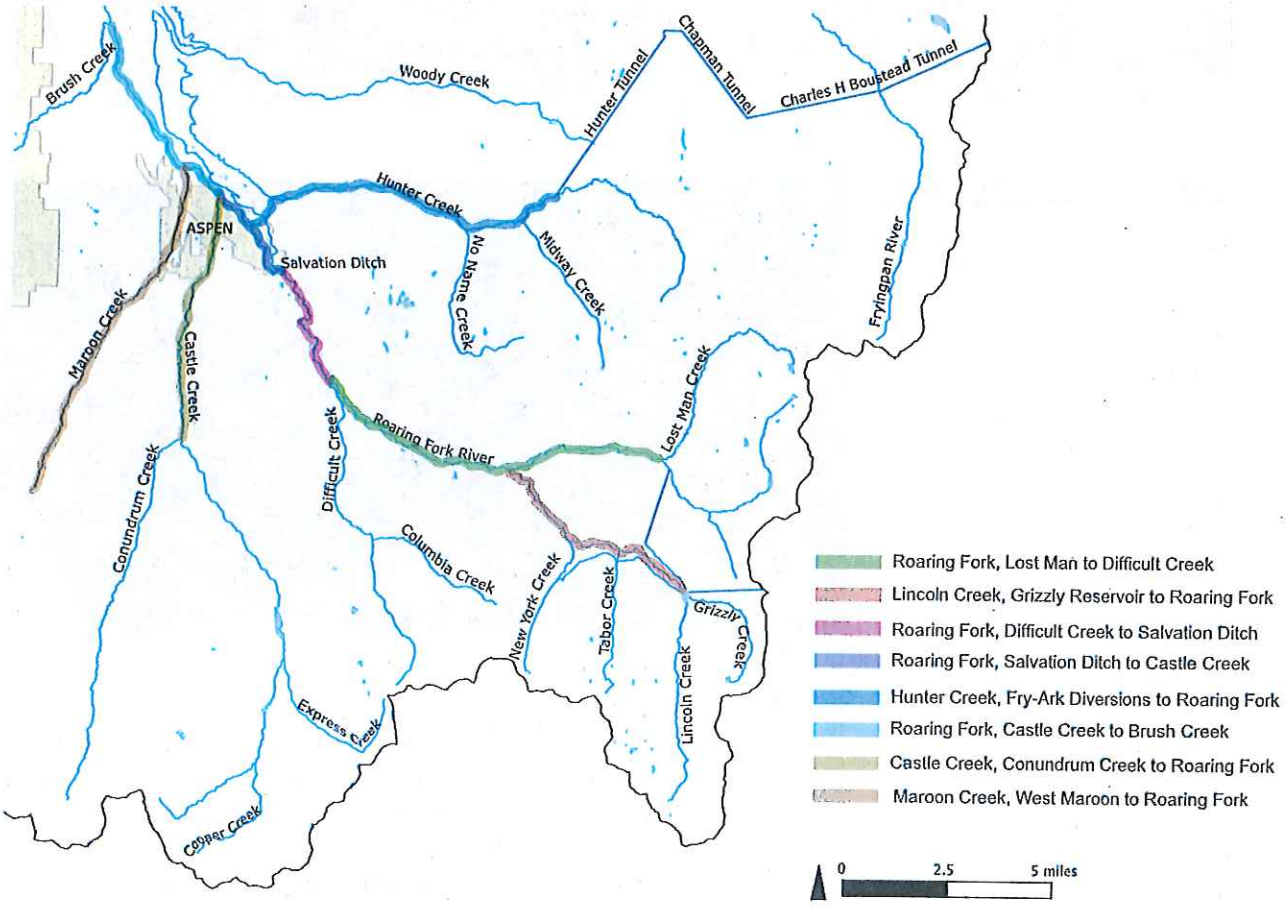
A wealth of investigations and reports focused on channel geomorphology, riparian ecology, fisheries, and hydrology were completed in the study area of the last 20 years. Most of these assessments evaluated current conditions and characterized the degree of departure from a non-impacted reference state using process based models or forensic, weight-of-evidence based approaches. The large variety of assessment methodologies—some rapid and coarse, some focused and intensive— employed by these studies produced evidence that reflects ecosystem processes across a range of spatial scales with varying degrees of objectivity (Table 1). Functional condition scores for various stream reaches in the upper Roaring Fork watershed were developed based on expert review and synthesis of information contained in the existing literature. (Table 2).

Table 2. Functional rankings applied to stream reaches in the upper Roaring Fork watershed.

Grade	Condition	Description
A	Reference Standard	Condition of the variable is self-sustaining and supports functional characteristics appropriate to sustain river health. Limited management required in order to sustain and protect this level of function given stressors from the modern landscape.
B	Highly Functioning	The condition of the variable maintains essential qualities that support a high level of ecological function, yet there is some influence of stressors at a detectable, yet minor, level. Requires some limited management to sustain and protect against stressors. The variable retains its essential qualities and supports a high level of ecological function.
C	Functioning	The condition of the variable has been altered and/or degraded by stressors that substantially influence the variable's functionality. The variable still supports basic, natural, stream/riparian functioning. Management is likely required to improve maintenance of the functional role of the variable.
D	Functionally Impaired	The condition of the variable is severely altered by stressors that impair the functionally variable's ability to support characteristic functioning and the overall health of the river. Extensive, active management is required to restore the functional role of the variable.
F	Non-Functioning	The condition of the variable is under the influence of massive deleterious alterations/stressors. The level of alteration generally results in an inability of the functioning variable to support characteristic functioning or it otherwise makes the area biologically unsuitable.
?	Not Assessed	Poor data resolution or insufficient data available for evaluation.

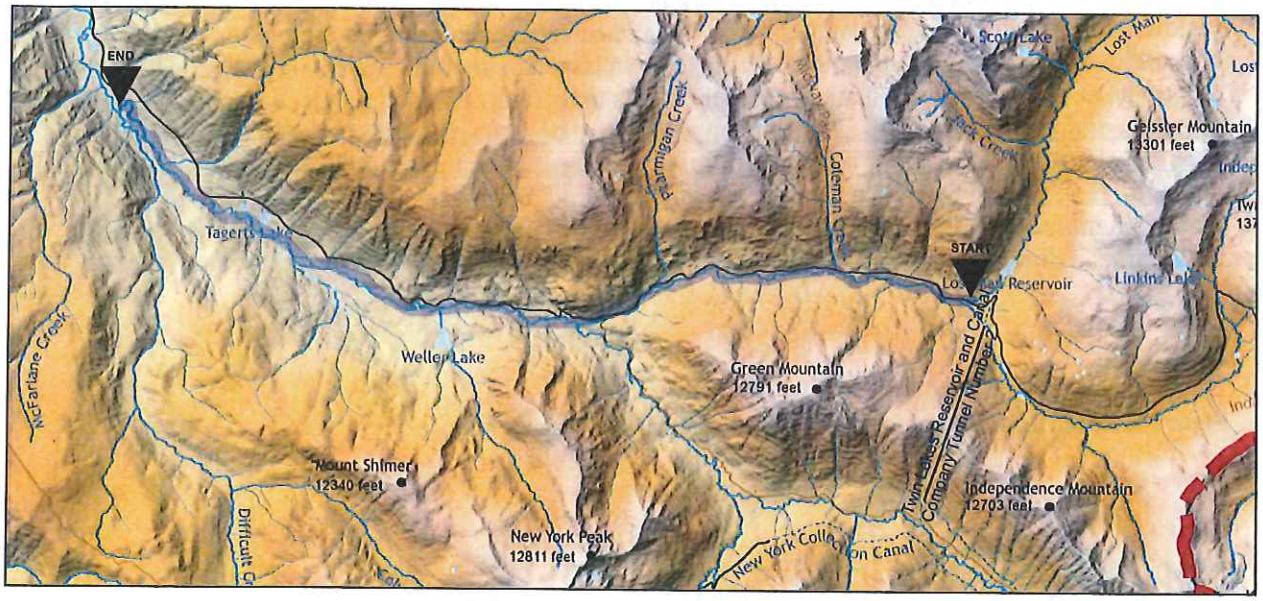
A team of hydrologists, ecologists, and water resource engineers reviewed the existing literature and used the criteria listed in Table 2 to arrive at consensus regarding the functional state of rivers and streams in the project area. Critically, assessments were conducted at the reach scale. Thus, localized severe impacts in an otherwise pristine stream reach did not result in a poor ranking for the entire reach, but was instead taken into consideration for the evaluation of the overall reach condition. The historical assessments reviewed and referenced here identified a wide variety of streamflow management opportunities and goals to lessen observed impacts to ecosystem function at a range of spatial scales and at different locations in the watershed. It is not the intention of this report to endorse or prioritize any of the opportunities or goals presented here. Rather, they provide a foundation for more nuanced discussion regarding opportunities and limitations for action on the Roaring Fork River and its tributaries. Functional assessment results and managements recommendations were broken out by stream reaches according to the geographic boundaries delineated in Figure 1.

Figure 1. Reach delineation for the riverine needs assessment.



Assessment Results

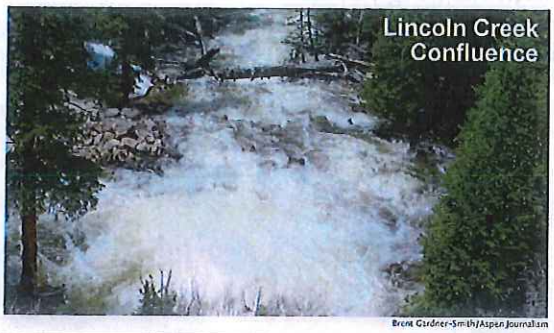
Roaring Fork River: Lost Man Creek to confluence with Difficult Creek

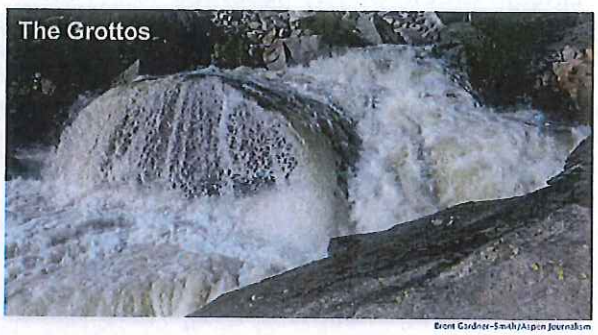


Indicator	Condition
Flow Regime	D
Sediment Dynamics	?
Water Quality	A
Floodplain Connectivity	C
Riparian Vegetation	C
Debris Supply	?
Channel Morphology	A
Aquatic Habitat	C
Aquatic Biota	B

Reach Description:

The upper Roaring Fork River between Lost Man Creek and Difficult Creek is characterized by steep gradients and narrow, bedrock controlled channels. Gradients decrease near Taggert Lake. The channel remains single threaded throughout this reach. The Colorado Natural Heritage Program (CNHP) identifies riparian areas along this reach as a Potential Conservation Area (PCA). Most of this segment flows immediately adjacent to Highway 82 and sees significant recreational use near Tagert Lake, the confluence with Lincoln Creek, and near the Grottos.





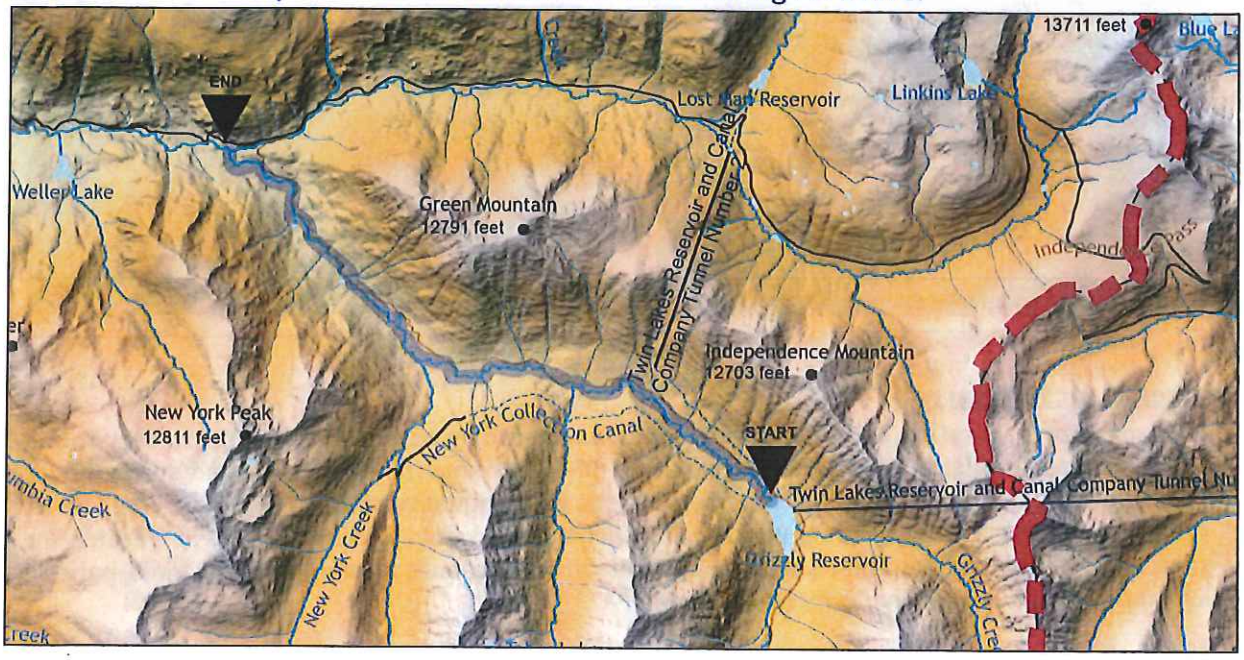
Assessment Summary:

Flow magnitude, duration, and inter-annual variation altered by trans-basin diversions. Year-round flows decreased at least 10% on average, with a 40-50% reduction in summer and spring flows. These flow reductions are expected to reduce aquatic habitat quality and availability. Short reaches, generally clustered near the confluences of Difficult and Lincoln Creeks, exhibit moderately or severely degraded aquatic and riparian habitat due to the presence of campgrounds, trails, parking lots and recreational uses adjacent to the river.[2,3,4,6]

Identified Management Opportunities and Goals:

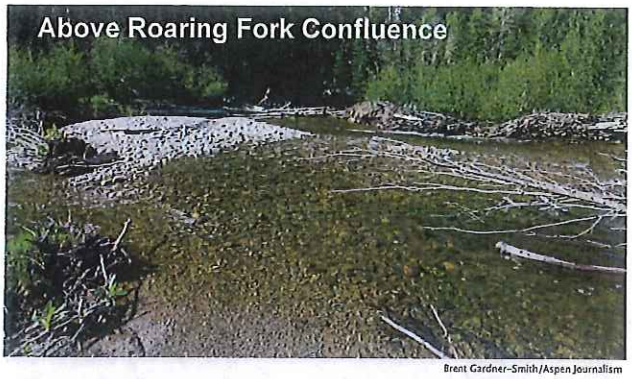
The Fry-Ark Project Operating Principles recommend flows from March to June between 24-120 cfs, minimum daily flows between May and July of 60 cfs, and minimum daily flows between August and April of 15. Notably, native streamflows are often inadequate to meet these flow recommendations. A secondary recommendation comes in the form of the ISF water right, which seeks to maintain late-summer streamflows above 15 cfs.

Lincoln Creek: Grizzly Reservoir to confluence with Roaring Fork River

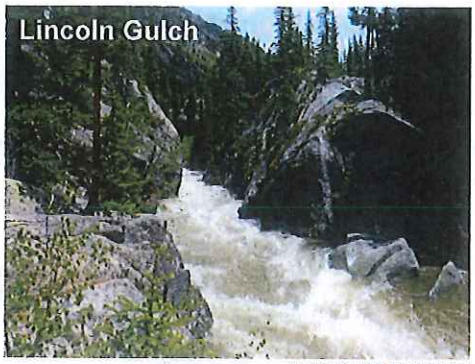


Indicator	Condition
Flow Regime	D
Sediment Dynamics	C
Water Quality	C
Floodplain Connectivity	B
Riparian Vegetation	?
Debris Supply	?
Channel Morphology	?
Aquatic Habitat	C
Aquatic Biota	?

Reach Description:
Lincoln Creek alternates between meandering alluvial channel forms and bedrock controlled canyons between Grizzly Reservoir and the Roaring Fork River. Grizzly Reservoir acts as a fore bay and small water storage impoundment for the Twin Lakes diversion system. Above Grizzly Reservoir, the creek and its tributaries drain area historically impacted by hardrock mining activities.



Brent Gardner-Smith/Aspen Journalism

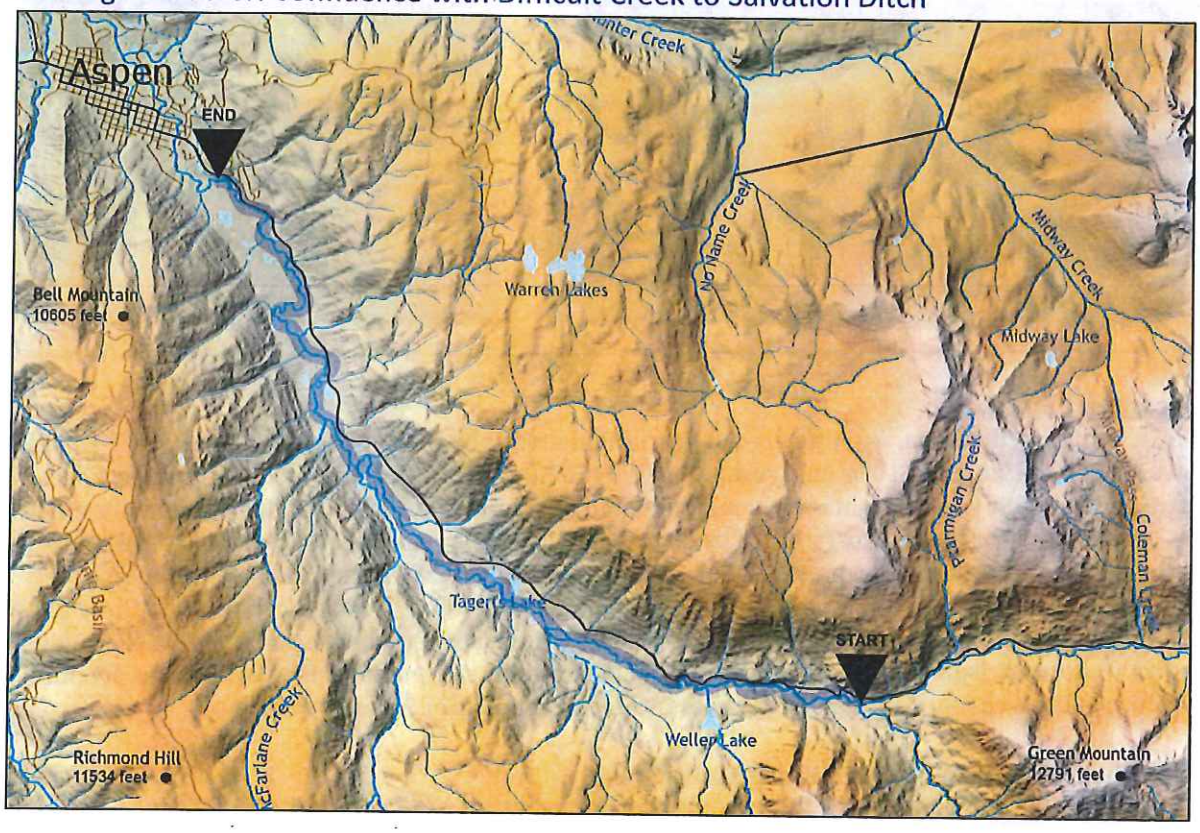


Brent Gardner-Smith/Aspen Journalism

Assessment Summary:
Flow magnitude, duration, and inter-annual variation altered by trans-basin diversions. Year-round flows decreased at least 10% on average, with a 50% reduction in summer and spring flows.[4] Instream Flow (ISF) water rights—recommended flows for protection of aquatic life—are often not met because they are junior to Twin Lakes bypasses. Riparian health has not been assessed on this reach. Episodic discharges of metals laden sediment from Grizzly reservoir may produce short-duration water quality impairments on Lincoln Creek and the Roaring Fork River. While the impoundment of metals-laden sediment within Grizzly Reservoir may represent a net water qulaty benefit to downstream waters, the disruption of the natural sediment regime is likely to produce some impacts on channel form and dynamics in alluvial sections of Lincoln Creek.

Identified Management Opportunities and Goals:
The CWCB seeks to maintain late-summer streamflows above the ISF water rights of 8 cfs.

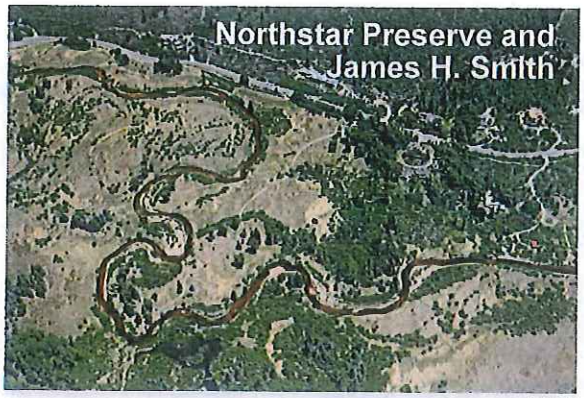
Roaring Fork River: Confluence with Difficult Creek to Salvation Ditch



Indicator	Condition
Flow Regime	D
Sediment Dynamics	B
Water Quality	A
Floodplain Connectivity	C
Riparian Vegetation	B
Debris Supply	?
Channel Morphology	B
Aquatic Habitat	B
Aquatic Biota	A

Reach Description:

Below Difficult Creek, the Roaring Fork River enters an alluvial valley where gradients decrease, riparian areas expand, and rates of channel migration increase. The river flows through national forest, private land, and county open space in this reach. CNHP identifies this area as a PCA. The Northstar Preserve above Aspen sees heavy recreational use.



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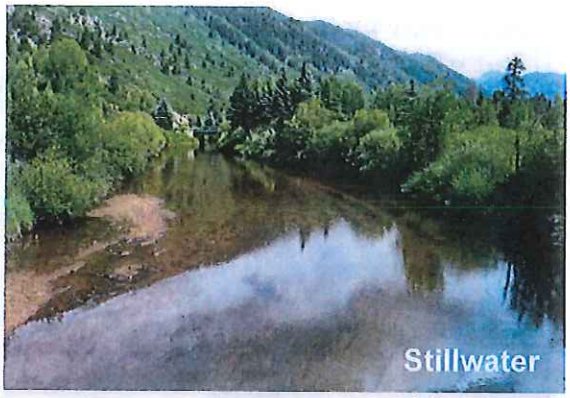
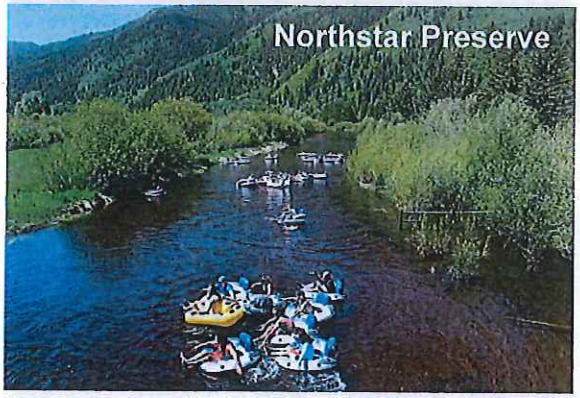
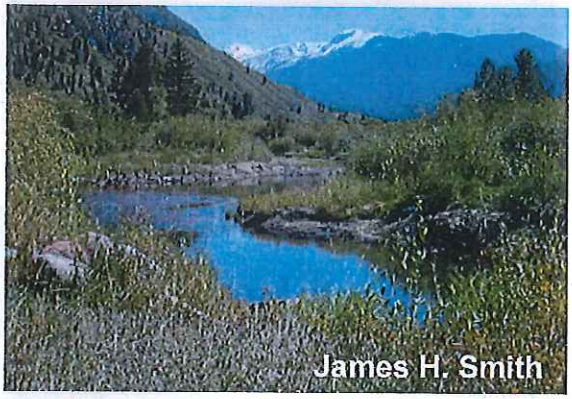


Paul Anderson/Aspen Journalism

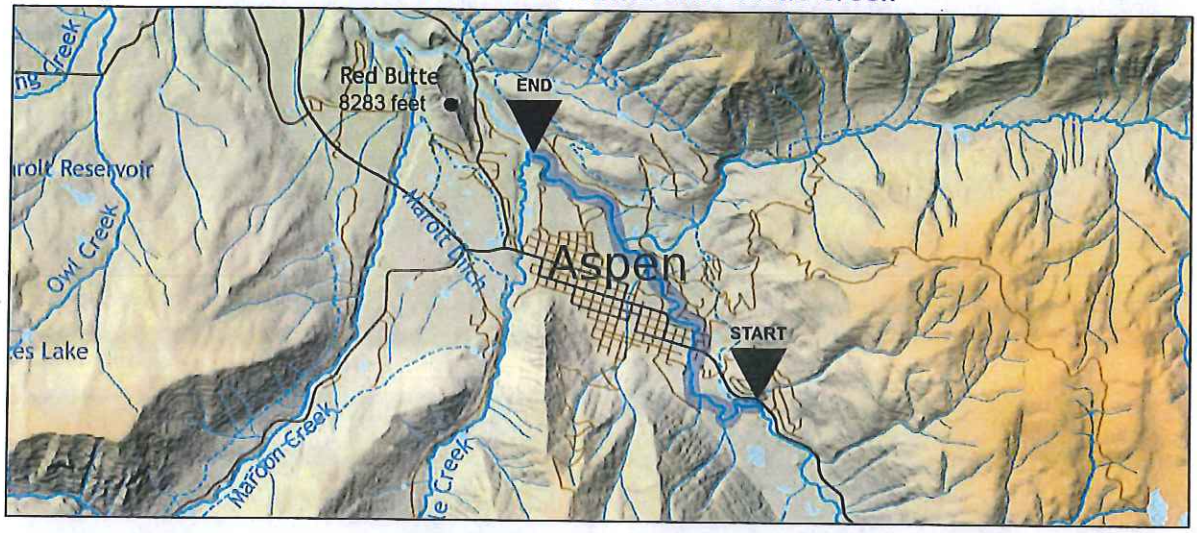




Assessment Summary:
Trans-mountain diversions alter flows in a similar manner to upstream segments. Channel geometry and floodplain connectivity through North Star Nature Preserve are altered as a result of reduced spring and summer flows and historical channel straightening activities. Aquatic habitat structure through North Star Preserve is moderately to severely altered from aggradation, in-channel structures and flow depletion; though limited macroinvertebrate monitoring does not indicate impairment to biota. Riparian communities above and through Northstar are also moderately to severely degraded due to changes in flow regime, development pressure, and invasive species.[1,4,9,10,11,12,14,20] This degradation seems concentrated in the area immediately above aspen and does not extend through a majority of this reach. Healthy upstream areas helped increase overall functional scores.

Identified Management Opportunities and Goals:
Maintain groundwater levels in the northwest corner of the North Star Preserve by replacing headgate controls and updating to impermeable dams on ditches connecting the wetlands to the river and at the diversion between wetlands and Stillwater Ranch pond. Remove artificial berms to connect old meander bends during high flow events to promote riparian health and floodplain connectivity. Restore riparian and aquatic habitat through removal of all cross-channel rock structures; spacing clustered rocks in-channel to create more cover and diverse habitat structure for fish; and placing/anchoring large woody debris. Stabilize lower bank areas devoid of wood vegetation but not actively eroding, and re-establish riparian vegetation with natural materials. Maintain flows above ISF water right of 32 cfs.

Roaring Fork River: Salvation Ditch to confluence with Castle Creek



Indicator	Condition
Flow Regime	D
Sediment Dynamics	C
Water Quality	C
Floodplain Connectivity	B
Riparian Vegetation	C
Debris Supply	?
Channel Morphology	C
Aquatic Habitat	C
Aquatic Biota	D

Reach Description:

The Roaring Fork River through the City of Aspen is boarded by a variety of land uses and infrastructure. In many areas, commercial and residential developments exist in historical riparian zones. Numerous bridges cross the river and several large water diversion structures move water from the river and into the City of Aspen or onto agricultural lands. This section of river is paralleled by numerous footpaths and bordered by several parks that provide access points for residents and visitors to interact with the river. The City of Aspen's primary stormwater discharge points meet the river in this reach.

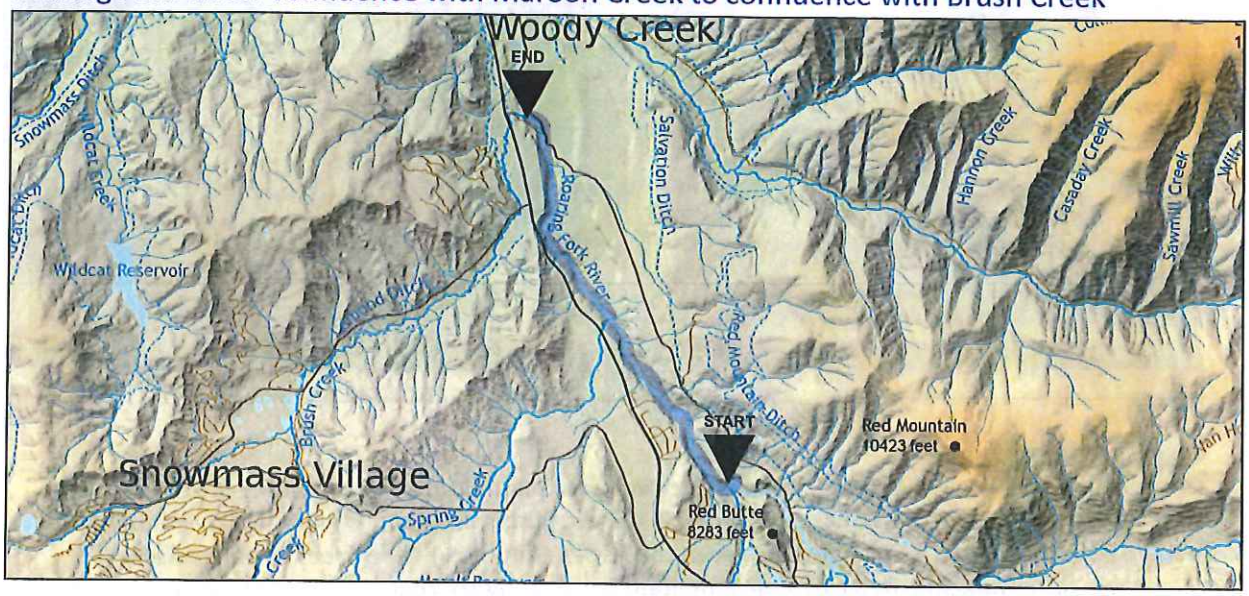
Aspen Center for Environmental Studies

Brent Gardner-Smith/Aspen Journalism

Assessment Summary:
The hydrological regime is significantly altered by trans-mountain diversions and surface water diversions above and within this reach. The ISF water right is often not met in the late summer as a result of this water use. The section between the Aspen Club and Castle Creek is particularly vulnerable to dewatering. Urban development is significantly encroaching on riparian areas and floodplains, impacting sediment transport characteristics, habitat and water quality by increasing fine sediment loading to the stream channel. In-channel structures contribute to a reduction in channel gradient, channel widening, bank erosion and localized aggradation. Aquatic biota are negatively impacted by channel alteration, non-point source pollution, stormwater runoff from the City of Aspen and, potentially, flow modifications. In-channel structures impede fish passage during low flows. Infrequent elevated water temperatures could be detrimental to fish populations.
1,2,3,4,5,11,12,13,19,20

Identified Management Opportunities and Goals:
Reconstruct boulder grade control structures that protect exposed sewer pipelines using a series of weirs at Procter Park, Newbury Park and above Jenny Adair Park. Remove boulder structure at Jenny Adair Park split flow channel. Remove pipelines crossing river downstream of Mill Street and deconstruct the kayak park upstream of the Aspen Art Museum to reclaim small area of functional floodplain.[1] To maintain current conditions, peak flows greater than 350 cfs should occur every other year and peak flows greater than 1,000 cfs approximately 1 in 10 years. Maintain ascending and descending limbs of the hydrograph in the current shape without a sharp increase or decrease. Maintain flows near 30 cfs during late summer base flow periods to protect habitat for juvenile and adult rainbow/brown trout.[13]

Roaring Fork River: Confluence with Maroon Creek to confluence with Brush Creek



Indicator	Condition
Flow Regime	B
Sediment Dynamics	B
Water Quality	B
Floodplain Connectivity	B
Riparian Vegetation	C
Debris Supply	A
Channel Morphology	A
Aquatic Habitat	B
Aquatic Biota	A

Reach Description:

Below Castle and Maroon Creek, the Roaring Fork River enters a steep gorge and gains significant amounts of streamflow. The topography in this area restricts development activity. A bike and footpath parallels the river through this section providing access to recreational users. This section of river is heavily used by whitewater boaters during the early summer months when flows on the river are high. This reach also supports a robust fishery that attracts numerous fisherman. The Roaring Fork River at Brush Creek is designated as a PCA by CNHP.

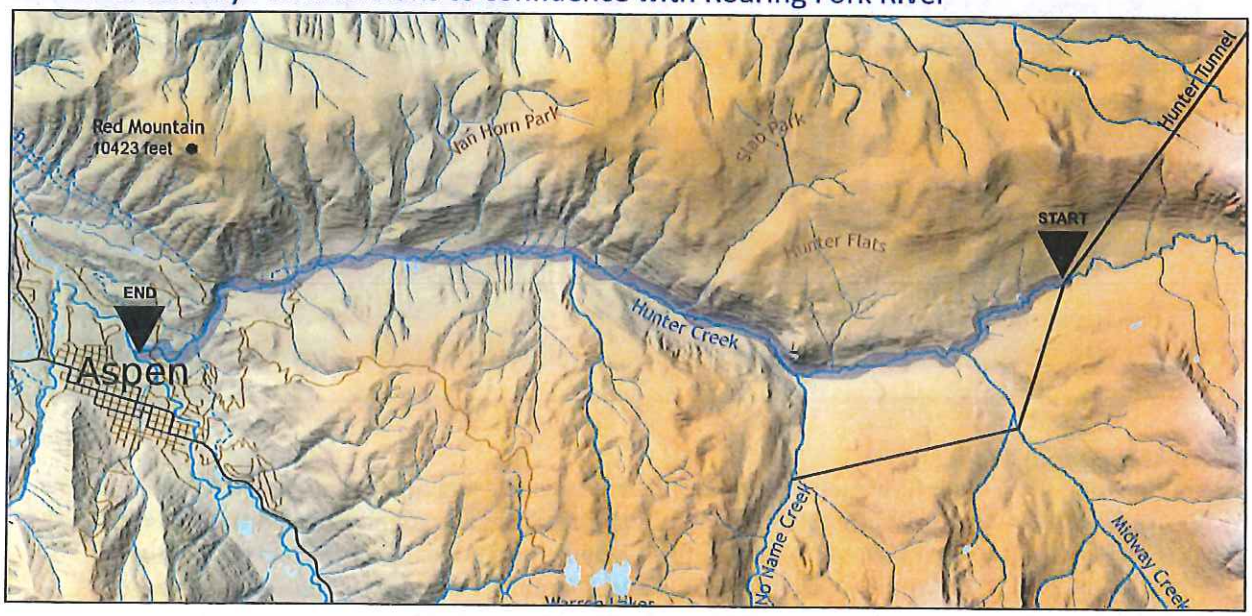
Aspen Times


Brent Gardner-Smith/Aspen Journalism

Assessment Summary:
Encroaching development negatively impacts riparian vegetation and aquatic habitat in several areas. Although a few sizable stretches of significant riparian woodland communities exist in the Airport Ranch Open Space, riparian habitat is heavily degraded near Brush Creek and below Maroon Creek. The proximity of Highway 82, development on adjacent lands, invasive weed introduction from recreational river access trails, and changes in hydrology contribute to degraded riparian conditions. Aquatic habitat is moderately degraded from similar threats, though a robust brown trout population remains. The historic railroad grade through the gorge area contributes to streambank erosion, but the impacts on channel form and dynamics are not evident.[4]

Identified Management Opportunities and Goals:
Maintain streamflows above the ISF water rights of 55 cfs between March and September, and 30 cfs for the remainder of the year.

Hunter Creek: Fry-Ark diversions to confluence with Roaring Fork River



Indicator	Condition
Flow Regime	D
Sediment Dynamics	?
Water Quality	?
Floodplain Connectivity	?
Riparian Vegetation	?
Debris Supply	?
Channel Morphology	A
Aquatic Habitat	C
Aquatic Biota	?

Reach Description:
Hunter Creek drains alpine and subalpine areas on the east side of the Roaring Fork River. Below the Fry-Ark diversion system, the creek transitions from a step-pool and cascade morphology to a single-threaded meandering channel form in several high-valley meadows. Hunter Creek is designated by CNHP as a PCA.

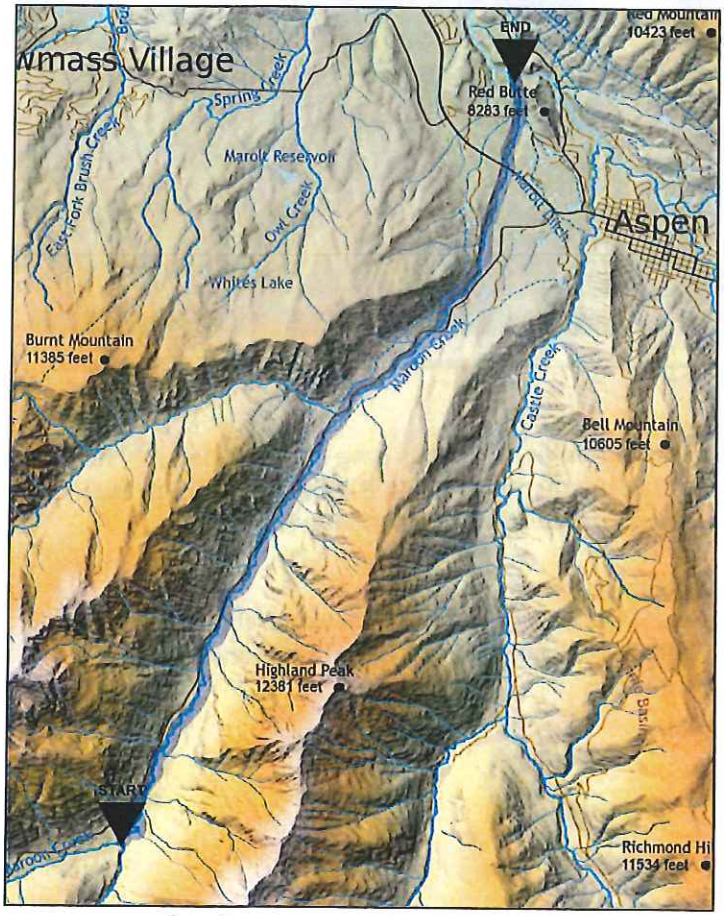
Brent Gardner-Smith/Aspen Journalism

Paul Anderson/Aspen Journalism

Assessment Summary:
The Fry-Ark Transmountain Diversion and other in-basin diversions have reduced May-July flows by up to 50% and ISF decreed ISF rights are often not met seasonally. Riparian vegetation and aquatic biota have not been recently assessed on Hunter Creek or its tributaries.[4]

Identified Management Opportunities and Goals:
Maintain late-summer streamflows above the ISF water rights of 12 cfs between the Fry-Ark diversion and Midway Creek, 17 cfs between Midway Creek and No Name Creek, and 30 cfs between No Name Creek and the Roaring Fork River.

Maroon Creek: West Maroon Creek to confluence with Roaring Fork River



Indicator	Condition
Flow Regime	B
Sediment Dynamics	?
Water Quality	A
Floodplain Connectivity	A
Riparian Vegetation	B
Debris Supply	A
Channel Morphology	B
Aquatic Habitat	B
Aquatic Biota	A

Reach Description:
Maroon Creek drains a steep, rugged subwatershed that is mostly National Forest and includes significant portions of Wilderness. While the upper watershed sees significant recreational visitation, most other sections along Maroon Creek are difficult to access. A road parallels a majority of the stream between the West Maroon Creek and the Roaring Fork River. The lower reaches of the stream are bordered by residential developments and a golf course. Maroon Creek is identified by CHNP as a PCA. However, the lowest reach near the Roaring Fork River is identified as a Conservation Area of Concern.[4]

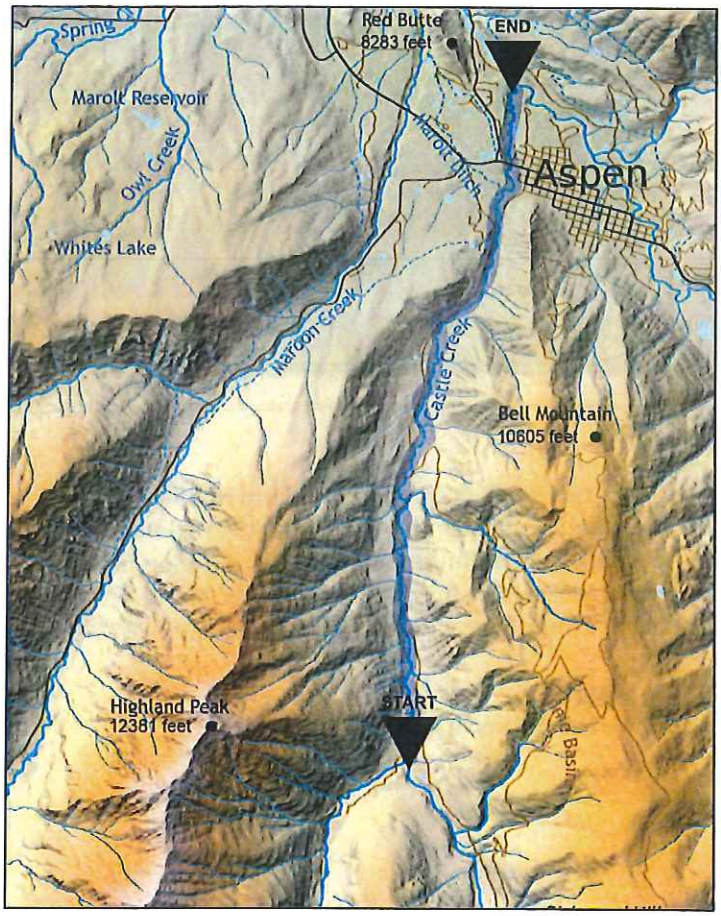
Brent Gardner-Smith/Aspen Journalism

Brent Gardner-Smith/Aspen Journalism

Assessment Summary:
Diversions for snow-making and municipal uses reduce flows in Maroon Creek up to 15-20% between October-April.[4] Both riparian and aquatic habitat are slightly modified where development is concentrated along streambanks near the Roaring Fork confluence. Habitat degradation is caused by flow alteration, development pressure, and invasive species in the riparian zone. Moderate modification of the riparian zone extends above the confluence with the Roaring Fork.[4, 15, 16, 17, 18]

Identified Management Opportunities and Goals:
Maintain late-summer streamflows above the ISF water rights of 14 cfs.

Castle Creek: Conundrum Creek to confluence with Roaring Fork River



Indicator	Condition
Flow Regime	C
Sediment Dynamics	?
Water Quality	A
Floodplain Connectivity	A
Riparian Vegetation	C
Debris Supply	A
Channel Morphology	B
Aquatic Habitat	C
Aquatic Biota	A

Reach Description:
Like Maroon Creek to the west, Castle Creek drains a steep tributary subwatershed to the Roaring Fork River. Development along this creek is more widespread, however. Residential land uses and roadways boarder a majority the creek between Conundrum Creek and the Roaring Fork River. The channel alternates between meandering, braided, and confined, but mostly flows through low-gradient and relatively wide valley bottoms. Castle Creek is identified by CHNP as a PCA.

Brent Gardner-Smith/Aspen Journalism

Brent Gardner-Smith/Aspen Journalism

Assessment Summary:
Surface water diversions for snow-making and municipal uses reduce base flows by up to 20-30%. between November-March.[4]Riparian and aquatic habitat is primarily impacted by flow alteration, and secondarily from trails, roads, and general development pressures. Approximately 25% of the riparian zone near the confluence with the Roaring Fork River is moderately modified. Aquatic habitat conditions degrade progressively going downstream (33% moderate modification; 5% heavy modification).[4, 7, 8, 15, 16, 17, 18]

Identified Management Opportunities and Goals:
Maintain late-summer streamflows above 13 cfs.

Annotated Bibliography

1) *Ayres Associates. 2011. Geomorphic Assessment of the Stability of the Roaring Fork River through the City of Aspen, Pitkin County, Colorado. Feb 11, 2011.*

   This report evaluated existing geomorphic conditions in the Roaring Fork River from the Salvation Ditch downstream to Castle Creek. The report contains maps of channel geomorphology and structure locations, identifies instream structures, and provides recommendations for geomorphic conditions. Recommendations from the report include modifying or removing man-made structures constructed in the channel. Several of these structures impede fish passage during low flows, decrease the channel gradient, induce localized aggradation, and increase channel width via bank erosion.

2) *Clarke, S., M. Fuller, and R.A. Sullivan. 2012. Roaring Fork Watershed Plan. Prepared for Reudi Water and Power Authority.*

   This plan is the result of findings from the *State of the Roaring Fork Watershed Report (2008)*, and collaborative discussion from subsequent public and technical meetings. The resulting goals, objectives and actions are organized under broad topics: Regional Water Management, Surface Water, Groundwater, Water Quality, and Riparian and Instream Habitat. No specific projects or flow-related recommendations for the upper Roaring Fork watershed were included in the report, but it did contain several recommendations for future efforts.

3) *Clarke, S. 2006a. Roaring Fork Watershed Streamflow Survey Report. Prepared for Roaring Fork Conservancy.*

   The project was designed to provide the technical foundation of the Roaring Fork Conservancy's broader goal of pursuing sustainable flows in the watershed, motivated by recognition that stream health is important both economically and environmentally to local communities. The investigation concluded that most cases of significant hydrologic alteration are seasonal and due to agricultural irrigation and snowmaking activities. It also found that transbasin diversions contribute to year-round alterations, particularly during peak flows, in the upper Roaring Fork and that CWCB instream rights are often not met as a result—particularly in Lincoln Creek and at Lost Man. No specific projects or flow-related recommendations for the upper Roaring Fork watershed were included in the report, but it did contain several recommendations for future efforts.

4) *Clarke, S. 2006b. State of the Roaring Fork Watershed. Prepared for Roaring Fork Conservancy.*

   Phase I of the Roaring Fork Watershed Plan effort characterized the condition of the Roaring Fork watershed's resources in terms of water quality, water quantity and overall ecosystem health.

5) *Colorado Department of Health and Environment. 2014. Integrated Water Quality Monitoring and Assessment Report.*

   The Roaring Fork River is provisionally listed on the 303(d) list for Aquatic Life use impairment between Hunter Creek and Brush Creek.

6) *Driscoll, M. 2011. Front Range Water Supply Planning Update: Increased Storage, Increased Demands, Increased Transmountain Diversions. Submitted to Roaring Fork Conservancy.*

7) *Espegren, G. 2011. Review of City of Aspen's Castle Creek Hydroelectric Project Aquatic Resource Documents. January 14, 2011.*

   This report reviewed the City of Aspen's Castle Creek Hydroelectric Project documents pertaining to the stream health and aquatic resources of Maroon and Castle Creeks. The objective was to determine whether Aspen had adequately addressed potential biologic impacts that could occur on these creeks as a result of proposed hydroelectric operations. Findings indicated that while Aspen was willing to ensure that the Colorado Water Conservation Board's (CWCB) decreed instream flow (ISF) rights on both Castle and Maroon Creeks were maintained, the use of R2Cross to evaluate environmental impacts to these creeks had significant limitations. Aspen's diversions during peak flow seasons would not likely have significant impacts on peak flows, however, hydropower diversion impacts on the ascending and descending limbs of the hydrograph, as well as during late summer and winter baseflows, could potentially impact riparian and aquatic health. Several recommendations were made for improving Aspen's environmental impact analysis and its proposed monitoring and adaptive management plan.

8) *Espegren, G. and L. Rozaklis. 2012. A Scientific/Social Framework for Managing Impacts of Water Diversions to Protect Stream Health in Pitkin County, Colorado. Prepared for Pitkin County Healthy Rivers and Streams. May, 2012.*

   Prepared in response to Pitkin County Healthy Rivers and Streams interest in developing a framework to analyze, evaluate and manage potential impacts of water diversions to protect aquatic health in Pitkin County streams. This report outlines a scientific/social decision-making framework utilizing the "Ecologically Sustainable Water Management (ESWM)" principles outlined by Richter (2005) and the "Ecological Limits of Hydrologic Alteration (ELOHA)" by Poff et al (2010). The report illustrates how this decision-making process might be applied to the City of Aspen's Castle Creek Hydropower Plant project. Conclusions indicate that the "iterative process of monitoring and adaptively managing stream diversions provides an opportunity to maximize the benefits to human uses while ensuring that aquatic health is maintained at a level that is acceptable to the local community."

9) *Goulder Associates. 2014. Geomorphic Assessment, North Star Nature Preserve. Prepared for Pitkin County Open Space and Trails.*

   Provided and evaluation of channel form and channel dynamics in the North Star Nature Preserve. Indicated man-made activities that may be affect stream function and channel evolution, including hydrological modification of the upper Roaring Fork River, and historical agricultural practices at the site.

10) *Hickey, A., J.C. Emerick, and K.E. Kolm. 2000. Preliminary Hydrologic and Biological Characterization of the North Star Nature Preserve, Pitkin County, Colorado. Division of Environmental Science and Engineering, Colorado School of Mines, Golden, CO.*

    This report details the hydrologic and biological characteristics of the North Star Nature Preserve, and makes recommendations for restoring the enclosed wetlands. The document includes groundwater data, vegetation identification, and information pertaining to small

mammals and birds in the Preserve. In-channel aquatic data were neither collected nor presented. Project recommendations for the North Star Nature Preserve include the following:

11) *Mason, S.K. 2012. Snapshot Assessment of the Roaring Fork Watershed. Prepared for Roaring Fork Conservancy. November 9, 2012.*

The assessment characterized low flow conditions on the Crystal and Roaring Fork Rivers in the autumn of 2012. The study employed a "synoptic sampling approach" to characterize upstream-downstream variability in streamflow as affected by tributary inputs and diversion outflows on the Roaring Fork River through the City of Aspen and along the Crystal River from Avalanche Creek to the confluence with the Roaring Fork River. Conclusions indicate that the upper Roaring Fork River was most vulnerable to low flows between the Aspen Club and the confluence with Castle Creek. Within this segment, diversions were found to deplete incoming streamflow by as much as 80% during the month of July. The study also concluded that extreme low-flow conditions on the Roaring Fork might produce water temperatures known to be detrimental to high quality trout populations.

12) *Mason, S.K. 2013. 2012 Upper Roaring Fork River Aquatic Life Use Assessment. Prepared for Roaring Fork Conservancy. December 12, 2013.*

The assessment increased existing macroinvertebrate sampling datasets at several long-term data collection sites and provided baseline conditions for additional locations. The analysis utilized Colorado's Multi-Metric Index (MMI), along with other statistical indices, to support a water quality assessment on the Roaring Fork River. Results indicated that five of the seven study sites attained Colorado Water Quality Control Division standards for aquatic life. Two sites near the City of Aspen were rated as "impaired." These results were consistent with sampling conducted in 2011 and continued to support the State's 2012 Provisional 303(d) listing of the Roaring Fork River below Hunter Creek. While the MMI assessment does not identify specific causes of impairment, it does indicate a general stress to macroinvertebrate communities from one or more sources. Potential sources of impairment were noted as (1) regularly occurring summer low flows attributable to transbasin and local diversions; (2) impacts from urbanization, such as alteration or destruction of riparian habitat, physical channel alteration and stormwater runoff; and/or (3) legacy effects of past land use practices or pollution.

13) *Miller, W.J. 2011. Final Report Evaluation of River Health: Roaring Fork River near Aspen, Colorado. Submitted to Pitkin County Attorney. Miller Ecological Consultants, Inc, Fort Collins, CO. December 21, 2011.*

The objective of this study was to determine current baseline river health conditions in the Roaring Fork River from the Salvation Ditch diversion downstream to the confluence with Castle Creek, a distance of approximately 3.2 miles. Within this reach, the city of Aspen's urban environment surrounds the majority of the river. This study included both physical and biological evaluations. The physical components included year-round hydrology, stream channel characteristics (including the near stream riparian zone), stream stability and instream habitat. The biological components included an assessment of benthic macroinvertebrates and fish populations. The study approach was a multi-phased analysis that included the following: 1) hydrologic analysis of existing and natural stream flows; 2) stream channel characteristics, including cross-sectional and longitudinal profiles; 3) geomorphic assessment of stream stability; 4) instream habitat evaluation using two-dimensional modeling methods; 5) benthic macroinvertebrate sampling; and 6) fish population sampling. The report noted several

recommendations and conclusions for habitat improvement and made recommendations for flushing flows.

14) *Miller Ecological Consultants, Inc. and Ayres Associates. 2011. Final Letter Report-Geomorphic Assessment of the Roaring Fork River and Impacts of Groundwater Changes on Wetlands, North Star Nature Preserve, Pitkin County, Colorado. Prepared for Pitkin County, Colorado. Miller Ecological Consultants, Inc., December 14, 2011.*

The objective of this report was to conduct a geomorphic assessment of the impacts of groundwater changes on the wetlands and grasslands along the valley floor and evaluate the current characteristics of the Roaring Fork River within the North Star Nature Preserve upstream of the City of Aspen. The assessment used existing literature, aerial photographs, topographic mapping and a field evaluation to complete the analysis. The study area on the North Star Nature Preserve extended from the Smith Open Space downstream to near Highway 82 and Stillwater Road. The report summarized existing reports and reviews historical USGS mapping. The report's recommendations for improving geomorphic conditions and potential actions in the study area included the following:

15) *Miller, W.J. and K.M Swaim. 2010. Castle Creek Hydroelectric Plant Environmental Report. Prepared for the City of Aspen, Water Utilities, Aspen, Colorado. Miller Ecological Consultants, Inc., Fort Collins, CO. October 8, 2010.*

This report provided a general description of existing conditions in the Castle and Maroon Creek's watersheds as well as specific descriptions of areas potentially affected by the proposed Castle Creek hydroelectric plant. This report summarized the "State of the Roaring Fork Watershed Report" (Clarke et al. 2008). Site-specific information on instream flows, fish populations, winter fish habitat, riparian and wetlands was collected by Miller Ecological Consultants, Inc. The new studies included R2Cross analysis in Castle Creek, fish population data on Castle and Maroon Creeks, winter habitat data for Castle Creek and boreal toad surveys.

16) *Miller, W.J. and K.M. Swaim. 2011. Castle and Maroon Creeks 2010 Aquatic Monitoring Report. Prepared for the City of Aspen, Water Utilities. Aspen, Colorado. Miller Ecological Consultants, Inc., Fort Collins, CO. June 6, 2011.*

17) *Miller, W.J. and K.M. Swaim. 2012. Castle and Maroon Creeks 2011 Aquatic Monitoring Report. Prepared for the City of Aspen, Water Utilities. Aspen, Colorado. Miller Ecological Consultants, Inc., Fort Collins, CO. May 21, 2012.*

18) *Miller, W.J. and K.M. Swaim. 2013. Castle and Maroon Creeks 2012 Aquatic Monitoring Report. Prepared for the City of Aspen, Water Utilities. Aspen, Colorado. Miller Ecological Consultants, Inc., Fort Collins, CO. September 11, 2013.*

This series of reports presented the results of the 2010-2012 monitoring in Castle Creek and Maroon Creek. The monitoring was conducted as part of the monitoring plan developed by Colorado Division of Wildlife to address possible impacts to fisheries and stream habitat related to the proposed increased water diversions associated with the City of Aspen's Castle Creek Hydroelectric Plant. Data were collected in fall 2010 at three sites on Castle Creek and three sites on Maroon Creek. Quantitative data were collected for fish populations, benthic macroinvertebrates, and aquatic habitat at each site. The 2012 report included combined results from all three years of monitoring.

19) *Roaring Fork Conservancy. 2006. Roaring Fork Watershed Water Quality Report.*

Discusses water quality conditions in streams and rivers around the Roaring Fork Watershed and identifies reaches of concern based on exceedances of State of Colorado water quality standards.

20) *Sanderson, J., B. Bledsoe, N.L. Poff, T. Wilding, W. Miller, and N. Fey. 2012. Colorado Basin Roundtable Watershed Flow Evaluation Tool Study. Prepared for Northwest Colorado Council of Governments. March, 2012.*

The Watershed Flow Evaluation Tool (WFET) is an approach for assessing nonconsumptive water use needs status at a coarse resolution across a large watershed. WFET assumes that the flow regime is the primary driver of aquatic and riparian structure and function. The approach entails developing relationships between streamflow and ecological characteristics in order to map ecological risks throughout a watershed related to changes in streamflow. Flow-ecology relationships were developed for trout, warm-water fish, macroinvertebrates, and riparian vegetation. The report recommended the following to reduce risks to cottonwood communities: