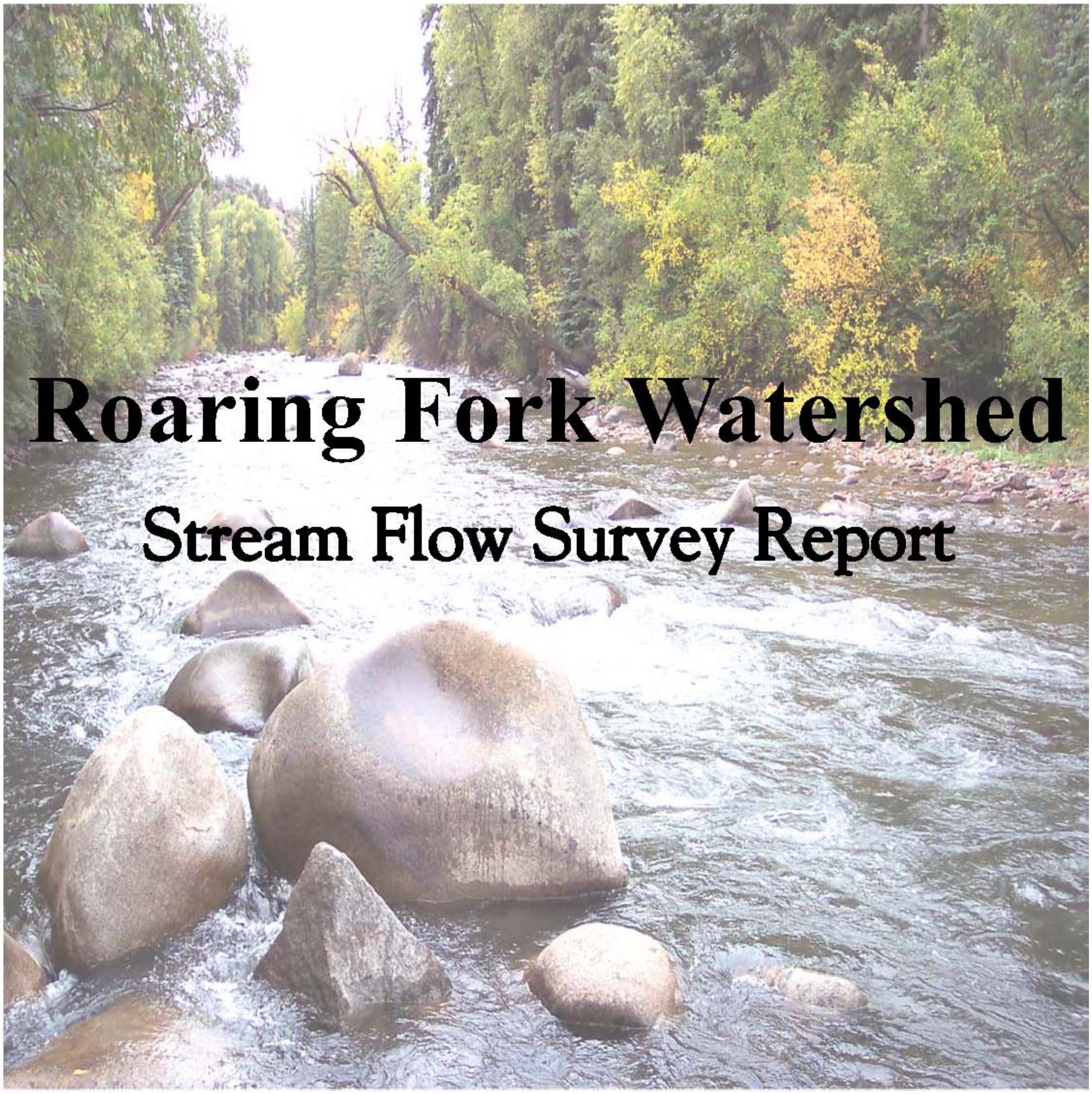
Roaring Fork Watershed

Stream Flow Survey Report



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Executive Summary

Similar to most western watersheds, the Roaring Fork Watershed's flows have been, and continue to be, altered to meet agricultural, municipal, and industrial demands within and beyond the watershed boundaries. Aspects of the flow regime, including flow magnitude, timing and duration of high and low flows, and rate of change, are related to important biological and geomorphological processes that influence overall stream health. With the recent recognition of the importance of stream health to the economic and environmental sustainability of the watershed, government officials and stakeholders are more willing to identify and pursue flow regimes that meet biological needs while still providing beneficial consumptive uses. This dialog brings forth some important questions such as "how much water is needed, at what times, and for what duration?".

These questions frame the Roaring Fork Watershed Stream Flow Survey Project (the Project). This report covers the project data collection and analyses preformed to date. Optimum conditions for one species or process may not be optimum for another; therefore, identifying desired flows should not focus on the needs of a single aspect. Stream ecosystems have evolved to adapt to a range of conditions, known as the range of natural variability. The range of natural variability for each flow parameter can be determined using daily mean stream flow data, where a sufficient period of unaltered flow data is available. The Project has involved gathering and synthesizing relevant data and assessing the applicability of appropriate tools to identify broad ecologically sustainable flow thresholds and critical areas to protect or restore. Hydrologic alteration was assessed for the Roaring Fork Watershed using daily mean stream flow gage data from three sources, as well as modeled stream flow data and several analytical methods. The modeled data representing pre-developed and developed monthly flows for the period of record (1908-1996) for 33 locations throughout the watershed provided better temporal and spatial representation of flows than the available gage data. A third assessment was made using real time daily mean stream flow data to determine how often and when Colorado Water Conservation Board instream flows were met.

The results of these analyses are discussed for the nine sub-watersheds in the Roaring Fork Watershed. We found that much of the significant hydrologic alteration is seasonal, contributed by activities such as irrigated agriculture or snowmaking. Although, the alterations can be severe (occur over all months in a season), there is a significant return flow from these activities. Other water uses cause hydrologic alteration throughout the year including trans-mountain diversions, Ruedi Reservoir management, and diversion for domestic water supplies. For example, Nettle Creek, a small tributary of the Crystal River that supplies water to Carbondale, experiences year-round hydrologic alteration. The trans-mountain diversions are one hundred percent consumptive. In the case of the Upper Roaring Fork River Sub-Watershed the effects occur in all seasons and result in unfulfilled CWCB instream flow rights. Although the Boustead Tunnel in the Fryingpan River Sub-Watershed diverts more water than the Twin Lakes Tunnel, severe effects in this sub-watershed are not seen year-round. Overall hydrologic alteration below Ruedi Reservoir is rated as severe. However, unlike many other alterations that result in lower, developed flows are significantly higher than pre-developed flows in all seasons for at least a period of one month.

These results, along with conservation targets identified by The Nature Conservancy's Conservation Action Planning Process, will be used to prioritize areas for more in-depth hydrologic analyses. Additionally, these results will be instrumental in identifying water quantity issues for the newly initiated watershed planning process. Integration with the design of the watershed plan enhances our ability to reach the overall Project goal, which is **to respond to instream flow issues and pursue approaches for achieving sustainable stream flows.** Plans to improve flows in two highly altered areas, and an overview of several potential flow protection or restoration options to achieve sustainable stream flows, are presented as they relate to the overall project goal.

Acknowledgements
We extend our gratitude to all of this study's financial supporters and partners. This is a unique, exciting, and ambitious effort and we couldn't have made the progress we have, or be able to continue with the project's vision, without the support of and belief in its goals and overall significance for maintaining healthy stream systems within the Roaring Fork Watershed.
The Roaring Fork Watershed Collaborative Water Group perceived the need for the Stream Flow Survey Project. Two individuals, Randy Russell, Garfield County and Cindy Houben, Pitkin County, were instrumental in getting the project started. Kristine Crandall spearheaded the project's initial phases, provided background information throughout the project and invaluable comments on a draft report. This project would not have been possible without the initiative and support of the past Roaring Fork Conservancy Executive Director, Jeanne Beaudry, the ongoing support of the current Executive Director, Rick Lofaro and the support of the Board of Directors. The Conservancy's Education Director Tim O'Keefe continues to incorporate information from the Project into outreach presentations and reviewed this study report. Eliza Hothckiss, Office Manager, provided help and good cheer in abundance.

Key to the project success was funding provided by: the National Fish and Wildlife Foundation, Colorado Conservation Trust, Colorado Watershed Protection Fund, Garfield County, Eagle County, Pitkin County, ESRI Conservation Program and the Environment Foundation.
We gratefully acknowledge the support of project partners and look forward to continuing relationships. Specifically, The Nature Conservancy who participated in project planning, provided technical guidance, reviewed grants and report drafts, and helped with education/outreach. Their Conservation Action Planning Process in the Roaring Fork Watershed is closely linked to the Stream Flow Survey Project. Specific thanks to Tom Iseman, Terri Schulz, Albert Slap, Robert Wigington, Chris Pague, and Mike Tetrault. Don Meyer, Dave Kanzer, Jim Pearce, and Dave Merritt from The Colorado River Water Conservation District were extremely helpful in overall project planning as well as providing technical GIS assistance and help in understanding CDSS StateMod data and other technical water issues. John Carney and Peter Nichols with the Colorado Water Trust support the goal of the project and are working with us to pursue options for achieving sustainable flows.

Several people that provided ideas, technical assistance and data were important to the study. Sheree Lynne, a graduate student from University of Colorado-Colorado Springs, provided invaluable ideas for data analyses and helped with data analyses. Colorado Water Conservation Board's Michelle Garrison promptly and graciously answered numerous questions regarding CDSS StateMod data. Two past Conservancy employees helped with the project. Jacob Bornstein provided statistical guidance and Chrissy Sloan, a legal fellow, provided policy guidance. Mark Lacy and Andrea Holland Sears, U.S. Forest Service, provided ideas and insight into this study. George Wear from the Colorado Division of Water Resources and Mark Henneberg from the Bureau of Reclamation provided help accessing stream gage data and background information about stream gage operations. Dean Wieser, Snowmass Water and Sanitation District provided stream gage data for Snowmass Creek.

Background

Purpose of the Project

The Roaring Fork Watershed Collaborative (The Collaborative) identified the need for the Stream Flow Survey Project. The Collaborative was formed in 2002 by representatives from three counties, one city, U.S. Forest Service (USFS), and two local non-profits. The effort has since grown to include 11 businesses; 24 government agencies (nine local, four county, two regional, four state, five federal); and 10 non-profits. The Collaborative is an important vehicle for: (1) information exchange, (2) identification of threats to water quality, (3) coordination of river protection activities, and (4) cooperation among disparate groups. The Roaring Fork Conservancy (The Conservancy) plays a pivotal role in the Collaborative as a founding and ongoing steering committee member.

The Roaring Fork Watershed Stream Flow Survey Project (the Project) was initiated in 2003 and over time has expanded in scope, level of funding, and number of cooperators. The Project's watershed-wide stream flow quantification effort provides a foundation for the broader goal **of responding to instream flow issues and pursuing approaches for achieving sustainable stream flows.**

The Project has involved gathering and synthesizing relevant data and assessing the applicability of appropriate tools to identify broad ecologically sustainable flow thresholds and critical areas to protect or restore. It will utilize and translate the results to educate and inform community interests about current and foreseeable stream flow challenges (an important target audience is the Collaborative) as well as developing plans to protect and restore flow altered reaches. Additional phases of the project (not included in this present scope or budget) will include in-depth stream flow analysis in targeted areas and prioritization of reaches for protection or restoration; implementation of plans; monitoring of results/adaptation of management; and assessing the potential impact of future land use changes in relation to water quality and quantity. The Conservancy anticipates carrying the Project forward to this next level.

The Project greatly improves the ability of the Conservancy, in collaboration with local and regional interests and governmental agencies, to respond to instream flow issues, to proactively specify and pursue legal and physical approaches for achieving sustainable stream flows, and to protect and enhance riparian and aquatic habitat. Questions that we will be able to answer once the Project has been completed include:

- What stream flows are necessary to sustain ecological function?
- What are the ecologically critical stream reaches in the watershed?
- Do these reaches have enough water?
- What are the key "threats" to these reaches?
- How can we restore flows to impacted reaches?
- How may changes in water demand and availability influence stream flows in the future?
- How does the Roaring Fork Watershed influence the broader Upper Colorado Watershed and how does the Upper Colorado Watershed influence the Roaring Fork Watershed?

The specific tasks associated with this study are:
Task 1: Data gathering, evaluation, and organization,

Task 2: Stream flow survey (includes developing strategies for protection/restoration),
Task 3: Synthesis of data into spreadsheets and GIS database,
Task 4: Distribution of database: report/map production, development of website interface, presentation to the Collaborative and specific interests throughout the watershed.
This report primarily addresses the progress of Tasks 1-3. Future project steps include: 1) a more in-depth flow alteration analysis of areas targeted by this study or lacking in flow data, 2) continued work on the Upper Roaring Fork and Lower Crystal river watersheds to improve flows, 4) identification and pursuit of opportunities in other flow altered areas to restore and protect flows, 5) integration of project results into a watershed plan, 6) development and implementation of a monitoring study, and 6) using results of monitoring study to adapt approaches to improve flows.
Project accomplishments to-date:

- Completed data gathering, evaluation and organization. (It should be noted that the Colorado Decision Support System Stream Simulation Model, a significant data source, is being updated and improved. The Project will take a more in-depth look at hydrologic alteration in targeted areas when these data become available. In addition, tools for editing the National Hydrography Data Set (NHD) became available in November 2005. We anticipate linking these future studies to this NHD stream layer.)
- Performed broad analysis of watershed-wide hydrologic alteration using existing data sources.
- Assessed where, when, and how often Colorado Water Conservation Board (CWCB) Instream Flow Program (ISF) appropriations are met using stream gage records.
- Identified options for flow protection and restoration (See Appendix B: Options for Flow Protection and Restoration).
- Began collaborative efforts to address flow alteration for two known flow altered areas: the Upper Roaring Fork River and the Lower Crystal River sub-watersheds.
- Expanded the Project's cooperating partners and the types of technical support that these partners are providing (See Partners Section).
- Provided three presentations to the Collaborative and 24 adult programs, reaching almost 1,000 people. Presentations outlined Project goals and presented project results to date.

Additional near-term tasks include:

- Adding this study report to the Conservancy website (www.roaringfork.org).
- Synthesizing and integrating the study's information with other data such as water quality, inchannel and riparian habitat condition, and biodiversity to develop overall aquatic condition assessments.
- Incorporating the results of this study into a Roaring Fork Watershed Plan.

Partners

Roaring Fork Conservancy

The Conservancy is coordinating the Project, a role that includes facilitation of contractors, partners, funding, and data providers; and distribution of the resulting information at the local level (e.g. through the Conservancy's website and the Collaborative). The Conservancy has written several grant applications to help fund the Project, and is taking the lead on its technical work. The Conservancy is working with The Nature Conservancy (TNC) to identify conservation targets in the Roaring Fork Watershed, and with TNC and the Colorado Water Trust (CWT) to prioritize opportunities for stream restoration and flow protection. We encourage collaboration to meet the Project's Goal.

The Nature Conservancy (TNC)

TNC is responsible for compiling information on key aquatic and riparian species and communities to identify conservation targets, developing a common understanding of the relationship between these targets and local stream flow patterns, and assisting partners to identify and execute protections for stream reaches that are negatively affected by altered flows as part of their Conservation Action Planning (CAP) Process. TNC has worked on the mainstem Colorado River for over a decade, through the Colorado River Endangered Fish Recovery Program, and launched its Colorado River Project in 2003 to identify and protect critical water-dependent plants and animals in the headwaters of the Colorado River system, including the Roaring Fork River and its tributaries. TNC's Index of Hydrologic Alteration (IHA) is a valuable tool for this Project because it assesses all flow parameters that influence ecological function such as riparian recruitment, channel forming processes, groundwater recharge, and aquatic organisms' life cycles. TNC has also put forth an approach called Ecologically Sustainable Water Management (ESWM) that provides ideas for developing sustainable water management solutions.

Colorado Water Trust (CWT)

CWT is helping develop approaches/strategies for flow protection and restoration. CWT is actively involved in providing legal expertise and transactional strategies for addressing specific low flow issues on the lower Crystal River.

Stream Health Initiative (SHI)

This initiative is a companion study assessing stream and riparian physical habitat on the Roaring Fork River and its major tributaries. It provides information critical to the identification of TNC CAP systems, stresses, and sources. The SHI study objective outlined in a report entitled **Stream Health Initiative: Stream and Riparian Physical Habitat Assessment for the Roaring Fork Watershed** (Malone and Emerick, Oct. 2004) is to document habitat conditions and create a comprehensive baseline inventory of the Roaring Fork River and its tributaries at the reach scale to identify areas for potential restoration and protection opportunities. The SHI's stream survey data will also be linked to the NHD stream layer allowing simultaneous analysis and display with data resulting from the Project.

Colorado River Water Conservation District (River District)

The River District is assisting with compilation of water quantity data and coordination of web hosting of the GIS database. The River District is a liaison with the USGS and their NHD project and will most likely be the local data steward for this integral data layer and supporting tools. The River District is supporting interpretation and adaptation of Colorado Decision Support System's (CDSS) stream simulation model (StateMod), and coordinates with Colorado Division of Water Resources (CDWR) and CWCB in adapting CDSS for the Project's use. The River District is interested in using this project as a prototype for multi-purpose planning objectives across its broader geographic area.

Roaring Fork Watershed Collaborative Water Group (The Collaborative)

The Collaborative is an ad-hoc group of local and regional government representatives, various government agency staff, and other community interests who are focused on and concerned about water issues in the Roaring Fork Watershed. The Conservancy continues to update the

Collaborative of the Project's progression, with a major goal of creating analyses and products that answer the questions important to this diverse group and as input into current efforts to develop a watershed plan.

Other

In addition, the USFS-White River National Forest and USGS have interests in and are providing technical support to the Project. ESRI's Conservation Program provided ArcGIS software and software maintenance costs for the Project. The CDWR, CWCB, U.S. Bureau of Reclamation (BOR), and USGS are key repositories of stream flow data and expertise upon which we draw. The U. S. Environmental Protection Agency is interested in utilizing and building upon the Project for the purposes of sustainable watershed management.

Study Area and Hydrologic Issues

The Roaring Fork Watershed (Figure 1) is located in Pitkin, Eagle, Garfield, and a small portion of Gunnison counties, in west-central Colorado. It has an area of 1451 square miles comprised of high mountainous terrain and deep intervening valleys, with altitudes ranging from 14,265 feet to 5,916 feet. The Roaring Fork River is the second largest tributary to the Colorado River in the state, yielding an average of almost 1,000,000 acre-feet per year. Stream and riparian biological resources are typical of mid- to high-elevation watersheds in the Southern Rocky Mountains. Headwater areas consist of cold, steep gradient streams that decrease with elevation. The watershed supports healthy non-native trout populations of brook, rainbow, and brown trout. The only native trout species, the Colorado River cutthroat trout (CRCT), is generally restricted to isolated stream reaches in the upper part of the watershed above barriers. The Colorado Division of Wildlife has classified two river reaches (42 miles) within the Watershed as Gold Medal waters, which are streams in Colorado offering the greatest potential for trophy trout fishing.

The Roaring Fork is a watershed at risk. While the water quality of the system has generally been characterized as excellent, urbanization is rapidly occurring (the valley's population is expected to increase by 24 percent between 2000 and 2010). Also, impacts from additional trans-mountain diversions are expected to increase. The Roaring Fork Watershed serves as a Mecca for in- and out-of-state visitors. The local and state economies depend on the continued attraction of tourists to the area for recreational activities such as skiing, hiking, angling and boating. On-going water quality, flow, and habitat assessment studies indicate that stream health in portions of the watershed is declining. There are occurrences of water quality not meeting state standards. Trans-mountain and in-basin diversions, and downstream water calls under the Colorado Water Priority System result in dewatering of certain stream reaches and the virtual elimination of some important peak flows. The operation of Ruedi Reservoir has altered the timing and magnitude of flows. The Colorado Statewide Water Supply Initiative (SWSI) Report (CWCB, 2004, http://cwcb.state.co.us/swsi/index.htm) recognizes the issues of rapid growth and lack of available water supplies in headwaters areas (i.e., Roaring Fork Watershed) and states that "recreation and the environment are key drivers for industries and economic health as well as important components to quality of life" in Colorado.

Hydrologic alteration impacts inchannel and riparian biological and geomorphological processes. Several groups have documented the potential consequences of altered flows. In 2005, the

American Fisheries Society issued a policy statement entitled: "Effects of Altered Stream Flows on Fishery Resources" (http://www.fisheries.org/html/Public_Affairs/Policy_Statements/ps_9.shtml). It says that unless stream flows are established, implemented, and protected, the following impacts can be expected to accelerate:

1. Replacement of unique regional fauna by fishes adapted to the more regulated stream environment.
2. Reductions in localized stream flooding will continue to degrade bottomlands and reduce stream productivity, adversely affecting stream fishes.
3. Riparian habitat will continue to be degraded, and degradation will adversely affect stream quality.
4. Reductions of stream flows will reduce and degrade stream habitat, increase summer water temperatures, reduce oxygen, and concentrate pollutants.
5. Fluctuating flows associated with power generation will reduce stream resources by promoting unstable channels. Such flows will alternately scour, and then promote downstream siltation of stream habitats.
6. Loss of spring peak flows below dams will result in perennial armoring of stream bottoms, with downstream effects of wider, shallower channels due to loss of stream power to move sediments. Alteration of natural hydrographs will result in changed species composition.

The Nature Conservancy identified almost 70 hydrologic parameters and their ecosystem influences. See Appendix C. Summary of IHA and Environmental Flow Component (EFC) parameters and their ecosystem influences.

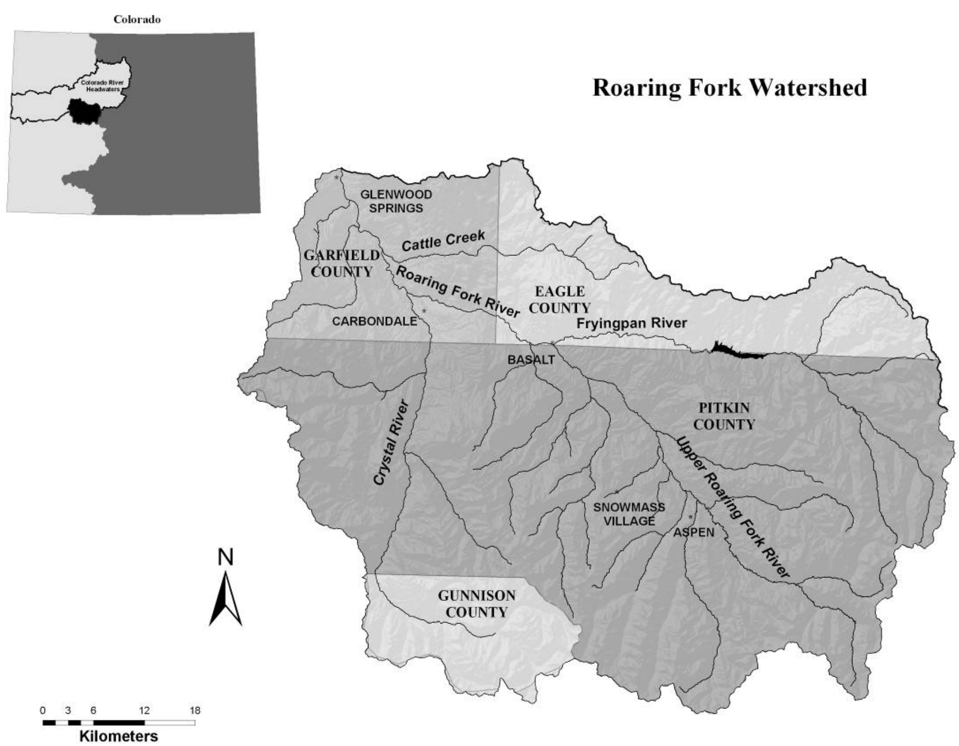


Figure 1. Overview Map of the Roaring Fork Watershed

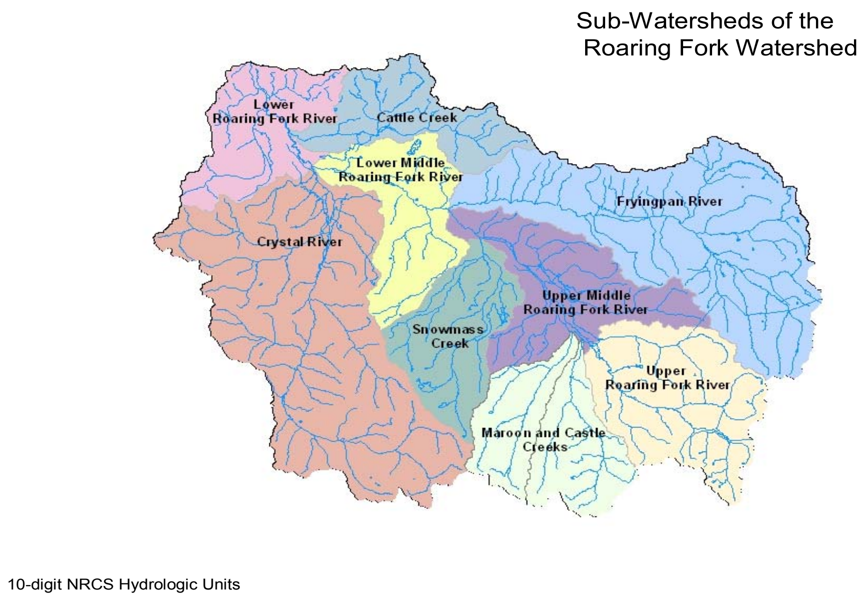


Figure 2. Sub-Watersheds of the Roaring Fork Watershed

The Roaring Fork Watershed is comprised of nine sub-watersheds derived from National Resource Conservation Service (NRCS) 10-digit Hydrologic Units (Figure 2). The landscapes of these sub-watersheds differ in both their inherent (e.g. geology, climate, vegetation, and topography) and human (land use and ownership) characteristics. These landscape characteristics influence both the type and magnitude of flow alteration. Figure 3 shows incorporated cities, ski areas, irrigated agriculture, and trans-mountain diversions within the Watershed. Table 1 provides a coarse overview of streams in the sub-watersheds.

Table 1: TNC's Aquatic System Classification by Sub-Watershed

SUB-WATERSHED	ELEVATION RANGE	DOMINANT GEOLOGY	DOMINANT GRADIENT	DOMINANT STREAM TYPE*
Fryingpan River	Alpine/ montane >6000'	granite/volcanic	moderate and low	headwater
Upper Roaring Fork River	alpine/montane	granite/volcanic	moderate and low	headwater
Maroon/Castle Creeks	alpine/montane	shale/sandstone/limestone	steep and very steep gradient	headwater
Upper Middle Roaring Fork River	alpine/montane	granite/volcanic	moderate and low	headwater
Snowmass Creek	montane	shale/sandstone/limestone	steep and very steep	creeks
Lower Middle Roaring Fork River	montane/foothill (<6000-9000')	shale/sandstone/limestone	moderate and low	large river
Crystal River	montane (6000-9000')	shale, sandstone and limestone	moderate and low	creeks
Cattle Creek	montane/foothill	shale/sandstone/limestone	moderate and low gradient (Upper Cattle Creek-steeper gradients	creeks/ large river
Lower Roaring Fork River	montane/foothill	shale/sandstone/limestone	moderate and low gradient	large river

*** based on number of first order streams above that point**

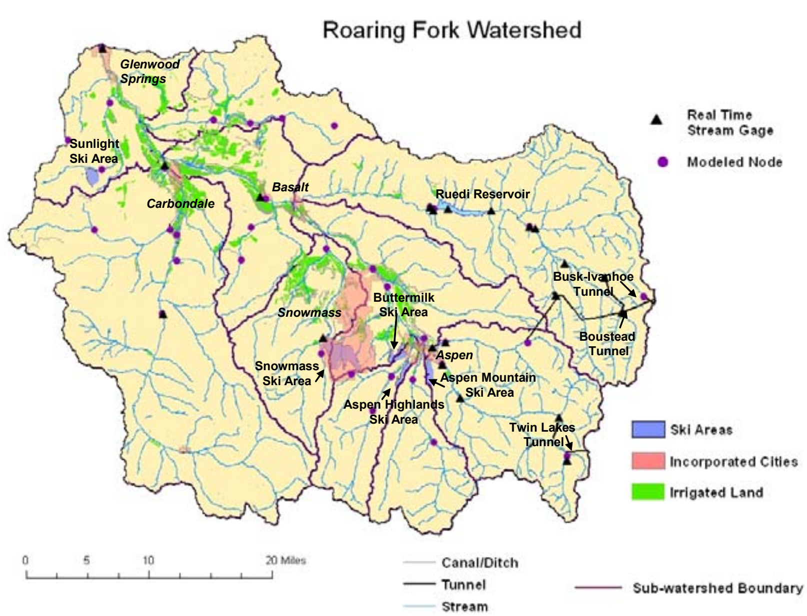


Figure 3. Locational map

The Fryingpan River and Upper Roaring Fork River sub-watersheds are both heavily influenced by trans-mountain diversions (Table 2). These trans-mountain diversions are decreed water rights that divert water from the Roaring Fork River Watershed for use in the Arkansas River Watershed. Unlike in-basin diversions, which return some water back to the stream system after use (i.e. runoff from irrigated fields, treated wastewater), trans-mountain diversions deplete 100 percent of the diverted water. The three major trans-mountain diversions in the watershed are:

Table 2. Trans-Mountain Diversions

TRANS-MOUNTAIN DIVERSION	APPROXIMATE CAPACITY 2004 Diversions (Acre-feet)	DATE OPERATION BEGAN	SOURCE
Twin Lakes	38,000	1935	Upper Roaring Fork River Sub-Watershed
Busk-Ivanhoe	4,123	1948	Fryingpan River Sub-Watershed
Boustead	53,971	1972	Fryingpan River and Upper Roaring Fork River Sub-Watersheds

Appendix D contains seasonal histograms of diversions through the Twin Lakes and Boustead Tunnels from 1973-1998 and for Twin Lakes Tunnel from 1935-2004.

Ruedi Reservoir in the Fryingpan River Sub-Watershed began operation in May 1968. The Reservoir has a total capacity of 102,373 acre-feet and provides replacement water for out-of priority depletions to the Colorado River by the Fryingpan-Arkansas Project, as well as water for Western Slope agricultural, municipal, and industrial uses. It was built and is managed primarily for water supply purposes, with secondary purposes including recreation, wildlife habitat enhancement, and flood control.

Aspen Mountain and most of Buttermilk and Snowmass ski areas are located in the Upper and Upper Middle Roaring Fork River sub-watersheds. Some of Buttermilk and Aspen Highlands ski areas are located in the Maroon/Castle Creek Sub-Watershed. Part of the Snowmass Ski Area is in the Snowmass Creek Sub-Watershed. Water from streams in these sub-watersheds is used for snowmaking.

Most of the City of Aspen and Snowmass Village are located in the Upper and Upper Middle Roaring Fork River sub-watersheds. A portion of the City of Aspen is located in the Maroon/Castle Creek Sub-Watershed. The town of Basalt which is located at the confluence of the Fryingpan and Roaring Fork Rivers straddles three sub-watersheds (Fryingpan, Upper Middle and Lower Middle Roaring Fork). El Jebel and parts of the towns of Basalt and Carbondale are located in the Lower Middle Roaring Fork River Sub-Watershed. The small towns of Redstone and Marble are located in the Crystal River Sub-Watershed, as is a portion of the town of Carbondale. The City of Glenwood Springs is located in the Lower-Roaring Fork River Sub-Watershed. The following list identifies the major municipal water supply sources:

City of Aspen:
Maroon Creek
Castle Creek

Town of Basalt:
Basalt Springs on Basalt Mountain
Well by the Public Works Shop
Well by the Middle School

Town of Carbondale:
Nettle Creek drainage (on the North Face of Mt. Sopris, senior water rights)
Well at the Crystal Hatchery
Well east of town near the Roaring Fork River

City of Glenwood Springs:
No Name Creek
Grizzly Creek
Roaring Fork River (Emergency pump near the 7th St. Bridge)

Snowmass Village
East Snowmass Creek Spring
East Snowmass Creek
West Fork of Brush Creek
Snowmass Creek

While irrigated agriculture occupies a small percentage of the total watershed area, these areas occupy a significant portion of the floodplain (Figure 3). The characteristics that make them desirable for agriculture such as proximity to roads and streams, flatter topography, and lower elevations also make them desirable for housing developments and other municipal uses. Irrigated agriculture predominantly occurs along the Roaring Fork and some of the major tributaries such as Woody, Snowmass, Capitol, Sopris, Cattle, and Four Mile creeks and the Crystal River.

Methods

Hydrologic alteration was assessed for the Roaring Fork Watershed using daily mean stream flow gage data from three sources as well as modeled stream flow data and several analysis methods. Software used in this study included: ESRI ArcGIS 9.1 GIS software; StatGraphics Plus 5.1 and Minitab 13.1 statistical software, Microsoft Office 2003 Excel spreadsheet, and Access database. The working projection and datum for the Project is UTM Zone 13, meters, NAD83. This is consistent with the data standard set forth by Executive Order to the Geographic Information Coordinating Committee for the State of Colorado by then Governor Roy Romer.

Data Sources

USGS, CDWR, and BOR stream gages

We obtained stream flow data for the period of record for all currently operating gages in the Watershed, referred to as **real time gages**. This stream flow gage data was used to assess how often and when the CWCB's minimum instream flow appropriations were met. This data was also evaluated by TNC's Indicators of Hydrologic Alteration (IHA) analyses.

In the Roaring Fork Watershed, stream gages are operated by the U. S. Geological Survey (USGS), CDWR, and BOR (http://waterdata.usgs.gov/co/nwis/nwis; http://www.dwr.state.co.us/Hydrology/flow_search.asp, and http://www.usbr.gov/gp/hydromet/). Although there were 72 gages in the watershed, only 23 are real time gages. See Figure 4 for a map of all stream gages in the Watershed and Appendix E for a table of real time gages in the watershed. USGS and BOR real time, preliminary (past year), and historical gage data are available online and were used for analysis. Only CDWR real time data is available online. CDWR archived data stored in an access database (Hydrobase) was used for analysis. CDWR is still working on archiving all of its stream gage data; therefore, data for some recent years is not yet available. Because archived data were not available after1997, analysis was not done for three gages: Fryingpan River near Ivanhoe Lake, Ivanhoe Creek near Nast, and South Fork Fryingpan River at Upper Station near Norrie. The gage at Snowmass Creek (SNOCRECO) is only used for administration, so historical data is not maintained by the CDWR. In some cases, gages were operated historically by USGS and are now operated by CDWR. Data for these gages was combined for analysis. Many of the gages have gaps in the data record. For the Indicators of Hydrologic Alteration (IHA) analyses, data from the Roaring Fork River near Aspen (09073400) Gage that started operation in 1964 was combined with data from the Roaring Fork River at Aspen Gage (09073500) that has approximately 15 years of data prior to 1935 when the Twin Lakes Trans-Mountain Diversions began operation. Their watershed areas differ only by one square mile (106 and 107 sq. mi. respectively).

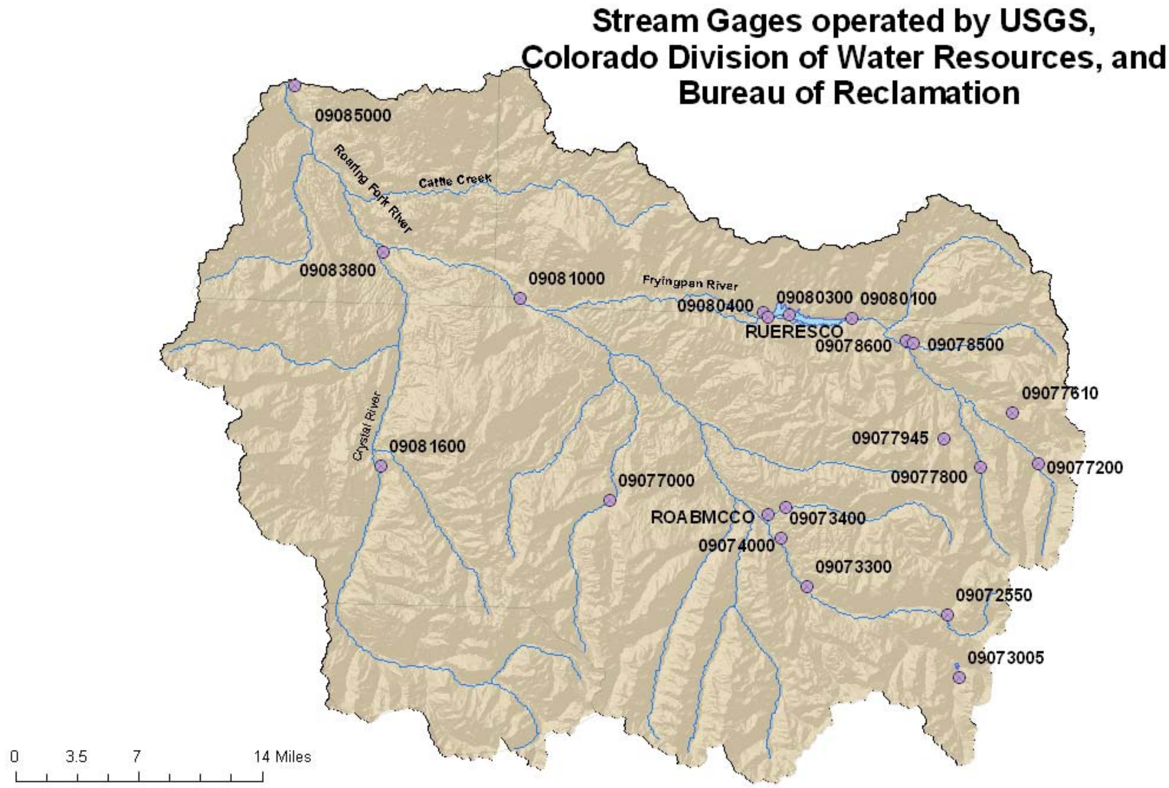


Figure 4. Location of real-time stream gages in the watershed.

Colorado Decision Support Systems Stream Simulation Model (CDSS StateMod)

The CDSS's StateMod hydrologic model was developed by the CWCB and the CDWR mainly for use in consumptive use modeling. The CDSS model is built with streams, gauging stations, diversions, water rights, and reservoir operation data. The advantage of using this system is that the relationships and model already have been built (a considerable investment). Stream gage and water diversion data are tied together. StateMod consists of four major components: the Base Flow Module, the Simulation Module, the Report Module, and the Data Check Module. The Base Flow Module produces a set of stream flows for water years October 1909 to September 1996, which would have occurred without human development such as diversions and dams. These stream flows are called **pre-developed stream flows**. The Simulation Module operates the river system and accounts for inflows, river gains, diversions, instream flows, well-pumping, and reservoir operations through time – referred to as **historical conditions**. Combining these two modules by taking the current depletions and applying them to the pre-developed flow record results in a third modeled output, known as **developed conditions**. This gives us an ability to estimate future streamflow conditions using current hydrologic alterations under varying climatic scenarios such as wet, dry, and average years.

Following is a general sequence for operating StateMod:

1. Develop a stream node network based on the location of key gages, river confluences, reservoirs, diversions, wells, and instream flows (see Appendix F for location of base flow and all nodes in Roaring Fork Watershed).
2. Construct the necessary monthly input files.
3. Check the input files by executing StateMod's Data Check Module.
4. Develop base stream flows by executing StateMod's Base Flow Module.
5. Simulate the stream system's operation by executing StateMod's Simulation Module.
6. Evaluate results and generate graphs and tables by executing StateMod's Report Module.
7. If desired, add daily simulation capability.

(http://cdss.state.co.us/ftp/StateMod.asp) StateMod Model - 9.96 (2001-08-31) documentation.

Current limitations for our use include: 1) Step 7 is in progress so the available output is on a monthly rather than daily basis, prohibiting calculation of some important hydrologic indices; 2) the output is dated- runs through 1996; and 3) there is limited spatial representation of flows throughout the watershed. These limitations will be overcome when the updated monthly and new daily data become available. Leonard Rice, a CWCB contractor, is performing this work. This updated model will use additional gage and diversion data and will be run through 2004. Appendix F shows the locations of the 33 pre-developed reporting nodes (base nodes) within the watershed and depicts the distribution of 132 direct storage and gage nodes (these report historical flows). In many cases the pre-developed nodes are not located at the mouth of the tributaries. We have requested that CWCB report pre-developed flows at more nodes (especially tributary junctions) in order to obtain the best representation of conditions throughout the watershed.

Water diversions and water rights

In the Colorado Decision Support System's (CDSS) Division Five Diversion Structures shapefile,(http://cdss.state.co.us/ftp/gis.asp downloaded 11/1/2004), there are 1785 stream structures in the Roaring Fork Watershed (District 38). CDSS also maintains a water rights data set (http://cdss.state.co.us/db/viewdata_rights.asp) that is linked via a Structure ID to diversion data. For this broad-scale analysis, the output from CDSS StateMod incorporates diversion data. In the future, we will be able to spatially reference the diversions in areas targeted for more in-depth analyses to the NHD.

Analyses

Figure 5 is a flow chart of how the three analyses described below, shown in pink, link to TNC's CAP process (purple) to identify high priority reaches and threats to aquatic and riparian biodiversity. This information feeds into the ongoing work (yellow) of identifying options for flow protection and restoration. It also informs the development of plans to improve flows in two areas, as well as future Project work (green) to meet the overall Project goal.

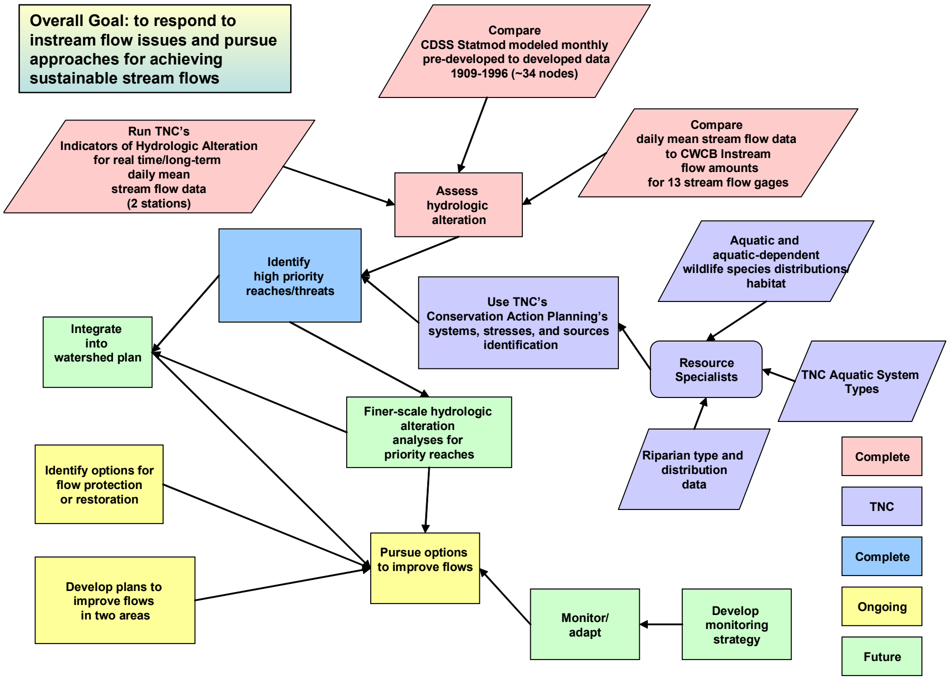


Figure 5. Flow chart of the project

Indicators of Hydrologic Alteration (IHA)

Long-term stream flow gages provide a window into past flow conditions. The longest continuous record for the watershed began in 1906 for the USGS Roaring Fork River at Glenwood Springs Gage. The data for this gage, located at the mouth of the Roaring Fork River, reflects the accumulation of hydrologic alterations throughout the watershed. Some alterations such as Ruedi Reservoir and the trans-mountain diversions can be tied to a specific time and place. IHA software developed by TNC allows us to analyze and summarize these discrete impacts (IHA v.7 http://www.freshwaters.org/tools//). IHA is a software package that hydrologists and ecologists can use to create a statistical description of a daily record of stream flow and to measure changes in this description over time. It is most commonly used with streamflow data. The IHA was developed by scientists at TNC's Sustainable Waters Program and by Smythe Scientific Software and Totten Software Design (TNC, 2005).

The IHA software calculates a suite of more than 60 ecologically-relevant statistics from a daily hydrologic data series. For example, IHA calculates the timing and maximum flow of each year's largest flood, then calculates the mean and variance of these values over some decades. If these statistics were changed significantly by an activity such as dam operation, one can then consider whether the change matters to the downstream ecosystem. This method is described in the paper "A Method for Assessing Hydrologic Alteration within Ecosystems," (Richter et al. 1996).

The IHA also includes the Range of Variability Approach (RVA) to support ecologically-based management of hydrological systems. This method, described in *How Much Water Does A River Need?* (Richter et al. 1997), helps with the design of adaptive management programs that use the quantified natural variation of a hydrological system as an interim management target. Using the

RVA, one can propose a range of variability for each IHA parameter as a management target and quickly calculate how frequently the system has met these goals during the data period.

The latest version contains a new suite of hydrologic flow parameters (Environmental Flow Components (EFCs)) which attempts to automatically identify and compute statistics on hydrologic events such as floods and droughts.

Lack of historical data and the prevalence of non-discrete impacts on flows are the main issues that hinder the utility of this method for the Roaring Fork Watershed. The real time stream gages in the watershed do not generally have the recommended 20 years of pre-impact record prior to the major flow impacts. Ruedi Reservoir and the Fryingpan-Arkansas Project, which impact the Fryingpan River and Lower Roaring Fork River watersheds, were operational around 1968, while trans-mountain diversions from the Upper Roaring Fork River Sub-Watershed through the Twin Lakes Tunnel began in 1935. Only the stream gage on the Roaring Fork River at Glenwood Springs has the suggested pre-impact record to support IHA analysis. However, water rights for in-basin diversions date back to the late 1800s and occur throughout the watershed. In-basin diversions and development that impact flows are not easily tied to one point in time or place, so parsing the gage data into pre- and post- impact periods for RVA analysis isn't appropriate for many areas within the watershed.

To identify the most appropriate indicators for each watershed, Olden and Poff (2003) recommend the following IHA parameters for snowmelt-dominated systems. They suggest using them in conjunction with more intuitive index selection criteria based on the particular ecological question of interest.

Table 3. Recommended IHA Parameters for Use in Snow-Melt Dominated Systems.

Hydrologic index	Definition
Variation in June flows	Coefficient of variation in June monthly flows
Mean January flows	
Mean February flows	
Mean March flows	
Mean December flows	
Annual minima of 90-day means of daily discharge	Magnitude of minimum annual flow of 90-day duration
Rise rate	Mean rate of + change in flow from one day to the next
Fall rate	Mean rate of - change in flow from one day to the next
Annual minima of 1-day mean of daily discharge	Magnitude of minimum annual flow of 1-day duration
Annual minima of 3-day means of daily discharge	Magnitude of minimum annual flow of 3-day duration
Annual maxima of 30 day means of daily discharge	Magnitude of maximum annual flow of 30-day duration
Annual maxima of 90 day means of daily discharge	Magnitude of maximum annual flow of 90-day duration
Low flow pulse duration	Mean duration of low flow pulse count
Low flow pulse count	Number of annual occurrences during which the magnitude of flow remains below a lower threshold.

Low flow pulses are defined as those periods within a year in which the flow drops below the 25th percentile of all daily values for the time period.

<u>Colorado Decision Support System Stream Simulation Model</u>

To assess hydrologic alteration, we compared pre-developed flows to developed flows. CDSS StateMod pre-developed and developed output was entered into an Excel spreadsheet for each of the 33 reporting nodes in the watershed. For comparison, this model output was converted to cubic-feet per second from total acre-feet per-month. Three metrics (Hydrologic Alteration, Percent of pre-developed flows, and a statistical significance test) were calculated to assess monthly flow alteration.

Hydrologic Alteration

We adapted the RVA to compare pre-developed with developed stream flows. The pre-developed variation in monthly flows was used as a reference for defining the extent to which the developed flow regimes have been altered. Richter et al. (1997) suggest that water managers strive to keep the distribution of annual values of the IHA parameters as close to pre-impact distributions as possible.

Each node's pre-developed monthly data was divided into three categories: a category with a third of the stream flows that were the lowest, a category with a third of the stream flows that were the highest, and the remaining third of the streamflow measurements in the middle – reflecting an "average" streamflow condition. These categories can be thought of as the third driest, average, and wettest months, respectively from 1909-1996 at each node. The observed frequency is the number of months, using data simulating developed conditions, counted in each category. The Hydrologic Alteration Factor is calculated for each of the three categories:

(observed frequency-expected frequency)/expected frequency

The Hydrologic Alteration Factor Equation

A positive hydrologic alteration value indicates that from 1910-1996 the number of months in a particular flow category (i.e. driest, average, and wettest) has increased from pre-developed to developed conditions, while a negative hydrologic alteration value indicates a decrease in the number of months.

Percent of pre-developed flows

Median values for pre-developed and developed conditions were calculated for each month for the period of record. The pre-developed median value was divided by the developed value and multiplied by 100 to determine the percent of pre-developed flow.

Statistical significance test

Pre-developed and developed data was imported into Minitab. The Kruskal-Wallis non-parametric test was used to test the assumption that the monthly medians are equal. If the P-value was less than .05, the hypothesis for the assumption that the monthly medians are the same was rejected. A seasonal and overall flow alteration category was assigned using the following criteria:

Seasonal Alteration

3 months out of 3 significantly different → severe alteration
2 months out of 3 significantly different → high alteration
1 month out of 3 significantly different → moderate alteration
0 months out of 3 significantly different → none

Overall Alteration

9-12 months out of 12 significantly different → severe alteration
5-8 months out of 12 significantly different → high alteration
1-4 months out of 12 significantly different → moderate alteration
0 months out of 12 significantly different → none

Whether developed flows were higher or lower than pre-developed flows was recorded as an attribute. Note this categorization of alteration emphasizes the number of months that are flow altered; the magnitude of the alteration is not incorporated into this classification scheme.

Colorado Water Conservation Board Instream Flow

In 1973, the Colorado Legislature created the Instream Flow Program with the passage of Senate Bill 97: "Further recognizing the need to correlate the activities of mankind with some reasonable preservation of the natural environment, the Colorado Water Conservation Board is hereby vested with the exclusive authority, on behalf of the people of the state of Colorado, to appropriate or acquire… such waters of natural streams and lakes as the board determines may be required for minimum stream flows...to preserve the natural environment to a reasonable degree."

Senate Bill 156, passed in 2002 amends Colo. Rev. Stat. § 37-92-102(3) to read:

> *...The board may acquire, by grant purchase, DONATION, bequest, devise, lease, exchange, or other contractual agreement, from or with any person, including any governmental entity, such water, water rights, or interests in water IN SUCH AMOUNT as the board determines ~~may be required~~ IS APPROPRIATE for ~~minimum~~ stream flows or for natural surface water levels or volumes for natural lakes to preserve OR IMPROVE the natural environment to a reasonable degree.*

Figure 6 shows the location of the water rights appropriated through the CWCB's Instream Flow Program in the Roaring Fork Watershed. Generally these are based on biological recommendations provided to the CWCB by various state and federal agencies and are based on the premise that the amount of water necessary to preserve an aquatic indicator species, like a trout, is the same amount of water necessary to preserve the entire natural environment (Espegren, 1998). CWCB's procedure for quantifying instream flows is consistent with Castleberry's three step adaptive management approach which recommends:

1) setting conservative interim flow standards based on current methodologies,
2) monitoring the adequacy of the interim standards, and
3) revising the interim flow standards as necessary.

While the Instream Flow Program is viewed as a positive step, there are several limitations. Although the instream flow rights exist they are not always met because all new appropriations are dated post-1973 and are administered within the State's water right priority system. Statgraphics Plus version 5.1 was used to determine how often, when, and by how much the recommended instream flows were met. For all real-time stream flow gages, we obtained daily mean data for the period of record and compared this to the instream flow amount(s) for the stream reach that coincided with the location of the stream gage. Appendix G is a table of the gages used in instream flow analysis and the CWCB's Instream Flow Tabulation. Monthly box and whisker plots were produced for each stream flow gage. The box encloses the middle 50 percent, where the median is represented as a vertical line inside the box. Horizontal lines, called whiskers, extend from each end of the box. The lower (left) whisker is drawn from the lower quartile to the smallest point within 1.5 interquartile ranges from the lower quartile. The other whisker is drawn from the upper quartile to the largest point within 1.5 interquartile ranges from the upper quartile. Instream flow amounts were superimposed on these plots to determine how often they were met. Variability among years in meeting recommended instream flow amounts was also assessed. For each gage a summary table was compiled with a count of the number of days the CWCB instream flow rights were not met for each month of every year for the period of record. From these data, monthly histograms were made showing the percent of time the instream flow amounts were not met.

Additionally, instream flows amounts do not directly consider the importance of other aquatic organisms, or in-channel and over-bank indicators. In 1996, an Instream Flow Subcommittee assembled by the CWCB to gather input on the public's desire for the future direction of the CWCB instream flow program, suggested the CWCB consider the following in-channel indicators: 1) quantifying channel-forming maintenance flows, 2) integrating water quantity with water quality and water temperature parameters, and 3) considering flows for recreation purposes. To address the over- bank indicators, a more holistic, ecosystem approach was suggested recognizing the importance of appropriating flows to maintain riparian and side-channel habitats. These habitats are capable of sustaining avian and mammalian species living along the stream corridor, in addition to the various life stages of aquatic species that live within the streams (Espegren, 1998).

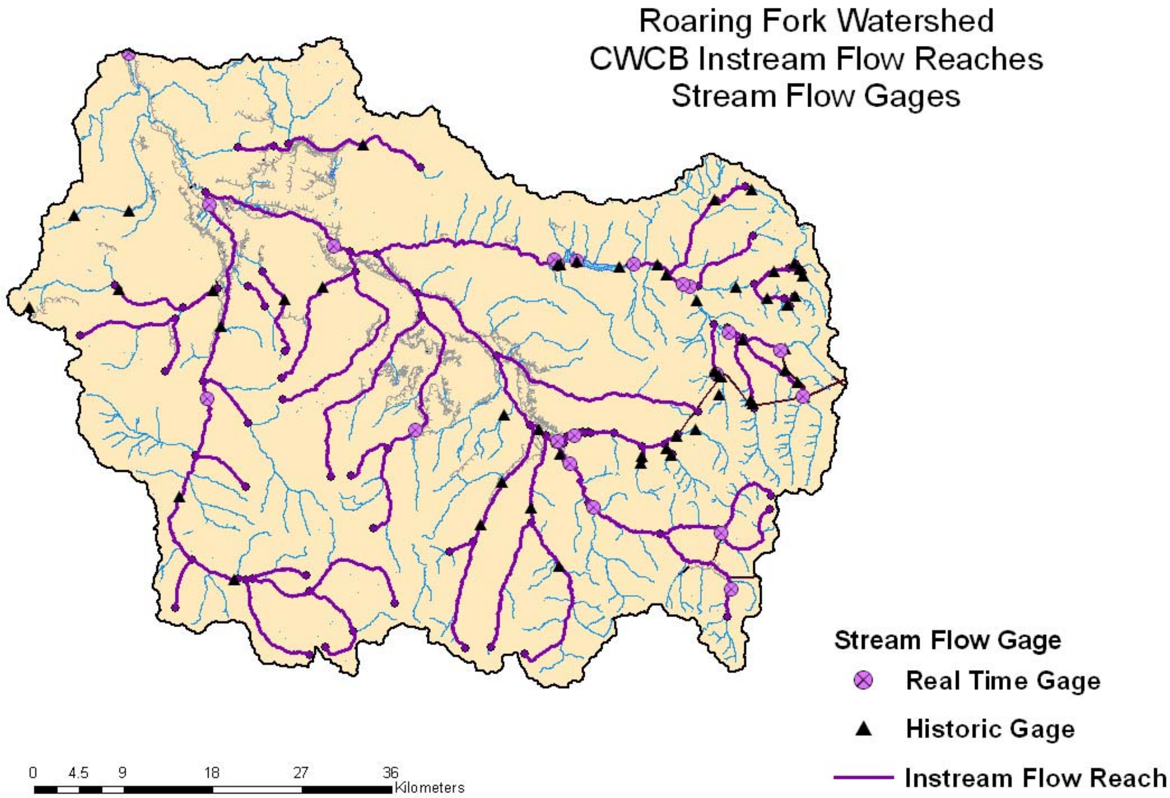


Figure 6. Location of the water rights appropriated through the CWCB's Instream Flow Program

Conservation Action Planning (CAP)

This study has a symbiotic relationship with TNC's CAP process. The study results will be used in the identification of stresses and sources. The CAP process is used to define and assess conservation targets. To this end, TNC and the Conservancy assembled a science review team in June 2005 to provide information on biodiversity in the Watershed. The team included representatives from local, state, and federal governments as well as the conservation community and expert consultants. The Conservancy is a member of the science working group and has participated in drafting viability/integrity specifications, reviewing preliminary viability determinations, and reviewing threat rankings. Through this process rare species, plant communities, and aquatic systems within conservation target sub-watersheds were identified. Within each conservation target, attributes and associated indicators are assessed for the three categories of landscape context, condition, and size. The hydrologic alteration results presented in this report will be used as landscape context indicators in many of the conservation target sub-watersheds. See Appendix H for an explanation of TNC's CAP.

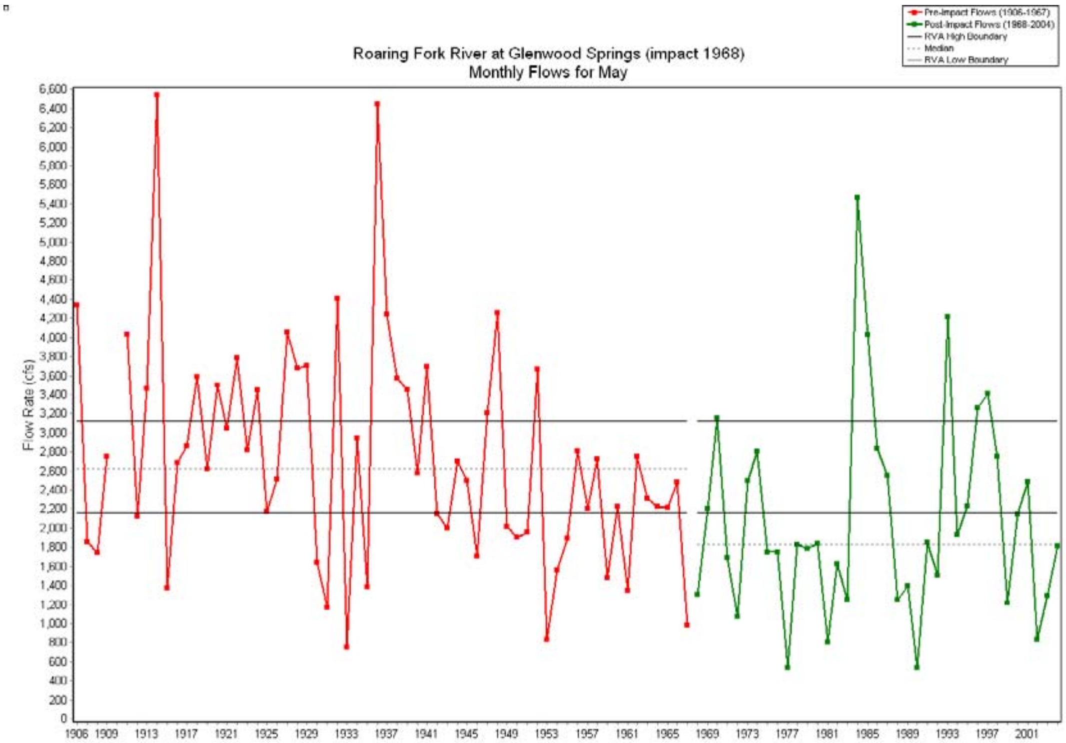
Results

IHA

Due to lack of a long-term data record, IHA analysis was only run for three stations on the Roaring Fork River: two that were combined at/near Aspen and the other at the mouth at Glenwood Springs. The Non-Parametric IHA Scorecards for both gages are found in Appendix I. Appendix J contains some of the graphical output of these analyses.

The easiest to interpret IHA results are obtained when there is a major impact associated with one point in time and there also is at least 20 years of data available before and after the impact. The flows at the Roaring Fork River at Glenwood Springs Gage are influenced by all the upstream flow alteration. Thus, picking one date for the impact is misleading. Even combining the two gages above Aspen does not provide the 20 years suggested pre-impact data record. Acknowledging these limitations for the watershed, we provide results for two gages to demonstrate the capabilities and output of this analysis. When daily CDSS StateMod daily data becomes available, we will use these modeled data as input into IHA, affording a more in-depth analysis of flow alteration. Importing CDDSS StateMod output into IHA will offer a more comprehensive view across the watershed as well as statistics on a more complete suite of hydrologic parameters.

We chose the date when Ruedi Reservoir became operational as the date of impact for the gage on the Roaring Fork River at Glenwood Springs. This gage integrates all of the upstream hydrologic alteration, sometimes resulting in an overall increased flow. Such is the case when the higher flows associated with the reservoir releases intersect with the lower flows associated with in-basin and trans-mountains diversions. Appendix J shows the Greatest Hydrologic Alteration Factors for this gage. IHA Parameter Group 1 is the magnitude of monthly water conditions. The median flows for seven months, in the winter, spring, and fall are different pre- and post-reservoir (Figures 7 is the RVA graph for May). The magnitude and duration of annual extreme water conditions is captured by Parameter Group 2, the annual minimums and maximums. All of these parameters are significantly different from before and after reservoir operations. Appendix J shows the three-day minimum flows and the three-day maximum for pre- and post-impact periods. The two parameters represented by IHA parameter Group 3-the timing of annual extreme water conditions- were not different pre- and post- impact. Parameter Group 4-the frequency and duration of high and low flow pulses was different for both low and high flow pulse count. Appendix J compares the low flow pulse count for pre- and post-impact. Post-impact conditions for the last group, which represents the rate and frequency of water condition changes, were all different from pre-impact conditions. The rise rate was lower and the fall rate and number of reversals was higher for the post-impact period than the pre-impact period.



Figures 7. Range of variation approach graph for May

Greatest Hydrologic Alteration Factors for the combined Roaring Fork River near and at Aspen gages are shown in Appendix J. All post-impacts medians for Parameter Group 1 were statistically significantly lower than pre-impact medians. Appendix J shows the RVA comparison for June and August and the comparison of the 30-day minimum and 30-day maximum for the two time periods. All medians for Parameter Group 2 (magnitude and variation of annual extreme flow water conditions) were statistically significantly different except base flow. No differences were seen in Parameter Groups 3 and 4. The three parameters in Parameter Group 5 (rise rate, fall rate, and number of reversals) were all different, with the rise rate being less after the impact and the fall rate and number of reversals increasing.

CDSS StateMod and CWCB ISF

Using CDSS StateMod data, hydrologic alteration assessments were made for the 33 nodes with pre-developed and developed modeled flow data. Appendix K contains tables and histograms summarizing the results of the hydrologic alteration for each sub-watershed arranged from upstream to downstream. This first-cut assessment revealed broad patterns in flow alteration (Figures 8-12). This analysis was coupled with a comparison of CWCB instream flow amounts to daily mean stream flow data to determine how often, when, and by how much the instream flows were met.

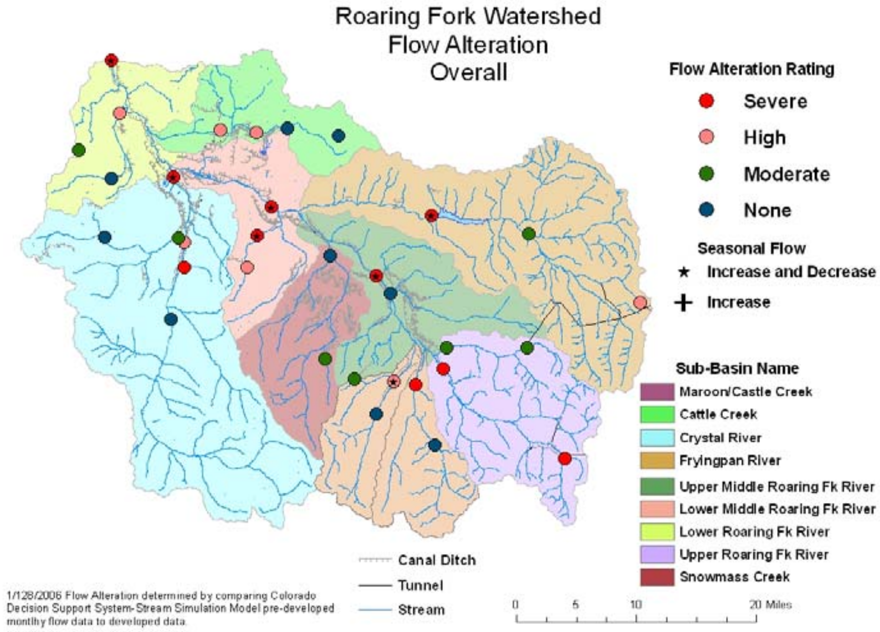


Figure 8. Overall hydrologic alteration by sub-watershed

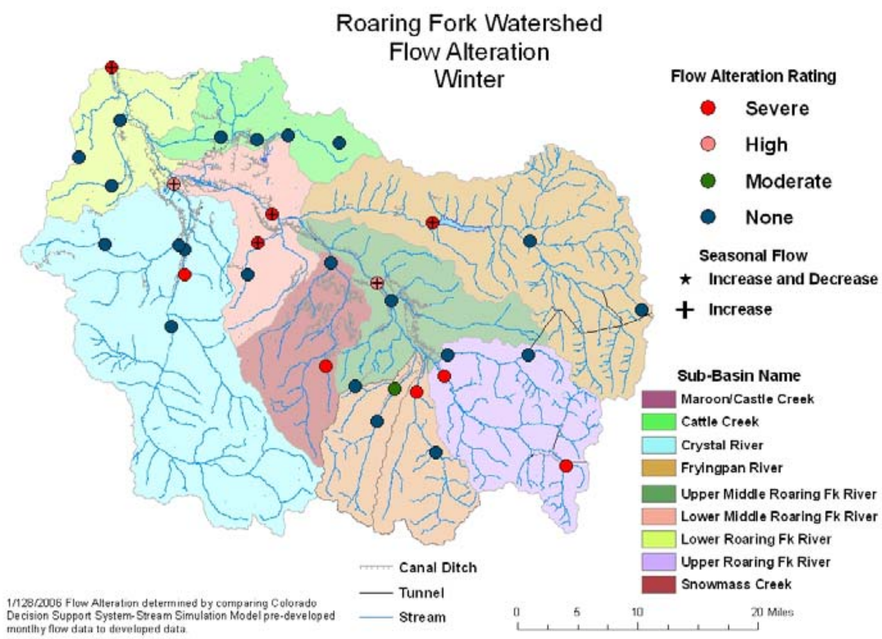


Figure 9. Winter hydrologic alteration by sub-watershed

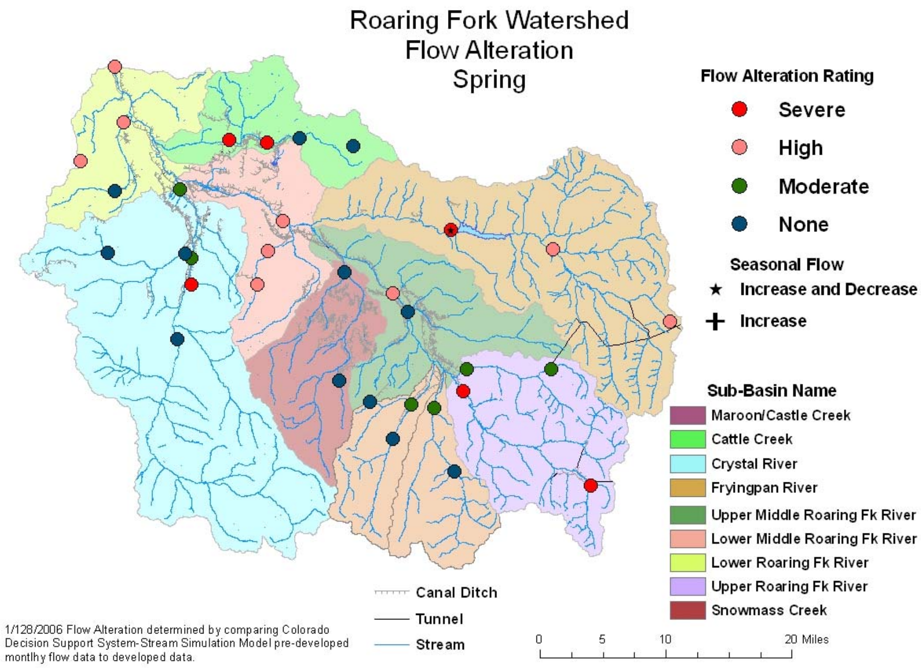


Figure 10. Spring hydrologic alteration by sub-watershed

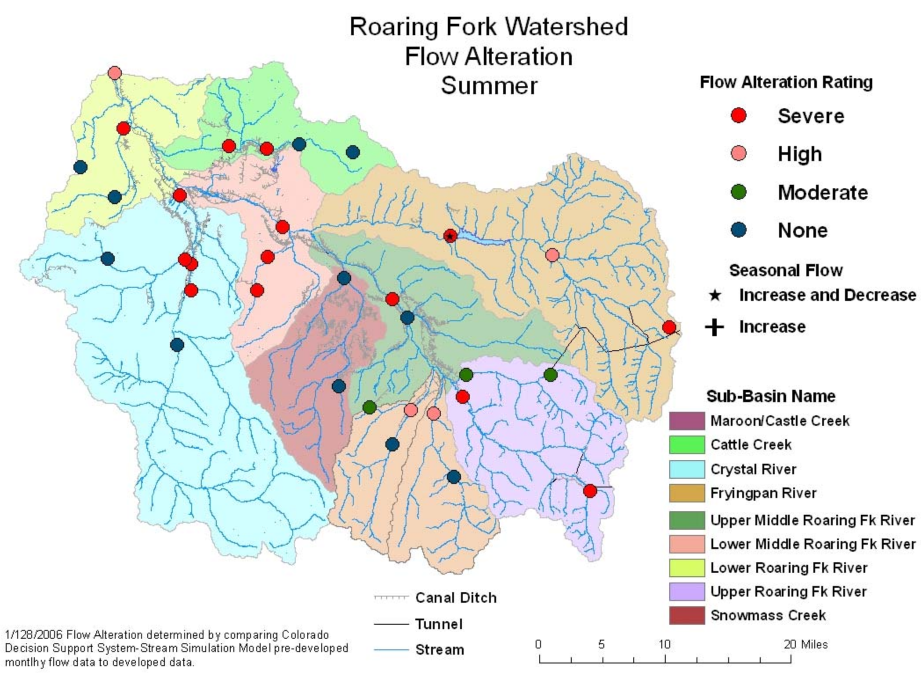


Figure 11. Summer hydrologic alteration by sub-watershed

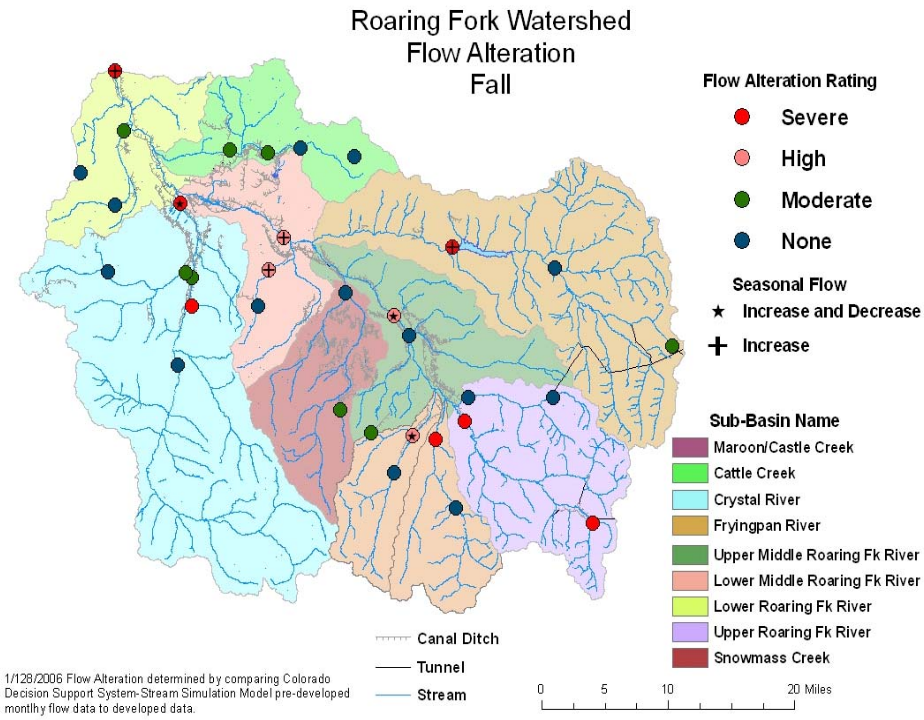


Figure 12. Fall hydrologic alteration by sub-watershed

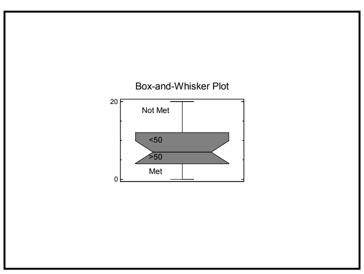
Appendix L contains a histogram of percent of each class of flow alteration both by season and overall, based on the test of statistical significance using CDSS StateMod data and a histogram of the percent of nodes where the developed flows were either higher, lower, both or the same as pre-developed flows both by season and overall. For both the summer and winter seasons, flow alteration is usually either severe or there is none, whereas with spring and to some extent fall, the impact can be high or moderate. The season with the highest percentage of nodes with severe flow alteration is the summer, followed by winter, fall, and then spring. Approximately, 60 percent of the nodes had lower flows in the spring and summer. Flows were never higher for all three months in the spring and summer, although the node on the Fryingpan below Ruedi Reservoir had higher flows in April and September and lower flows for the other 4 months. Although 10-20 percent of the nodes in fall and winter had higher flows, there was an equal amount or higher number that had lower flows in these two seasons. One thing to keep in mind in looking at these results is that the locations of the reporting nodes were not picked for this study and so do not fully represent conditions throughout the watershed. In many cases there are no reporting nodes at the mouths of major rivers that would better integrate conditions upstream.

Table 4 and Figure 13 summarize the results of the comparison of CWCB's instream flows to daily mean stream flows and Appendix M shows the box and whisker plots for each gage. Also as a note of caution, the gage records vary considerably in their period of record and continuity of gage operation. Winter gage data is most likely to be missing or estimated, due to presence of ice.

Table 4. Comparison of CWCB's ISF's to Daily Mean Stream Flows.

GAGE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Chapman	met	met	met	met	>50	>50	not met	met	met	met	met	met
Fryingpan Thomasville	met	>50	<50	not met	not met	not met	<50	met	met	met	<50	<50
Fryingpan Meredith	met	met	met	>50	>50	met	<50	met	met	met	met	>50
Fryingpan Ruedi	>50	met	met	met	met	met	met	met	met	met	met	met
Roaring Fork Lost Man	not met	n/a	n/a	n/a	n/a	n/a	n/a	n/a	<50	<50	<50	not met
Lincoln	not met	not met	not met	not met	not met	not met	not met	not met	not met	<50	>50	<50
Roaring Fork Difficult	met	met	>50	<50	<50	<50	met	met	met	met	met	met
Roaring Fork Aspen	met	50%	<50	not met	not met	met	met	met	met	met	met	met
Hunter	<50	not met	not met	not met	not met	not met	<50	met	met	met	>50	<50
Roaring Fork Maroon	met	met	met	met	met	met	met	met	met	met	met	met
Roaring Fork Emma	met	met	met	met	met	met	met	met	met	met	met	met
Crystal Avalanche	met	met	met	met	met	met	met	met	met	met	met	met
Crystal Carbondale	>50	met	met	met	met	met	met	met	met	met	<50	<50
TOTALS												
not met	2	2	2	4	4	3	2	1	1	0	0	1
<50	1	0	2	1	1	1	3	0	1	2	3	4
> 50	2	2	1	1	2	1	0	0	0	0	2	1
Met	8	8	7	6	5	7	7	11	11	11	8	7

n/a not enough data



If ISF amount is:

- Above box → not met
- Above median line but not outside of box → < 50
- Below median line but not outside of box → > 50
- Below box → met

Figure 13. CWCB Instream Flow Analysis Results

The following discussion of hydrologic alteration is by season and sub-watershed. Nodes are the points where data were gathered and modeled. The assumption is that the node reflects the upstream reach.

<u>**Winter**</u>

Winter is defined as January, February, and March. Sixty-four percent of the nodes had no detectable alteration in winter. The remaining impacted nodes were split evenly between having higher and lower developed flows than pre-developed flows. The six nodes that had more flows were either due to agricultural return flows or reservoir operations. Lower flows can be attributed to one of three activities: trans-mountain diversions, snowmaking, or municipal diversions.

The biggest alteration in the Fryingpan River Sub-Watershed is below Ruedi Reservoir, resulting from reservoir operations. Unlike most of the other hydrologic alterations in the Roaring Fork River Watershed, this alteration results in developed flows being much greater than pre-developed flows. This information needs to be evaluated in context with information obtained as part of the Ruedi Futures Study. As part of the Ruedi Futures Study, the Conservancy undertook the Fryingpan Valley Economic Study and Miller Ecological Consulting undertook the Fryingpan/Roaring Fork Rivers Fishery Study. Key finding from the Fishery Study indicated that the installation and operation of the dam caused changes in the Lower Fryingpan River's thermal regime. During winter months, formation of anchor ice, which is influenced by stream flow levels, can negatively impact the aquatic environment. Information from the economic and fishery study is being provided to the Bureau of Reclamation so that they may consider and implement appropriate changes in their operation of the dam. CWCB instream flows are usually met in the winter at the Chapman Gulch at Nast Gage and the Fryingpan River at Meredith Gage.

However, the gage on the Fryingpan near Thomasville located between these two often does not meet the CWCB instream flow of 30 cfs. More in-depth analysis is needed in this area to understand gage data relative CWCB instream flow amounts. Lime Creek, a major tributary of the Fryingpan, enters between the upstream gage near Thomasville and the lower gage at Meredith. George Wear of CDWR indicated that some gages such as the Fryingpan River at Meredith and the North Fork of the Fryingpan River gages are often influenced by ice resulting in estimates of flows (pers.com, 12/05/05). The Fryingpan River near Thomasville and Chapman Gulch gages do not freeze so these gages are used for extrapolation of flow patterns to the other gages. Additionally, the Fryingpan River Gage at Meredith has a longer period of record. The Fryingpan River below Ruedi Reservoir Gage shows instream flows are almost always met.

The Upper Roaring Fork River Sub-Watershed is influenced by the Twin Lakes Tunnel (also known as the Independence Pass Trans-mountain Diversion Tunnel) in the winter (Appendix D). Based on data from 1935-2004, the average diversions are: 2.48, 2.30, and 1.97 cfs for January, and February, and March, respectively. Data for both of the CDSS StateMod nodes on the Upper Roaring Fork River show significant hydrologic alteration for all three months. Winter flow alteration is not detected on the Hunter Creek nodes. Instream Flow analysis was conducted for the three real time stream gages in this sub-watershed. The gage on the Roaring Fork River above Lost Man Creek was not used because data are not available for the winter months when ice and the channel configuration make accurate data collection impossible (Figure 14). Almost all flows recorded for the gage at Lincoln Creek below Grizzly Reservoir and most flows for the two gages on the Roaring Fork (one above Difficult Creek and the other near Aspen) were below the CWCB instream flow. In stark contrast to the flow alteration analysis for Hunter Creek, the instream flow analysis showed that virtually all winter days were below the instream flow amount. The CWCB winter instream flow amount of 16 cfs appear to be too high for this stream given that the median estimated pre-developed flow amounts for this gage in January, February, and March were 5.1, 4.7, and 5.3 cfs.

Figure 14. Roaring Fork above Lost Man Creek Gage (7/8/05 and 10/21/05)

Two nodes in the Maroon/Castle Creek Sub-Watershed show hydrologic alteration. Developed flows for all three months at the Castle Creek node (3800869) and one month (March) at the

Maroon Creek node (381028) were significantly different from pre-developed flows resulting in severe and moderate ratings. Both of these streams are used for snowmaking and municipal water supplies. No real time stream gages are available in this sub-watershed for instream flow analysis.

There are two nodes in the Upper Middle Roaring Fork River Sub-Watershed. The one on Woody Creek showed no hydrologic alteration in the winter. In January and February the hydrologic analysis for the other node on the mainstem showed lower pre-developed flows than developed flows, most likely from delayed agricultural return flows, giving this node a moderate hydrologic alteration rating. Flow data from the Roaring Fork River above Maroon Creek Gage showed that the CWCB instream flow amount was always met.

In the Snowmass Creek Sub-Watershed, the node on East Sopris Creek shows high hydrologic alteration due to diversions into the Brush Creek Watershed for snowmaking and for Snowmass Village municipal use. The node on Capital Creek shows no hydrologic alteration in the winter. There is one real time stream gage in this sub-watershed on Snowmass Creek. However, these data were not available online. The Snowmass Water and Sanitation District was able to provide data from 2001, however this data need to be reformatted for future analysis.

The node on the Roaring Fork River in the Lower Roaring Fork River Sub-Watershed shows significant hydrologic alteration. Because of the influence of Ruedi Reservoir operations on this reach, the developed flows were estimated to be higher than the pre-developed flows. Irrigation return flows may also be contributing to the higher flows. This node is located at the gage on the Roaring Fork River at Emma. Obviously, with these higher than expected flows, the instream flow was always met. The other two nodes in this sub-watershed are on West Sopris Creek. The node in the headwaters shows no hydrologic alteration. Developed flows are significantly higher than pre-developed flows for the lower node which may be caused by agricultural return flows.

This same phenomenon is seen on the Lower Crystal River. January and February developed flows are statistically significantly higher than pre-developed flows. The only other node in the Crystal River Sub-Watershed that shows any hydrologic alteration is on Nettle Creek, classified as having severe hydrologic alteration with lower flows than expected. This creek is a water source for Carbondale. Winter instream flows were almost always met at both gages on the Crystal River. No hydrologic alteration is seen for the two nodes on Thompson Creek.

Nodes in the Cattle Creek and Lower Roaring Fork River sub-watersheds indicate no hydrologic alteration with the exception of the node representing the gage on the Roaring Fork River at Glenwood Springs. The releases from Ruedi Reservoir and the accumulated agricultural return flows show up at the mouth of the Roaring Fork River. There are no CWCB instream flow appropriations for the Lower Roaring Fork. Although there are instream flow water rights for some of Cattle Creek, there are no corresponding gages for comparisons.

Spring

Spring is defined as April, May, and June. Of the 33 nodes that we had data for, 61 percent had significantly lower developed than pre-developed flows in at least one month, 36 percent had no change from pre-developed flows, and three percent had both higher and lower developed flows.

Beginning in May the two upper nodes in the Fryingpan River Sub-Watershed show developed flows lower than pre-developed flows as water is diverted through the Boustead and Busk-Ivanhoe tunnels (Appendix D). Both of these nodes have high hydrologic alteration scores. The higher than expected flows seen in winter continue through April for the Fryingpan River node below Ruedi Reservoir. Then the trend reverses in May and June as snowmelt begins to be stored in the reservoir. Because all three months are statistically significantly different from developed flows, this node received a severe rating. April CWCB instream flows amounts are infrequently met at the Chapman Gulch near Nast Gage, and less than 50 percent of the time at the gages near Thomasville and at Meredith. The instream flows are almost always met in May and June at these gages.

As diversions by the Twin Lakes Tunnel ramp up to capture spring peak flows, the nodes on the Upper Roaring Fork River are rated as having severe hydrologic alteration in the spring. By June the developed median flow is 4 percent of the pre-developed flows on Lincoln Creek and 32 percent at the node for the gage on the Roaring Fork near Aspen. The Roaring Fork River above Lost Man Creek Gage has limited data for the spring months. When data was collected in June, the CWCB instream flow was met less than 50 percent of the time. About 65 percent of the 26 year record for the Lincoln Creek below Grizzly Reservoir Gage have data for the spring months. These data show that CWCB instream flow is usually not met (Figure 15). For all three months the gages at Roaring Fork River above Difficult Creek, Roaring Fork River near Aspen, and for May and June for the Hunter Creek Gage the CWCB instream flow is met most of the time. The CWCB instream flow is met less than 50 percent of the time in April for the Hunter Creek Gage. The histogram in Figure 16 shows the percent of days CWCB instream flow amounts were not met in April for the period of record. Both nodes on Hunter Creek showed significantly lower developed flows than pre-developed in June. Modeled developed flows for the upper node were 26 percent and the lower node's flow were 42 percent of pre-developed flows.

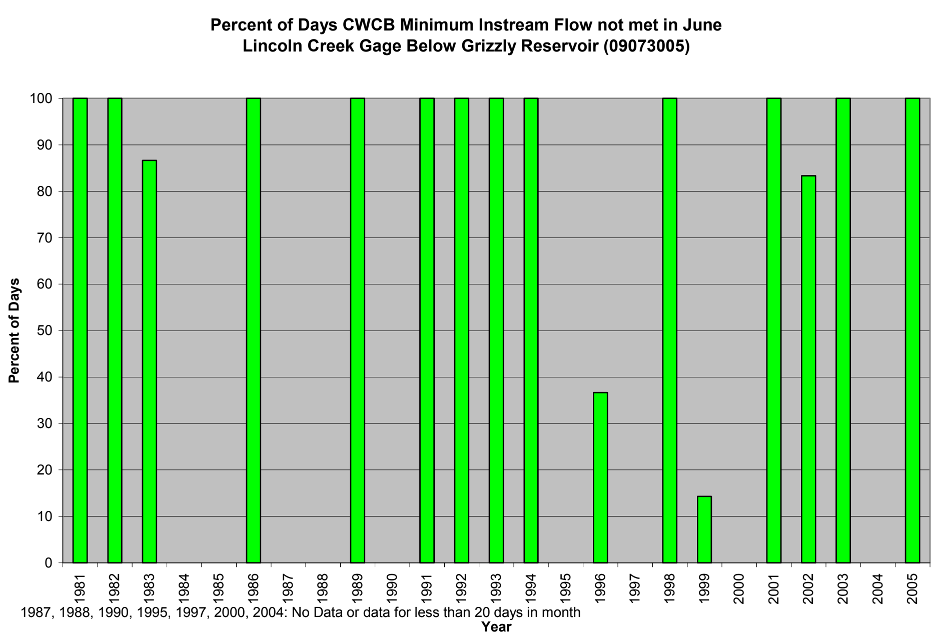


Figure 15. Lincoln Creek Gage histogram

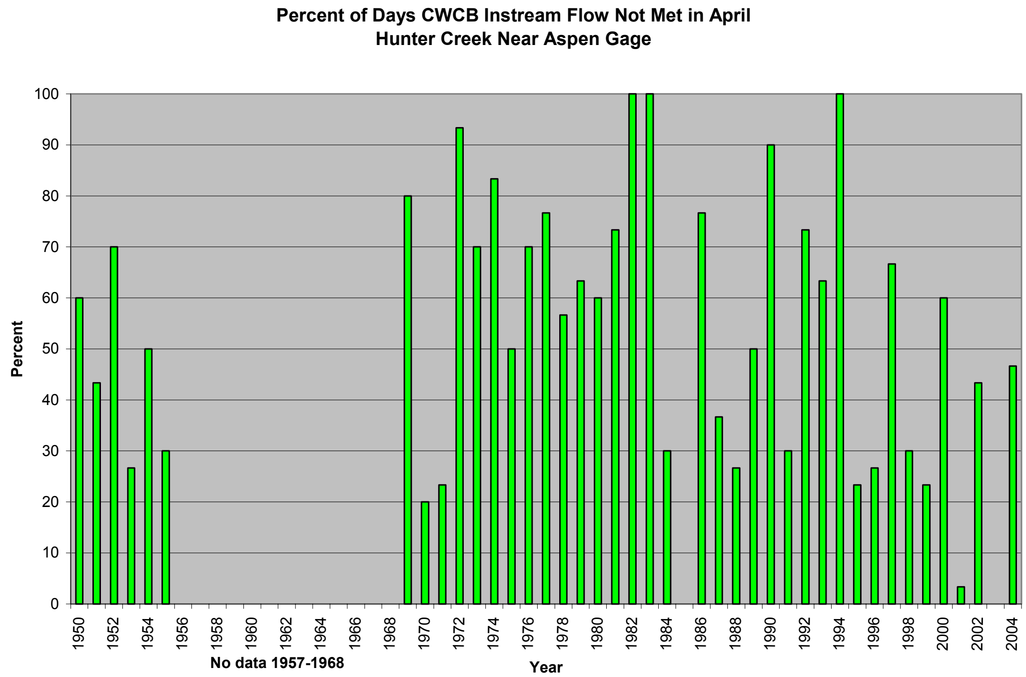


Figure 16. Hunter Creek Gage histogram

Developed flows were less than pre-developed flows for two nodes (3800869 and 3801028) in the Maroon/Castle Creek Sub-Watershed for the month of April resulting in a moderate hydrologic alteration rating. This is most likely due to water being diverted for snowmaking at the end of the ski season along with municipal uses.

For the Upper Middle Roaring Fork River Sub-Watershed, the node on Woody Creek shows no hydrologic alteration in the spring. Moderate hydrologic alteration is seen at the node on the mainstem of the Roaring Fork because of lower developed flows in May and June. Water is starting to be diverted for agricultural uses and less is available because of the Twin Lakes Trans-mountain Diversions.

No hydrologic alteration is seen for the nodes in the Snowmass Creek Sub-Watershed in the spring.

The Lower Middle Roaring Fork River Sub-Watershed shows the same pattern as the Upper Middle Roaring Fork River with lower developed flows in May and June. Diversions for agriculture as well as decreased availability because of trans-mountain diversions are mostly likely the cause. However, only the lower node on the mainstem of the Roaring Fork is influenced by the trans-mountain diversions from both the Upper Roaring Fork River and the Fryingpan River sub-watersheds and Ruedi Reservoir operations for the latter. The two nodes on West Sopris Creek are influenced by the trans-basin diversions to the Crystal River Sub-Watershed as well as in-basin diversions.

The two lower nodes on the Crystal River have moderate hydrologic alteration because of lower developed flows in May. As runoff peaks in June, the developed flows are not significantly different from pre-developed flows. CWCB instream flows are consistently met for both gages on the Crystal River in the spring.

The middle stretch of Cattle Creek shows lower developed flows for all three months receiving a severe hydrologic alteration rank. Developed flows in May and June are 20-40 percent of pre-developed flows. Irrigation season probably begins earlier in the Cattle Creek Sub-Watershed due to lower elevations and physical aspect of this sub-watershed.

Most nodes in the Lower Roaring Fork River Sub-Watershed received a high rank as May and June developed flows were less than pre-developed flows. The exception is Upper Four Mile Creek, which had no hydrologic alteration.

Summer

Summer is defined as July, August, and September. Forty-five percent of nodes ranked as having severe hydrologic alteration in summer. No nodes showed higher developed flows compared to pre-developed flows.

In the Upper Fryingpan River Sub-Watershed, developed flows are less than pre-developed flows in the summer months except during September at the node representing the gage on the Fryingpan near Thomasville, which has the same flows. The node below the reservoir gets a severe rank, but pre-developed flows are lower than developed flows in July and August (48 percent and 79 percent) and higher (192 percent) in September. CWCB instream flows are met most of the time for the gage at Chapman Gulch near Nast and in July for the gage on the Fryingpan River near Thomasville. For the latter gage the August and September CWCB instream flows are met less than 50 percent of the time. At the Fryingpan River at Meredith Gage just upstream of the reservoir, in September CWCB instream flows are met in July and August and more than 50 percent of the time in September. Below the reservoir at the Fryingpan near Ruedi Gage the CWCB instream flows are almost always met.

After reaching the maximum diversion amounts in June, Twin Lakes Tunnel continues to divert an average of 123 cfs in July. This level of diversion results in developed flows in Lincoln Creek comprising only 2 percent of the pre-developed flows in July. Developed flows get closer to pre-developed flows in August and September (39 percent and 80 percent) but are still statistically significantly different resulting in a severe rank for this node. Downstream at the node representing the gage on the Roaring Fork near Aspen, the rank is still severe with percent of pre-developed flows for July being 31 percent, August-53 percent, and September-85 percent. Downstream Colorado River calls likely account for some of the recovery at the end of summer. The nodes on Hunter Creek have moderate hydrologic alteration ranks because of lower developed flows in July (35 percent and 49 percent of pre-developed flows, corresponding to the upper and lower nodes). At the gage on the Roaring Fork River above Lost Man Creek the CWCB instream flow is met less than 50 percent of the time in July and September, increasing to most of the time in September. Meeting CWCB instream flows for the Lincoln Creek at Grizzly Gage is a little better with just above 50 percent being met in August and just below 50 percent in July and September. The CWCB instream flow is met at both the other downstream gages on the Roaring Fork River.

Developed flows in the Maroon/Castle Creek Sub-Watershed are similar to pre-developed flows in summer, although the lower node on Castle Creek was statistically significantly different from pre-developed flows in August and September (the developed flows were 89 percent of the pre-developed flows). On Maroon Creek the developed flows for the lower node received a high rank because of lower flows in August and September. Willow Creek, a tributary to Maroon Creek, had lower flows in September. Since these two watersheds provide water for the City of Aspen, more in-depth analysis is needed to understand the timing and amount of these diversions.

In the Upper Middle Roaring Fork River Sub-Watershed, pre-developed flows on Woody Creek approximated developed flows for the summer months. However, the node on the mainstream of the Roaring Fork River showed significantly different developed flows for July, August, and September of 68 percent, 74 percent, and 89 percent of pre-developed flows most likely due to trans-mountain diversions and some irrigation.

There was no hydrologic alteration detected using the two nodes in the Snowmass Creek Sub-Watershed for the summer months.

In the Lower Middle Roaring Fork River Sub-Watershed all three nodes showed severe hydrologic alteration. On West Sopris Creek at the node where water is diverted to the Crystal River Sub-Watershed, the developed flows for July, August, and September are 50 percent, 44 percent, and 83 percent of pre-developed flows, respectively. For the downstream node on that creek the developed flows are 64 percent, 61 percent, and 79 percent of pre-developed flows, respectively. On the mainstem of the Roaring Fork River, the developed flows are 61 percent, 65 percent and 88 percent of pre-developed flows for the three summer months.

All four nodes in the Lower Crystal River Sub-Watershed show severe hydrologic alteration in the summer corresponding to irrigation withdrawals in addition to year-round municipal uses. Nettle Creek, being relatively small and supplying drinking water, had the worst percentage-wise shortages with developed flows for July, August, and September being 30 percent, 11 percent, and 21 percent of pre-developed flows. The CWCB instream flow was met less than 50 percent of the time in August and September for the Crystal River below Carbondale Gage for the five years of record (Figure 17). The flows upstream of this gage are often lower than at the gage because the gage is influenced by return flows. There was no detected difference between pre-developed and developed flows in the Upper Crystal above Avalanche Creek and in North Thompson Creek. Correspondingly, the CWCB instream flow amounts at the Crystal River above Avalanche Creek Gage were almost always met.

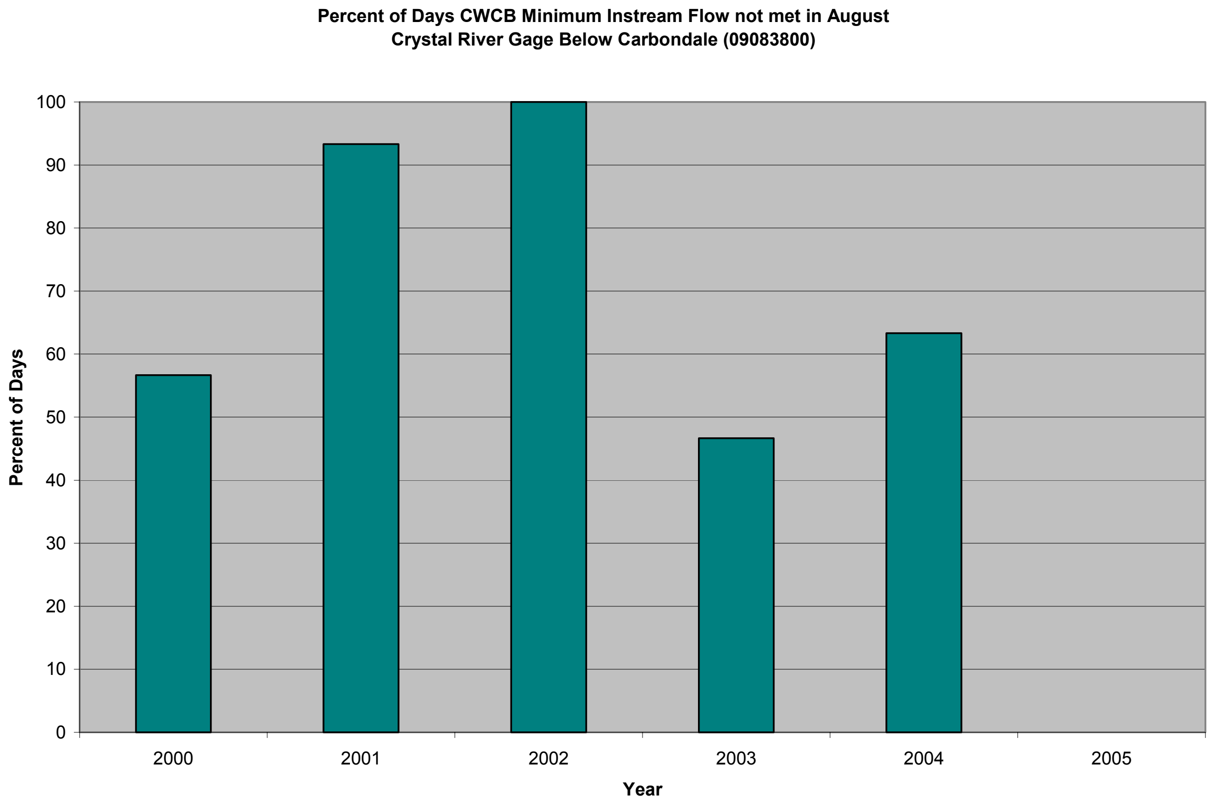


Figure 17. Crystal River below Carbondale Gage histogram

Analysis for the two upper nodes on Cattle Creek detected no difference in flows for the summer months. In the mid-section of the Sub-Watershed, where water is withdrawn for irrigation, both nodes showed significantly drier developed conditions than pre-developed conditions. At the higher of these two nodes the percentages of developed to pre-developed flows for July, August and September were 36 percent, 64 percent, and 42 percent, and for the lower node the percentages were 56 percent, 44 percent, and 43 percent, respectively.

The Lower Roaring Fork River Sub-Watershed had severe hydrologic alteration in the lower sections of Four Mile Creek similar to Cattle Creek. However, the percentage of pre-developed to developed flows was much greater (86 percent, 79, and 80 percent). The node at the mouth of the Roaring Fork showed moderate hydrologic alteration with the developed data having more drier months than identified for the pre-developed data in July and August. Developed flows in July were 71 percent of pre-developed flows and they were 72 percent of pre-developed flows in August. The node at the mouth of the Roaring Fork showed moderate hydrologic alteration with the developed data having more months below the range of variability low boundary (derived from the 33rd percentile of the pre-developed data).

Fall

Fall is defined as October, November, and December. Forty-three percent of the nodes had no change in flows from pre-developed to developed conditions.

At the Ivanhoe Reservoir Tunnel and Fryingpan near Thomasville Gage nodes, hydrologic alteration is moderate with October having more months in the developed data set below the 33rd percentile (drier months). For the Tunnel node, developed flows are 62 percent of pre-developed flows and are 90 percent of pre-developed flows for the gage node. Developed flows below the reservoir are significantly higher than pre-developed flows as the reservoir releases to make room for snow-melt in the spring. For October the developed flows are 202 percent of pre-developed flows, in November the percentage increases to 268 percent, and it increases further in December to 293 percent. At the Chapman Gulch at Nast Gage, CWCB instream flows are almost always met. At the Fryingpan River near Thomasville Gage CWCB instream flows are not always met in November and the situation worsens in December when the instream flows are met less than 50 percent of the time. The flows relative to the CWCB instream flows improve at the Fryingpan at Meredith Gage where the instream flows are almost always met.

For the Upper Roaring Fork River Sub-Watershed node at the Independence Pass trans-mountain tunnel, the fall developed flows are significantly different than pre-developed flows although the percentages are much higher than it was for this same node in the spring (developed flows for October are 86 percent of pre-developed flows, for November-72 percent, and December-82 percent). A similar pattern is found downstream at the Roaring Fork near Aspen Gage node (92 percent, 80 percent, and 88 percent, respectively). No hydrologic alteration was detected at the Hunter Creek nodes for the fall. Using the limited gage data recorded in October at the Roaring Fork above Lost Man Creek Gage, the CWCB instream flow was rarely met. There is insufficient gage data available for November and December to determine whether instream flows are met. At the Lincoln Creek below Grizzly Reservoir Gage, CWCB instream flows were not met. CWCB instream flows were usually met in October and November at the Roaring Fork River above Difficult Creek Gage and less often in December. Moving downstream to the Roaring Fork River near Aspen Gage, CWCB instream flows were almost always met in October, and were met about 50 percent of the time in November and less than 50 percent of the time in December.

Fall hydrologic alteration in the Maroon/Castle Creek Sub-Watershed is highly variable and difficult to interpret. Severe alteration is seen at the lower node on Castle Creek. On Willow Creek, a tributary of Maroon Creek, hydrologic alteration is moderate with lower developed flows than pre-developed flows in October (86 percent). No hydrologic alteration is seen at the upper node on Maroon Creek. Oddly, the lower node on Maroon Creek has high hydrologic alteration because of lower developed flows than pre-developed flows in October and higher developed flows than pre-developed flows in November. These types of anomalies are being passed onto CWCB to verify and rectify, if necessary, in their updated model.

In the Upper Middle Roaring Fork River Sub-Watershed, no fall hydrologic alteration is seen on Woody Creek. The node on the mainstem has high hydrologic alteration because of higher developed flows than pre-developed flows in November and December. This may be attributable to irrigation return flows.

No fall hydrologic alteration is seen on Capitol Creek in the Snowmass Creek Sub-Watershed. Moderate hydrologic alteration shows up on East Snowmass Creek because of lower developed flows than pre-developed flows in December, most likely due to snowmaking activities at Snowmass Ski area.

In the Lower Middle Roaring Fork River Sub-Watershed, hydrologic alteration is high on the lower West Sopris Creek node and on the mainstem due to higher developed than pre-developed flows in November and December, once again most likely due to irrigation return flows.

In the Lower Crystal River Sub-Watershed, irrigation appears to influence flows. The most downstream node has lower developed flows than pre-developed flows in October, with the reverse trend seen in November and December. The October pattern is seen in the nodes above and on Thompson Creek, but return flows do not seem to influence these nodes. No hydrologic alteration is detected in North Thompson Creek or the Crystal above Avalanche Creek. Because of withdrawals for the Carbondale Water Supply, Nettle Creek has severe hydrologic alteration. CWCB instream flow is met more than 50 percent of the time at the Crystal River below Carbondale Gage.

The two lower nodes on Cattle Creek have lower developed flows than pre-developed flows in October (53 percent and 37 percent) and no detectable difference for the other two months, resulting in a moderate rating.

Lower flows in October are also seen at the lower node on Four Mile Creek in the Lower Roaring Fork River Sub-Watershed (70 percent). Severe hydrologic alteration is seen at the node representing the Roaring Fork River at Glenwood Springs Gage because of significantly higher developed flows than per-developed flows in all three months (118 percent, 185 percent, and 163 percent, respectively). Reservoir releases and irrigation return flows are the most likely causes of these high flows.

Threat Identification

Flows have been altered in the Roaring Fork Watershed by in-basin diversions associated with agriculture and municipal uses, dam operations, and trans-mountain diversions. In the future these threats to flows in the watershed are projected to increase: municipal use often associated with conversion of agricultural lands to development, trans-mountain diversions, and snowmaking. More work needs to be undertaken to better understand the long-term effects on biological and geomorphological processes from chronic flow alteration. Pitkin County has undertaken a study to better understand how groundwater influences and is influenced by flow alteration. The Aspen Global Change Institute is undertaking a study to assess some of the local impacts expected from climate change. Besides trans-mountain diversions, there are other out-of-basin threats such as downstream calls from the Colorado River Compact, downstream agricultural demands, Endangered Fish Recovery Program flow support, and operation of the Shoshone Power Plant.

The Conservancy is working with TNC on a threat assessment. Fifteen threats have been identified within the watershed of which four are associated with hydrologic alteration. These include trans-mountain diversions, and in-basin agricultural, municipal, and ski industry-related diversions. The influence of these threats on each conservation target sub-watershed is scored from low to very high. These scores are combined in the CAP program to determine an overall threat rank and a threat rank for the conservation target sub-watershed.

Focus Areas

These analyses help us quantify the magnitude, timing, and location of hydrologic alteration, taking us one step closer to achieving the ultimate goal of restoring flows that sustain the environment and foster economic sustainability. To this end, we have begun work in two known flow altered areas: the Upper Roaring Fork and Lower Crystal River sub-watersheds.

Upper Roaring Fork River Sub-Watershed

The Conservancy has partnered with the River District, TNC, Aspen Field Biology Lab, Pitkin County, City of Aspen, The Twin Lakes Reservoir and Canal Company (Twin Lakes Co.), the Southeastern Colorado Water Conservancy District, BOR, USGS, and USFS to address hydrologic alteration in the Upper Roaring Fork River Sub-Watershed. The major streams in the Upper Roaring Fork River Sub-Watershed are often de-watered, and biologically and geomorphologically important peak flows are virtually non-existent due to large amounts of these headwater streams being diverted into the Arkansas Watershed (Figure 18).

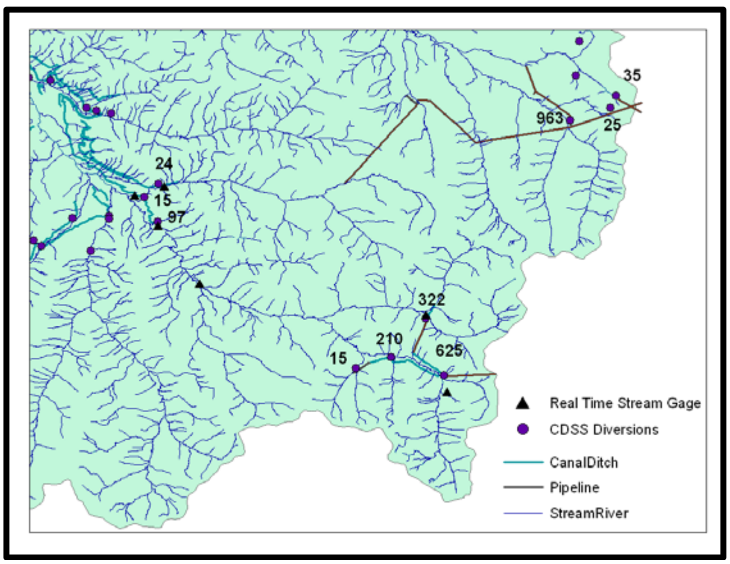


Figure 18. Upper Roaring Fork River Sub-Watershed trans-mountain diversions. (Numbers are decreed amounts in cfs)

The Twin Lakes Co. collects snow melt from 45 square miles of the Upper Roaring Fork River Sub-Watershed. About 12 miles of tunnels, culverts, and ditches comprise the Independence Pass Tran-mountain Diversion System, which sends water to Grizzly Reservoir and then through the Continental Divide to the Arkansas Watershed. The average amount diverted based on data from 1938-2004 is 39,245 acre-feet, and from 1994-2004 is 36,111 acre-feet. In 1993 the maximum amount of 62,671 acre-feet was diverted.

In the early 1960s with the construction of the Fryingpan-Arkansas Project, an attempt was made to mitigate for losses to the Hunter Creek system within the Operating Principles of the Fryingpan-Arkansas Project. Appendix N has the text of the relevant operating principle. The

U.S. Fish and Wildlife Service and the Colorado Game and Fish Commission recommended minimum average flows (see table in Appendix N) and stated that “in maintaining the recommend averages, at no time shall the flow be reduced below 15 cfs during the months of August to April, inclusive, or below 60 cfs during the months of May to July inclusive, providing the natural flow during the said period is not less than these amounts.” The obligation to supply these minimum stream flows on the Roaring Fork River is limited to 3,000 acre-feet annually.

The 3,000 acre-feet will not restore pre-developed flows to the diverted streams in the Upper Roaring Fork River Sub-Watershed. However, progress is being made in developing a flow prescription based on the 3,000 acre-feet. The aforementioned partners have met and participated in a field trip to discuss alternatives. Table 5 is the interim flow prescription for the summer of 2005 and winter of 2006. These are being refined as better information is made available.

Table 5: Interim Flow Prescriptions for the Summer of 2005.

Dates	Roaring Fork (cfs)	Lincoln (cfs)
Jun 1-7	1.5	2
Jun 7-30	4	4
Jul 1-14	4	4
Jul 15-31	4	4
Aug 1-14	4	6
Aug 15-31	4	3
Sep*	2.1	2.1

The winter 2006 flow prescription calls for ~3 cfs to be released from Grizzly Reservoir into Lincoln Creek.

The outstanding issues are:

- Is 3,000 acre-feet enough water to help stream reaches within Lost Man Creek, the Roaring Fork River, and Lincoln Creek?
  If not, should the focus be on the Roaring Fork River and Lincoln Creek?
- What are the existing and desired aquatic/riparian species and communities and what are their flow requirements?
- How can water be more accurately measured at the Roaring Fork above Lost Man Gage; and could a new USGS innovation using a trace chemical work to determine stream flows more reliably?
- How would costs be shared for new gages or improvements?
- How much would it cost to improve outlet works at the Lost Man and the Roaring Fork dams? Who would pay for this work?
- What is the best timing for releasing the 3,000 acre-feet?
- Would an occasional “flushing flow” benefit aquatic habitat and dependent fish species?
- How can altered management alleviate effects of sudden releases from Grizzly Reservoir on scouring of Lincoln Creek and the Upper Roaring Fork River?
- How can altered management re-establish floodplain recharge in the North Star area and other alluvial areas along the Upper Roaring Fork River?

Lower Crystal River Sub-Watershed

The 2002 drought underscored the need for improved flows in the Lower Crystal (Figure 19). Several meetings have been held to identify issues and potential options to restore flows to the Lower Crystal River. A preliminary seepage study was performed on two of the major ditches and the results showed ditch gains, most likely due to the timing of the study. Additional funding is needed to complete a follow-up study earlier in the year. Last winter the Conservancy met with TNC and CWT to determine how we could work together to improve flows. CWT has taken the lead on developing a strategic plan for this work (Appendix O).

Crystal River Basin Diversions

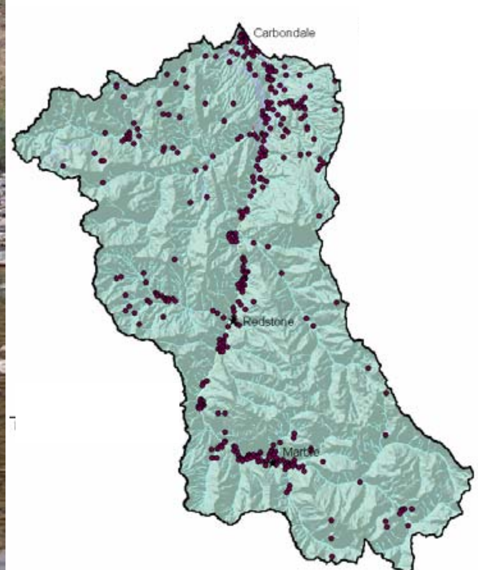


Figure 19. Crystal River

Discussion and Conclusions

Water is and continues to be the focus of many news articles and legislative activities. Too much or too little water can have economic and environmental consequences. But how much water do we need? How much water does a river need? These questions are one in the same. As Sandra Postel points out in her book *Liquid Assets: The critical need to safeguard freshwater ecosystems*" (2005), rivers, lakes, wetlands and other freshwater ecosystems provide a host of benefits to society. They supply and support drinking water, agricultural needs, and fish populations; store seasonal floodwaters helping to lessen flood damages; recharge ground water supplies, which can ensure that drinking water is available during dry spells; filter pollutants and purify drinking water; and provide diverse habitats that support the myriad species performing much of this ecological work. In a recreation-driven economy such as the Roaring Fork Watershed, water also provides substantial economic benefits from activities such as angling, boating, and snowmaking.

In 1973, recognizing the need to correlate the activities of mankind with some reasonable preservation of the natural environment, the State of Colorado vested the CWCB with the authority to appropriate or acquire such waters of natural streams and lakes as may be required to preserve the natural environment to a reasonable degree. The CWCB Instream Flow Program has acquired water rights on many of the major streams in the Roaring Fork Watershed. CWCB instream biological flow recommendations are based on the premise that the water needed to preserve an aquatic indicator species, like a trout, is the same amount of water necessary to preserve the entire natural environment. The goal of preserving the environment to a reasonable degree is hampered because the CWCB's relatively junior water rights are not always met and the importance of other inchannel and over-bank indicators of the natural environment is not explicitly recognized. Senate Bill 156, passed in 2002, expands opportunities for instream flow protection. The law allows CWCB to acquire or accept donations of senior water rights to improve the health of Colorado's rivers.

In 2003, the Colorado General Assembly commissioned an 18-month study (SWSI) to explore, basin by basin, existing supplies and existing and projected demands through the year 2030. The SWSI team identified four issues that needed more attention: water efficiency in agriculture and municipal uses, alternatives to permanent dry-up of agricultural lands; quantification of recreational and environmental needs, and the gap between future water use and available supplies. Obviously, the quantification of recreational and environmental needs is a necessary component of the assessment of the gap between future water use and available supplies. Four technical round tables have been formed to address these issues.

These four round tables will provide technical information to a newer complementary effort, House Bill 1177-Colorado Water for the 21st Century Act. HB 1177 initiates statewide discussions on how water may be managed and shared among river basins to meet future water demands.

Answering the question "How much water does a river need?" is a central component to all three efforts. *Rivers for Life: managing water for people and nature* by Postel and Richter (2003) discusses the evolution of the natural flow regime paradigm. As put forth by Poff and his colleagues (1997), the natural flow regime meets the needs of all river species over the course of seasons, years, decades, and centuries by the natural variations in a river's flow. Recognizing that returning to natural flow conditions in many cases is unlikely, they suggest developing a set of flow prescriptions based on 1) the size, frequency, timing, duration, and year to year variation in the natural flow regime 2) desired levels of ecosystem protection, and 3) likely ecological consequences of potential flow regimes. Lastly, they suggest an adaptive management approach, in other words learning by doing.

A natural flow regime is discerned from examining the river's natural hydrograph using data from relatively unimpacted streams, data prior to an impact, or data that models pre-developed conditions. Hydrologic alteration occurs when current conditions differ significantly from the natural flow regime. This study examined long-term stream flow data and compared modeled pre-developed and developed monthly flow data to provide a broad-scale assessment of hydrologic alteration and an indication of the natural flow regime with regard to magnitude and timing of flows. Results show where and when the greatest hydrologic alterations are. Gage data was also compared to ISF instream flow rights to determine where, when, and how often these rights are met. The results allow us to target more in-depth analyses and restoration efforts in areas that are the most altered and protection efforts in relatively unimpacted areas. This study is crucial to reaching the overall Project goal of **responding to instream flow issues and pursuing approaches for achieving sustainable stream flows.**

Forty-five percent of nodes ranked as having severe hydrologic alteration in the summer. Severe alteration was seen in all sub-watersheds with the exception of the Snowmass Creek Sub-Watershed. Sixty four percent of the nodes had lower developed than pre-developed flows. Only September at the Fryingpan below Ruedi Reservoir node had higher developed flows than pre-developed flows. Instream flow amounts were not entirely met at the Fryingpan River near Thomasville, Fryingpan River at Meredith, Roaring Fork above Lost Man, Lincoln Creek, Hunter Creek, and Crystal River at Carbondale gages. Irrigation, municipal uses, or trans-mountain diversions are associated with the summer hydrologic alteration.

Forty-two percent of nodes had no detectable hydrologic alteration in the fall. Twelve percent of nodes had higher developed than pre-developed flows and nine percent had both higher and lower developed flows. The higher flows are associated with agricultural return flows or Ruedi Reservoir operations. The four nodes with severe hydrologic alteration and having lower developed than pre-developed flows are associated with the Twin Lakes Trans-Mountain Diversion, snowmaking activities, or municipal water supply. CWCB instream flow levels were not entirely met in the fall at the Fryingpan near Thomasville, Fryingpan at Ruedi, Roaring Fork above Lost Man, Lincoln Creek, Roaring Fork above Difficult Creek, Roaring Fork near Aspen, Hunter Creek and Crystal River below Carbondale gages.

Sixty-four percent of the nodes had no detectable alteration in winter. The remaining 35 percent were split evenly between having higher and lower developed flows than pre-developed flows. The six nodes that had more flows were either due to agricultural return flows or Ruedi Reservoir operations. The three nodes that had both higher and lower developed flows than pre-developed flows are most likely caused by continued diversions through October followed by return flows. Lower flows can be attributed to one of three sources: trans-mountain diversions, snowmaking, and municipal uses. Instream flow amounts were not always met over the three months for all of the gages influenced by trans-mountain diversions.

In spring, 61 percent of the nodes had significantly lower developed than pre-developed flows in at least one month, 36 percent had no change from pre-developed flows, and three percent had both higher and lower developed flows. Eighteen percent of the nodes had significant hydrologic alteration in all three months. Severe hydrologic alteration was seen from trans-mountain diversions, municipal water supply and irrigation. Spring hydrologic alteration from irrigation withdrawals seem to occur at lower elevations. CWCB instream flow amounts were not met for all three months at the Lincoln Creek below Grizzly Gage. In April, the instream flow amounts were also not met or met less than 50 percent of the time at the Roaring Fork above Lost Man, Chapman Gulch, Fryingpan near Thomasville, Fryingpan at Meredith and Hunter Creek gages.

The IHA and hydrologic alteration analyses provided similar flow results for the Roaring Fork River at Glenwood Springs and Roaring Fork at/near Aspen gages. Although the IHA analysis for the Roaring Fork River at Glenwood Gage did not identify a significant difference in flows for October, July, and August, the hydrologic alteration analyses did. Several factors contribute to this. The IHA analysis parses the data into two time periods using a single impact date whereas modeled data used in the hydrologic alteration analyses estimates both developed and pre-developed flows for the same time period. The data used for the IHA analysis extends through 2004 and data used for the hydrologic alteration analyses extended through1996. The IHA analysis for these three gages provides an opportunity to see the comprehensive flow analyses that this software produces such as magnitude and duration of annual extreme water conditions, timing of annual extreme water conditions, frequency and duration of high and low pulses, rate and frequency of water condition changes, monthly low flows, extreme low flows, high flow pulses, small floods, and large floods. The hydrologic alteration analyses using modeled data on pre-developed and developed flows gave a better representation of flow conditions throughout the watershed. The ISF analysis compliments these other two, pinpointing reaches where these flows are not met.

Future Work

This study's results will be presented to the Collaborative and made available on the Roaring Fork Conservancy's website and incorporated into outreach presentations within the next few months. These data will provide information on water quantity for a proposed watershed plan. In addition, assessment of overall aquatic health using information from ongoing and past studies is a necessary component of the plan. Results from this study will be integrated with available data on water quality, inchannel and riparian habitat condition, channel stability, and biodiversity. National Hydrography Data (NHD) provides a framework to compile these data for analysis and display (Appendix P). Powerful graphics and analysis are needed to engage the public, decision makers, land managers, and other stakeholder groups.

We will continue to identify and pursue flow protection and restoration options in the Upper Roaring Fork and Lower Crystal River watersheds. Based on the overall assessment of aquatic health and the results of the watershed plan, additional areas may be targeted for protection or restoration. Targeted studies are needed in these flow altered areas to discern the specific impacts of flow alteration on biological and geomorphological processes. These studies would provide the baseline for a monitoring program. Monitoring is an essential component of an adaptive management approach to improving flows.

We look forward to using and refining the results of this study in continuing toward the overall Project goal. This study quantified hydrologic alteration throughout the watershed. The next step is to obtain the CDSS StateMod updated monthly and new daily data. This data will be imported into the IHA for more in-depth analysis. The advantages of these data are: 1) the daily time step will allow a more complete suite of hydrologic parameters to be calculated; 2) the ability to compare pre-developed flows to developed flows for the same years so comparisons are not influenced by climatic variations and the influence of multiple and chronic impacts can be evaluated; 3) an extension of the period of record from 1996 to 2003 or 2004; and 4) improved distribution of nodes throughout watershed.

This study points out the need for more stream flow gages in the watershed and consistency in data output formats for stream gage data. Needed gages in approximate order of priority are: the

Roaring Fork River above the confluence with the Fryingpan River; Brush, Snowmass, Cattle, Four Mile, Three Mile, Sopris, and Coal creeks. For these creeks, gages should be located close to their confluences. The CDWR and CWCB are working on a plan to better gage the lower Crystal River. Currently the gage on the Crystal River below Carbondale is influenced by return flows and does not represent low flow conditions immediately upstream. Ongoing work in the Upper Roaring Fork River is assessing the need for improved flow measurement techniques for stream reaches experiencing conditions such as a constrained, high gradient channel with large boulder substrate in low flows influenced by ice.

As we progress toward the overall project goal we will provide updates to the Collaborative and on our web site and incorporate these into outreach presentations. We welcome any feedback you have on the project.

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GIS Map servers related to stream flow and related projects

Colorado River Water Conservation District gage page:
http://www.southwestdata.org/Website/crwcd/GagePage/viewer.htm
U.S. Geological Survey Colorado Water Science Center: Directory of Project Information and Data-Collection Sites
http://co.water.usgs.gov/Website/projects/viewer.htm
Colorado Decision Support System Map viewer: http://cdss.state.co.us/DNN/MapViewer/tabid/62/Default.aspx
U.S. Geological Survey Streamstats: http://water.usgs.gov/osw/streamstats/