HEALTHY RIVERS AND STREAMS
CITIZENS ADVISORY BOARD

Courthouse Plaza Building
Plaza 1
Aspen, CO
February 16, 2012 - 4 p.m.

4:00	**Public Comment**	
4:05	**Board Comment**	
4:15	**Approval of Minutes** January 19, 2012 meeting	
4:20	**Pitkin County Stream Health Methodology** Greg Espegren, Aquatic Specialist and Lee Rozaklis, Hydrologist AMEC Environment and Infrastructure	
	Executive Session a. Aspen Hydro Project C.R.S. 24-6-402 (4)(b)	
	Discussion of drought relief from instream flows	

Upcoming 2012 regular meeting dates
March 15
April 19
May 17

HEALTHY RIVERS AND STREAMS CITIZENS ADVISORY BOARD
Meeting Minutes
January 19, 2012
Aspen, CO

Board members present: Ruthie Brown, Greg Poschman, Lisa Tasker, Andre Wille, Rick Neiley, Bill Jochems, and Steve Hunter

Board members absent: None

Others present: John Ely, Lisa MacDonald, Michael Owsley, Bill Miller

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Discussion of Reports on Roaring Fork River Health Study and Northstar Assessment - Bill Miller of Miller Ecological Consultants presented a powerpoint to the Board on the results of his river health and geomorphic assessments on the Roaring Fork River. Mr. Miller has been working on two projects for the River Board analyzing the RF through three different flow regimes. The methodology Mr. Miller employed is the latest science for analyzing flows.

The Northstar objective was to look at geomorphic assessment of impacts of groundwater changes on wetlands and grasslands along the valley floor and evaluate the current characteristics of the Roaring Fork River within Northstar Nature Preserve. The river health study objective was to determine baseline river health conditions.

Mr. Miller discussed the results of his studies and provided recommendations to the Board.

Appointment of Chair and Vice Chair for 2012

Greg Poschman volunteered to Chair the Board. Approval by unanimous acclamation.
Bill Jochems volunteered to be the Vice-Chairman. Approval by unanimous acclamation.

Approval of Minutes

Mr. Jochems moved to approve the minutes from October 20, 2011, November 17, 2011 and December 6, 2011. Ms. Brown seconded the motion. The motion passed 7 to 0.

Discussion of Colorado River Basin Water Supply and Demand Study

The Board discussed the request for comments regarding the study. The study highlights methodologies for closing the gap, so comments might be along the assumptions that were used to define the gap to solutions that are organized to try and meet that supply and demand. An opinion letter is due February 1, 2012 if the Board has comments.

Mesa Land Trust request for participation in Amicus Brief

The Board received a request on behalf of Mesa Land Trust (MLT) asking for support from the land trust community in filing an amicus curiae (friend of the court) brief with the Colorado Court of Appeals, in the case of *Mesa County Land Conservancy v. Sam A. Allen, et al*, Colorado Court of Appeals Case No. 2011CA1416. On June 2, 2011, the Mesa County District Court entered a final order in favor of MLT compelling the water rights in question remain tied to the land, as required by the conservation easement. The property owner wants the ability to dry the land and then transact the water. There is a request to recommend to the Board of County Commissioners to lend its name and support to the amicus brief.

Mr. Neiley moved to recommend to the Board of County Commissioners participation in the amicus brief. Mr. Wille seconded the motion. The motion passed 7 to 0.

Executive Session

Mr. Neiley moved to enter into executive session pursuant to C.R.S. § 24-6-402 (4)(b) for the purpose of discussing the Aspen Hydro Project and Aspen Diligence Water Application, Chairman Poschman seconded the motion. Motion passed 7 to 0.

Adjourn

The meeting adjourned at approximately at 6:45 pm.

Approved:	**Attest:**
Greg Poschman – Chairman Healthy Rivers and Streams Board	Lisa MacDonald

A Scientific/Social Framework
for Managing Impacts of Trans-Basin Water Diversions
to Protect Stream Health in Pitkin County, Colorado

February 2012

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A Scientific/Social Framework for Managing Impacts of Trans-Basin Water Diversions to Protect Stream Health in Pitkin County, Colorado

Introduction

This report was prepared in response to the Pitkin County Healthy Rivers and Streams (HRS) Board's interest in developing a framework that can be used to analyze, evaluate and manage the potential impacts of water diversions to protect the aquatic health of streams in Pitkin County.

While all diversions deplete stream flows to some extent, the HRS Board is particularly concerned about trans-basin diversions, which are 100% depletive to the basin of origin. Three major trans-basin diversion projects currently divert water from the Roaring Fork watershed: the Fryingpan-Arkansas Project, the Busk Ivanhoe System and the Independence Pass Transmountain Diversion System (Driscoll 2011)[1]. Driscoll notes that these projects currently divert over 40% of the native flow from the Roaring Fork and Fryingpan River headwater tributaries and that "each of the projects is still incomplete, with undeveloped conditional water rights, excess diversion capacity, and even major structural components that could yet be built".

We begin this paper with a brief discussion of current science regarding stream flow regimes and healthy streams and the practical implications of applying that science to managing impacts of water diversions to protect stream health. We conclude that evaluation and management of impacts of water diversions to protect stream health must necessarily be an ongoing process that involves scientific and social considerations as well as ongoing monitoring and adaptive management. Based on this conclusion, we recommend that the HRS Board adopt a scientific/social decision-making framework, combined with monitoring and precautionary adaptive management to accommodate the needs of water development while maintaining healthy streams. We then describe our recommended framework and illustrate its application utilizing the City of Aspen's proposed Castle Creek Hydropower facility as an example.

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[1] A fourth trans-basin diversion project – the Homestake Diversion Project - also diverts water from the upper Homestake Creek watershed in Pitkin County.

Stream Flow Regimes and Healthy Streams

In 1973, Colorado recognized instream flow as a beneficial use of water and vested the Colorado Water Conservation Board (CWCB) with the exclusive authority to appropriate water rights as may be required for minimum stream flows that "preserve the natural environment to a reasonable degree" (CRS 37-92-102(3))[2]. The CWCB and Colorado Division of Wildlife typically use the R2Cross methodology to quantify such minimum flows to appropriate instream flow rights (Espegren 1996). However, Colorado's application of the R2Cross methodology for this purpose typically results in one or two specified minimum flow rates covering the entire year for a given stream segment, which does not address the more complex and variable flow regime needed to maintain stream health. The use of R2Cross as a habitat modeling tool has been criticized by the science community as not addressing flow needs for intra- or inter-annual hydrologic variability and not providing the necessary variable flow regime critical to riverine ecology (IFC 2002). Scientists now recognize that "the naturally variable flow regime, rather than just a minimum flow, is required to sustain freshwater ecosystems" (Poff et al., 2010).

Today, it is generally accepted that it is in society's best interests to consider both aquatic/riparian ecosystems and humans as legitimate "users" of freshwater (Arthington et al., 2006). While scientists often refer to stream flow as "the master variable" (Poff et al., 1997) or the "maestro…that orchestrates pattern and process in rivers" (Walker, Sheldon & Puckridge, 1995), they also recognize that a *healthy stream* is "an ecosystem that is sustainable and resilient, maintaining its ecological structure and function over time while continuing to meet societal needs and expectations" (Meyer 1997). Scientists have also defined *environmental flows* as "the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihood and well-being that depend on these ecosystems" (Poff et al., 2010). These definitions lead to the conclusion that a *healthy stream* can exist with appropriate *environmental flow* protection while also serving human uses. Given the limited availability and critical importance of flowing water ecosystems in semi-arid Colorado and the range of available water supply alternatives for meeting human needs, healthy streams in Pitkin County should be defined in a manner that accommodates human needs to the extent that does not significantly impact aquatic and riparian ecosystems.

Scientists have determined that stream flow modifications can induce ecological alterations (Poff et al., 2010). However, they also recognize that it is often difficult to determine which attributes of an altered flow regime are directly responsible for aquatic impacts (Bunn and Arthington 2002). Based on a global literature review of 165 scientific papers on ecological responses to altered flow regimes, Poff and Zimmerman (2010) conclude that while existing literature does not support the development of general, transferable quantitative relationships between flow alteration and ecological response, sufficient evidence exists to infer that "flow alteration is associated with ecological change and that the risk of ecological change increases with increasing magnitude of flow alteration."

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[2] More recently, the Colorado legislature has expanded the scope of the CWCB's authority when it comes to acquiring water, water rights, or interests in water from others (as opposed to appropriating new instream flow rights). The CWCB can now engage in such activities "to preserve <u>or improve</u> the natural environment to a reasonable degree."

A Scientific/Social Decision-Making Framework

These two conclusions – that healthy streams can accommodate some amount of human needs without significantly impacting aquatic and riparian ecosystems, and that reliable ‘cookbook’ formulas for quantifying environmental flows are not yet available – have led scientists to propose a decision-making framework that combines scientific and social considerations with adaptive management to evaluate, quantify and manage the relationships between flow alteration and stream health.

Two examples of such a decision-making framework include the Ecologically Sustainable Water Management (ESWM), proposed by Richter et al (2005), and the Ecological Limits of Hydrologic Alteration (ELOHA), proposed by Poff et al (2010). Both examples have received attention in the scientific and water management literature and are summarized below.

Summary of Ecologically Sustainable Water Management (ESWM)

Richter (2005) states that ESWM “is built on the understanding that societal values for a river are optimized when water is stored, diverted, and released in a manner that meets human needs for energy production, water supply, and other municipal and industrial needs while maintaining adequate flows to sustain a healthy ecosystem.”

Richter designed ESWM as a tool to guide hydropower owners through a three-phase framework for ecologically sustainable water management. As such, the focus of Richter’s 2005 paper is using ESWM within the Federal Energy Regulatory Commission’s hydropower relicensing process. However, ESWM can be broadened and applied in other decision-making processes where the goal is to manage the impacts of a specific water diversion project to ensure protection of the aquatic environment.

The ESWM framework consists of a **Problem Definition** phase where ecosystem flow requirements are compared against the impact of human activities to identify potential areas of incompatibility. It then moves into a **Search for Solutions** phase where collaborative dialogue is encouraged and manipulative experiments are conducted in an attempt to identify potential solutions to these areas of incompatibility. The last phase is **Adaptive Management** where the impacts of water diversions on aquatic health are balanced and fine-tuned over time using an iterative monitoring and adaptive management plan, which requires sufficient governance authority and funding support.

Summary of Ecological Limits of Hydrologic Alteration (ELOHA)

The ELOHA framework reflects the consensus view of the international scientific community of a process for developing and implementing environmental flow standards at a regional scale. ELOHA is grounded in several important scientific foundations:

- The natural variable stream flow regime has been identified as the most important determinant of river ecosystems.
- There is a rich tool box available for hypothesizing flow alteration-ecosystem response relationships and identifying environmental flow needs.

- There is a sound conceptual foundation for doing regional flow assessments based upon river classification.
- Hydrologic models of appropriate sophistication are necessary for this work and are readily available.
- Sustainable water management requires a collaborative and ongoing socio/scientific management and governance process.

The ELOHA framework consists of a scientific process, a social process and a monitoring and adaptive management feedback loop. The scientific process establishes a hydrologic foundation for analysis, classifies rivers based upon their hydrologic and geomorphic aspects, analyzes flow alterations that would be caused by a given development proposal, and suggests flow alteration-ecosystem response relationships for each river type. The social process identifies societal values, water management needs and acceptable ecological conditions; establishes environmental flow standards, and creates the necessary implementation structures and agreements for applying those standards. The monitoring and adaptive management feedback loop provides a means for fine-tuning environmental flow standards over time through ongoing monitoring and refining of flow alteration-ecosystem response relationships and adjustment of project operations.

Poff recognizes that scientific uncertainty exists in the flow alteration-ecological response relationships and suggests that these relationships will need to be developed over time by combining information from existing hydro-ecological literature, expert knowledge and field studies across gradients of flow alteration. As such, the ELOHA process must take place in an environment where stakeholders are willing to evaluate acceptable risk as a balance between ecological goals, economic costs, and scientific uncertainties associated with the relationships between flow alteration and aquatic health.

The ESWM and ELOHA frameworks are similar in structure as both rely on a combination of scientific knowledge and social values to find a balance between ecological flow requirements and water management schemes. They also both utilize an iterative monitoring and adaptive management plan approach to fine-tune stream flow requirements over time.

Recommended Framework

There is an inherent interaction between science and society built into the ESWM and ELOHA frameworks. Our review of the literature shows that scientists believe this interaction is necessary to achieve a balance between aquatic health and human water needs. They also believe that an iterative monitoring/adaptive management approach is necessary because of: (1) the uncertainty in the relationship between altered flows and ecological response, and (2) the likelihood that ecological flow requirements will vary between individual streams and water development projects. We therefore recommend that the HRS Board adopt a decision-making framework derived from the ESWM/ELOHA frameworks to address water development needs while assuring protection of the aquatic health of streams in Pitkin County. Our recommended decision-making framework is depicted as a series of steps and sub-steps in Figure 1 below.

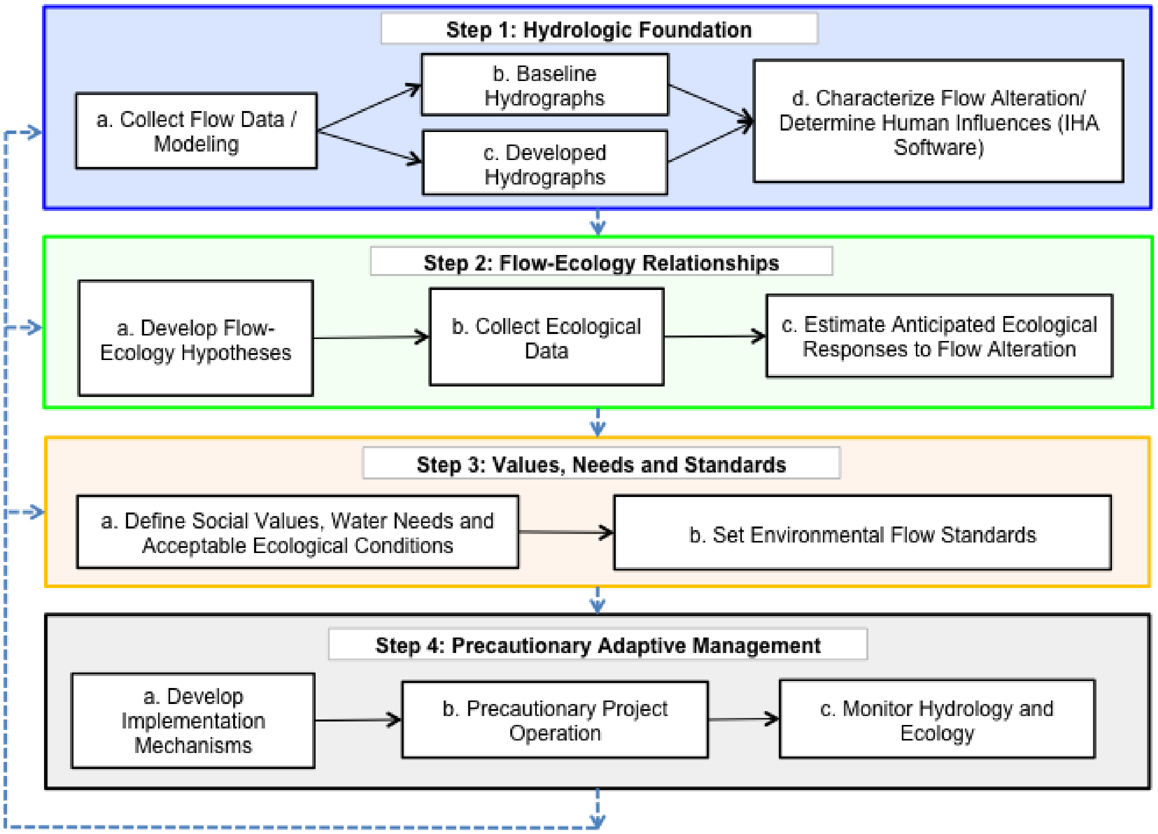

Figure 1: Recommended Decision-Making Framework

There are four primary steps in our recommended framework: (1) developing a hydrologic foundation, (2) establishing flow-ecology relationships, (3) instituting a scientifically supported social process to articulate an acceptable balance between protecting stream health and meeting water development needs, and (4) implementing a precautionary adaptive management process. Steps 1 through 3 are followed in progression to develop an initial set of acceptable flow standards that address all aspects of the natural flow hydrograph needed to maintain healthy streams (Step 3b). These initial flow standards are then implemented and become part of an iterative, monitoring and adaptive management feedback loop (Step 4). Each step is described in greater detail below.

We note that the process illustrated above and described below could be implemented both in a reactive manner, in response to a specific trans-basin diversion proposal, and (particularly Steps 1 – 3) as part of a pro-active effort by Pitkin County and local stakeholders to better define water needs for stream health prior to and in anticipation of future trans-basin diversion proposals.

Step 1: Hydrologic Foundation

Establishing a hydrologic foundation is an essential component in assessing the impacts of flow alteration upon stream health and necessarily involves hydrologic modeling based upon relevant stream flow data. In this step, the natural and pre-project stream flow regimes and the effects of a trans-basin diversion proposal upon those stream flow regimes would be characterized.

Step 1a: Flow Data and Modeling

A hydrologic model is a key component of our recommended framework. It is essential for characterizing the stream flow regime, water potentially available for diversion, and changes in stream flow attributable to diversions and human activities. Hydrologic modeling should meet the following general requirements:

- Modeling should cover a hydrologic study period of at least twenty years, which should include representative wet years and dry years, in order to capture a representative range of natural flow conditions.
- Stream flow should be modeled on a daily time step and should be based upon actual stream gage records representative of the proposed diversion location, in order to realistically model short-term flow variations. While predictive models may be useful for estimating daily flows for ungaged streams (Sanborn and Bledsoe 2006), such models should be verified by measurement of stream flows at or near the proposed project location for a period of at least five years, which period should include wet years and dry years.
- Modeling should produce results at the proposed diversion location and at strategic downstream locations where changes in hydrology, geomorphology and/or aquatic health are likely to occur due to diversions, storage, return flows, inflow from surface tributaries or surface water/groundwater interactions.

Steps 1b and 1c. Baseline and Developed Hydrographs

Hydrologic modeling should be used to produce stream flow time series for three conditions: natural flows, pre-project (which should reflect flow alterations attributable to existing projects/activities), and post-project (which should reflect incremental flow alterations attributable to the proposed project). In cases where the effects of existing diversions and human activities are minimal, pre-project conditions can be considered to be the same as natural flow conditions. Development of hydrographs for these three conditions will facilitate examination of incremental and cumulative impacts.

Step 1d. Characterize Flow Alteration

Computer software, like the Nature Conservancy's Indicators of Hydrologic Alteration (IHA) (Richter et al 1996) should be used to quantify the range of variability for natural flow, pre-project and post-project conditions, and the degree of change between conditions (Richter et al., 1997). IHA generates a statistical characterization of temporal variability for 33 biologically relevant hydrologic parameters and provides a straightforward way of comparing those parameters for natural, pre-and post-project stream flow regimes. These parameters capture changes in five fundamental characteristics of the natural flow regime; magnitude, timing, frequency of occurrence, duration, and rate of change.

One option that may be suitable on some stream segments for evaluating changes in IHA parameters between natural, pre- and post-project conditions is the Range of Variability Approach (RVA) (Richter et al., 1997). The RVA utilizes IHA output to set initial post-project flow management targets as +/- one standard deviation from mean pre-project values, or between the 25th and 75th percentiles of pre-project flow ranges, for ecologically important IHA flow parameters. The RVA was intended to develop initial flow targets to "jump-start" an adaptive management plan in instances where little or no ecological information was available to support flow determinations. Recently, the Nature Conservancy utilized the RVA approach to set initial targets for certain aspects of environmental flows (within 25th and 75th percentiles of pre-project values) as part of a collaborative evaluation of a proposed water development project in Colorado (The Nature Conservancy of Colorado, 2008). It should be noted that the RVA should be considered only as an evaluation 'starting point' for determining flow needs for healthy streams, and that it may not be an appropriate 'starting point' for all stream segments.

The IHA software can also be used to calculate 34 additional flow parameters that describe five environmental flow components[3] (EFCs). These EFCs were added to "complement the original 33 IHA parameters and characterize the hydrograph in a manner representative of key flow-ecology relationships" (Mathews and Richter, 2007):

1. Low (base) flows: determine the amount and characteristics of habitat that is available for most of the year.

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[3] Low flow and extremely low flow EFCs may be the most important parameters to consider on unregulated streams where the greatest threat to environmental health are simple water diversions that are not likely to significantly affect high flow EFCs. On streams regulated by dams, high flow EFCs may also be important considerations.

2. Extreme low flows: droughts that may alter water chemistry, concentrate prey species, dry out floodplains, elevate water temperatures, diminish dissolved oxygen, and restrict movement.
3. High flow pulses: rain and snowmelt provide respite from stressful low flows, lowering elevated water temperature, increasing oxygen supplies, flush wastes, and improve upstream and downstream access.
4. Small floods: overbank flows every 2-10 years allowing access to floodplains and backwater/slough habitats with significant food resources providing fast growth, velocity refuge, spawning and rearing habitat and recharge shallow aquifers.
5. Large floods: occur rarely, but are critical to healthy aquatic habitat. Move sediment and woody debris, form new habitats and refresh water quality conditions in main channel and floodplains. May also be detrimental (scour spawning beds, flush organisms downstream, remove vegetation) but are necessary from time-to-time.

Olden and Poff (2003) performed a comprehensive review of 171 indices of hydrologic alteration. They acknowledged that many of the 171 parameters they evaluated are difficult to calculate and they found merit in automating these calculations using the IHA software. Lastly, they concluded that “one can select a subset of optimal indices based on ... the region and the particular ecological question being asked.” For snowmelt streams like those found in the Roaring Fork River basin, Olden and Poff found the following IHA indices to be most important in explaining changes between pre-and post-project hydrologic impacts:

1. Coefficient of variation for the month of March,
2. Mean monthly flows for September, October, November, December,
3. Annual minimum flow of 90-day duration,
4. Average duration of low flood (<25th % percentile) pulse count, and
5. Average rate of rise and fall.

Sanderson et al. (2011) developed a Watershed Flow Evaluation Tool (WFET) specific to Roaring Fork River basin streams and found the following IHA flow metrics most useful in their IHA analysis:

1. Mean annual flow,
2. Mean August flow,
3. Mean September flow
4. Mean January flow,
5. Mean annual peak daily flow.

The subset of flow metrics identified by Olden and Poff (2003) and Sanderson (2011) should be given primary consideration for snowmelt streams like those found in the Roaring Fork River basin. However, since the IHA software calculates all 33 IHA parameters and 34 EFC parameters automatically, we suggest that all parameters be given consideration as different types of water development projects will alter the natural flow regime differently.

Mathews and Richter (2007) encourage the use of IHA as an interactive tool to explore flow-ecology relationships. They suggest that IHA can be used to quickly characterize natural flow conditions and habitats to which native species have adapted. The output from this initial IHA analysis establishes a hydrologic baseline that can be used to develop hypotheses about flow-ecology relationships and the likely effects of altered flow conditions upon those relationships, which is an important next step in the modified ESWM/ELOHA adaptive management process.

Step 2: Flow-Ecology Relationships

As mentioned previously, scientists believe that sufficient evidence exists to infer that flow alteration is associated with ecological change and that the risk of ecological change increases with increasing magnitude of flow alteration (Poff and Zimmerman 2010). Therefore, the second step in our recommended framework is to develop flow-ecology relationships specific to Pitkin County streams and stream segments that would be the affected by proposed trans-basin diversions.

Step 2a. Develop Flow-Ecology Hypotheses

The first sub-step would be to develop hypotheses for relationships between stream flows and the aquatic and riparian ecosystems of potentially affected streams/stream segments. While responses to potential changes in all major statistical aspects of the natural flow regime should be addressed, the flow parameters of particular relevance to Pitkin County streams (as defined in Step 1d) should be the primary area of focus.

Bunn and Arthington (2002) suggest four principles that describe how aquatic biodiversity can be influenced by flow regimes:

- Principle 1: Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition.
- Principle 2: Aquatic species have evolved life history strategies primarily in direct response to the nature flow regimes
- Principle 3: Maintenance of natural patterns of longitudinal and lateral connectivity in streams is essential to the viability of populations of many riverine species, and
- Principle 4: The invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes.

Figure 3 (on the following page) illustrates the ecological connections between aquatic biodiversity and the natural flow regime as proposed by Bunn and Arthington (2002).

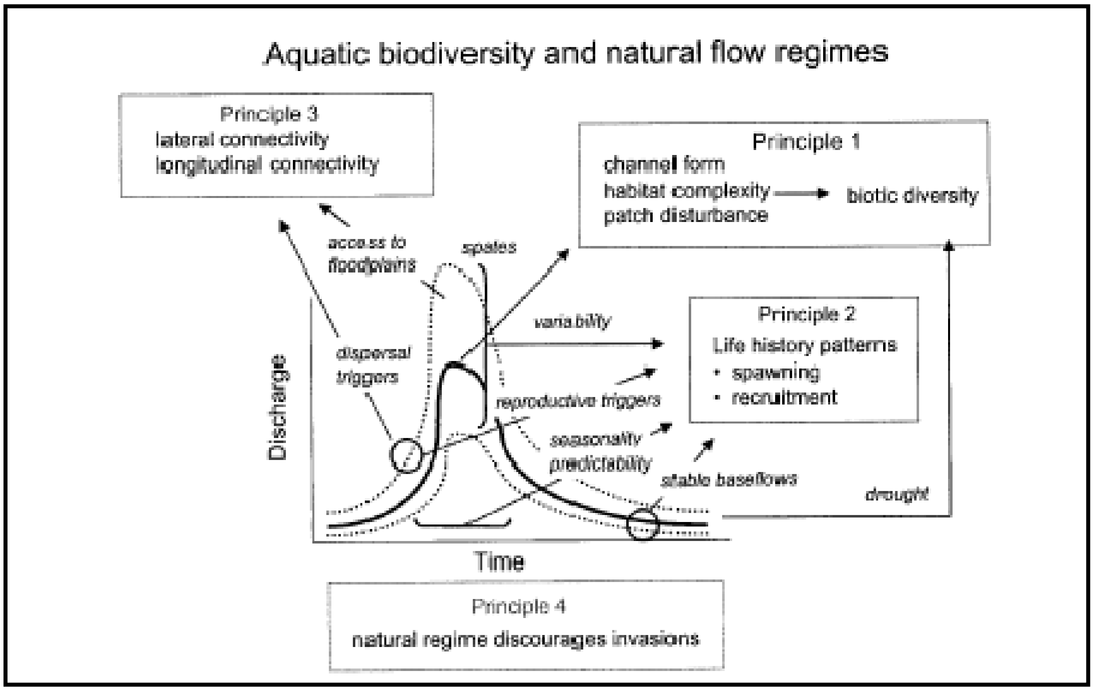

Figure 3. Aquatic biodiversity and natural flow regimes from Bunn and Arthington (2002)

With these general ecological principles in mind and the natural flow IHA analysis in hand, an interdisciplinary team of biologic and hydrologic experts would develop a set of hypotheses regarding how the aquatic and riparian ecology of the stream is likely to respond to the potential changes of various aspects of the flow regime. In developing hypotheses, experts would rely upon previous experience, literature values, and findings from previous field studies conducted in Pitkin County.

Step 2b. Collect Ecological Data

The expert team would also specify any additional field data collection/studies needed to test the flow-ecology hypotheses formulated in Step 2a and the predicted flow-ecology responses developed in Step 2c. Such data collection efforts and field studies should be initiated well in advance of any formal consideration of a proposed project, and should be site-specific and of sufficient duration to generate meaningful results that cover a representative range of hydrologic and habitat conditions.

Step 2c. Predict Ecological Responses to Proposed Flow Alterations

The results of the IHA flow alteration analysis should be used to highlight the component(s) of the natural flow regime that would be altered by an existing or proposed water diversion project. Combining the IHA analysis from Step 1d and the general aquatic ecological principles discussed previously in Step 2a, the interdisciplinary expert team would generate initial predictions of how the specific flow regime that would result from a proposed project may affect stream health and they would identify areas of potential incompatibility.

As we discussed previously, relationships between altered flows and ecological response are difficult to quantify and generalize in part because of the confounding effect of other environmental variables and naturally-occurring, inter- and intra-annual variability in flow. In addition, just as each stream is unique, each water diversion project and its associated flow alteration scheme are also unique. There is clearly a need for additional research in this area but until the relationships between flow alteration and ecological response can be more clearly defined, an iterative adaptive management approach will likely be required to fine-tune the relationship between flow alteration and ecological response on a stream-by-stream basis.

Step 3. Social Process to Define Values, Needs and Standards

At this point in our recommended framework, proposed flow alterations would be known and anticipated ecological responses to flow alterations would be hypothesized. The next step would be a scientifically supported collaborative dialogue that would define social values and water needs, define acceptable ecological conditions for Pitkin County stream health, and set environmental flow standards for a proposed project. This dialogue would also provide a starting point for the precautionary adaptive management process that constitutes Step 4 of our recommended framework.

Step 3a. Define Social Values, Water Needs and Acceptable Ecological Conditions

Richter et al (2005) state that societal values for rivers are optimized when water is developed for human needs while maintaining adequate flows to sustain healthy ecosystems. Richter also found that water managers, scientists and water users can find mutually compatible solutions when they can to focus on a well-defined set of conflicts.

This social process provides an important opportunity to integrate scientific understanding of ecological flow relationships with human needs for water development. Within this process, local communities and project proponents are challenged to find a balance between water development goals and environmental health knowing that there is an inherent risk of environmental degradation. Setting the level of environmental risk is a task that needs to be determined by local governments and stakeholder groups based on local priorities for development and sustainability (Poff et al 2010).

This social process will require the local community and project proponents to balance the tradeoffs between resource exploitation and resource conservation. The social process may be the most difficult and contentious part of the ESWM/ELOHA process as competing interests and values have the potential to collide.

Articulation of social values should address the relative importance of meeting ecological and human needs, recognizing that human water needs range from essential and non-substitutable (i.e. drinking water) to essential but substitutable (i.e. crops for human consumption) to non-essential (i.e. water for lawns, car washes, new growth).

Water needs for the proposed project should be specifically described in a manner that addresses the following aspects, which are critical to minimizing the impacts of diversions upon stream health:

- the degree to which project water is needed to serve existing uses versus new growth,
- an adequate commitment to water use efficiency
- an appropriate level of demand-side reduction in response to significant droughts,
- full utilization of all other reasonably available supply-side alternatives,
- the project's ability to meet both out-of-basin and in-basin water needs.

Acceptable ecological conditions should be defined in a manner that would protect the existing health of the potentially affected streams, including maintenance of stream flows above "minimum flow" requirements, while recognizing the resiliency of aquatic ecosystems and their adaption to flow variability, including occasional low flows. The goal should be to maintain aquatic and riparian ecosystems that are sustainable and resilient and that maintain their ecological structure and function over time.

Step 3b. Set Environmental Flow Standards

Development of the initial set of acceptable flow recommendations will be informed by the results of the scientific process (Step 2c) and the social process (Step 3a). The results of the scientific process are a quantification of project-specific alterations to the existing flow regime and science-based hypotheses about the expected environmental response to the altered flow regime. The social process has balanced the level of acceptable ecological risk that may be associated with a particular water development project on a particular stream.

The social process of establishing acceptable flow standards is likely to consist of facilitated workshops or town meetings where representatives from local stakeholder groups, water development interests, the scientific community and local governments are allowed to express their opinions and views. To avoid polarization and conflict, participants should be reminded that the ultimate goal of the social process is to develop an initial set of stream/project-specific flow recommendations that can be used as a first step in conducting water management experiments and in the development of a monitoring and adaptive management plan.

This initial set of stream/project-specific flow recommendations should address environmental flow needs, focusing on protecting the key aspects of natural flow variability, over the entire annual hydrograph and should not be limited to any minimum flow requirements that may have been previously determined as part of an earlier phase of project development or CWCB instream flow right appropriations. Flow recommendations should be formulated not only from an annual perspective, but from a multi-year perspective as well. They could include certain aspects of flow requirements that may not be required in every year, but that should occur with a statistical occurrence frequency (for example, a flood flow of X cfs attained for a sustained period of at least Y days at least once every Z years).

In instances where environmental variables are clearly associated with threshold levels of water abstraction, determining an initial flow recommendation may be relatively clear. In contrast, when the relationship between flow alteration and environmental response is linear, with no clear threshold value, setting initial flow recommendations may require a stakeholder consensus process.

The degree of risk that is acceptable to the local community should reflect a balance between perceived ecological values and the level of scientific uncertainty in the relationship between environmental response and flow alteration (Poff et al 2010). Projects that are located on streams with high ecological or social values should be required to start up slowly and increase diversions in small increments over longer periods of time if, and only if, environmental parameters are found to remain stable (see Appendix A – Castle Creek Case Study). Initial flow recommendations on streams with lower ecological or social value may allow for more liberal project start-up conditions and shorter time periods to achieve full project development.

Based on the scientific and social outcomes of Step 3b of our recommended framework, initial flow targets are implemented and the experimental, monitoring and adaptive management process begins[4].

Step 4. Implement, Monitor and Adaptive Management

The next step in our recommended framework involves designing and conducting an experimental, adaptive water management plan that implements the initial flow standards, monitors the results of these flow experiments and adapts the management plan iteratively to achieve the desired balance between human water needs and environmental health. The monitoring/adaptive management plan should be objective and strictly science-based. It should also include "control" site(s) to monitor natural variability in aquatic health that may be associated with issues unrelated to the altered flow regime such as climate change, drought, etc. This plan should be designed to determine whether the preliminary hypotheses regarding the relationship between altered flows and environmental response are correct and whether project diversions should be allowed to increase, or required to decrease, over time.

Poff et al (2010) conclude that "Scientists must maintain an active role in the adaptive management of flows" and that "Effective adaptive management means designing, implementing and interpreting research to refine flow alteration-ecological response relationships, and ensure that this new knowledge translates into updated, implemented flow standards."

An interdisciplinary science team should form the core of the monitoring and adaptive management plan committee. In addition, water managers should participate to ensure that recommendations from the core team can be implemented.

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[4] It should also be noted that there may be instances when the aquatic impacts from a project are determined to be so small and inconsequential that the project is allowed to move forward without the need for a monitoring and adaptive management plan. Conversely, there may also be instances when the aquatic impacts of a project are determined to be so large that no level of adaptive management is acceptable and the project should be opposed.

Development of an adaptive management plan that allows interpretation of flow alteration-ecological response relationships is challenging. Ecological responses are often related to multiple hydrologic variables and there may be other environmental factors besides flow alteration that affect aquatic health. As such, Poff et al (2010) suggest that it is desirable to consider ecological responses in terms of independent flow variables that can be directly manipulated by water managers. The primary goals of the adaptive management team will be to formulate a plan that asks the right questions and design a study that answers those questions objectively.

Enforceable operating agreements, monitoring plans, funding mechanisms and defined roles should all be in place before project construction or operation begins and before the adaptive management plan is initiated.

Summary of Castle Creek Hydropower Plant Case Study

We utilized our recommended framework to evaluate the impacts of the proposed Castle Creek Hydropower facility on Maroon Creek. Diversions from Maroon Creek were assumed to be similar to a transbasin diversion from Maroon Creek since all diversions were 100% consumptive to Maroon Creek. Appendix A contains a full description of our recommended framework application. A brief summary of our findings is as follows.

We ran the IHA software to evaluate the altered flow regime at two different locations (nodes) on Maroon Creek. The first location was immediately below the historic return flow point of the Maroon Creek hydropower facility on Maroon Creek. This point allowed us to evaluate the potential impacts of the new, proposed diversions to the Castle Creek hydropower facility. The second node was located immediately below the Maroon Creek diversion structure which allowed us to evaluate the historic impacts of the Maroon Creek hydropower facility on Maroon Creek.

The results of our IHA analysis indicated that peak flows were not impacted dramatically at either node. However, the natural base flow regimes as well as the lower ends of the ascending and descending limbs of the natural hydrograph were significantly reduced at both locations. These results led us to question whether the post-project flows during the season between September and April would compromise aquatic habitat for fish and aquatic invertebrates.

In response, we proposed an Aquatic Resources Mitigation Proposal (see Appendix A). This proposal suggested that Aspen adopt a “precautionary and incremental approach to operating its hydroelectric project to ensure that the aquatic and riparian environments of these creeks are protected”. This document also formed the basis for an iterative monitoring and adaptive management plan.

Our Mitigation Proposal was presented at a meditation session in Aspen for public input. While there was no formal agreement reached at that meeting, the proposal was well received. Since that time, the Castle Creek Hydropower project has encountered some additional legal hurdles but we believe the Mitigation Proposal will be reconsidered at some time in the future. The combination of a precautionary, incremental startup and iterative monitoring and adaptive management plan should help insure that the project is implemented in a way that preserves the aquatic health of Maroon Creek.

Summary

We believe that our recommended framework will become a valuable tool for Pitkin County as it works towards its Roaring Fork Watershed Plan goal of ensuring long-term, sustainable development and protection of local water resources (Driscoll 2010). As the need arises for the County to evaluate the potential impacts of water diversion projects, our recommended framework can be used to evaluate and balance the relative benefits of diverting water from a stream for human uses against the benefits that accrue from leaving the water instream to preserve aquatic health. The iterative process of monitoring and adaptively managing stream diversions provides an opportunity to maximize the benefits to human uses while ensuring that aquatic health is maintained at a level that is acceptable to the local community.

Critics of the adaptive management approach argue that it is often difficult, or impossible, to reverse a project once it becomes operational. They also express concern that project proponents may be unwilling to curtail diversions under an adaptive management plan unless aquatic impacts can be clearly linked to the operation of their project. We suggest that these issues can, and should, be addressed during the development of the monitoring and adaptive management plan through permitting conditions or other legal mechanisms to ensure that all parties will perform in accordance with the plan.

The monitoring and adaptive management approach is sometimes referred to as “learning by doing”. Critics of the approach ask “why can’t we learn from what’s already done”? This is a valid concern which circles back to the complexity and scientific uncertainty associated with quantifying the relationships between altered flows and ecological response.

As discussed by Poff (2010), there is a critical need for localized studies to advance the current state of the scientific hydro-ecological knowledge. One of the primary surface water goals stated in the Roaring Fork Watershed Plan (Clarke et al. 2011) is “identifying environmental flow needs, including an assessment of historical flow alterations and their ecological consequences”. Sanderson et al (2011) also suggest that the Watershed Flow Evaluation Tool (WFET) that they developed within the Roaring Fork River basin should “create a foundation for and encourage research explicitly focused on flow-ecology relationships”. In light of these recommendations, Pitkin County may want to consider opportunities to investigate these flow-ecology relationships at the local level.

References

Arthington A.H., Bunn S.E., Poff N.L., & Naiman R.J. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications 16(4) 1311-1318.

Bunn S.E. & Arthington A.H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30(4):492-507.

Clarke, S., Fuller, M. & Sullivan, R.A. 2011. Roaring Fork Watershed Plan – March 2011 Draft. Ruedi Water and Power Authority (Sponsor) and Roaring Fork Conservancy (Lead Consultant).

Driscoll, G.M. 2010. Roaring Fork Watershed Plan: Phase II Guidance Document. Ruedi Water and Power Authority (Sponsor) and Roaring Fork Conservancy (Lead Consultant).

Driscoll G.M. 2011. Front Range Water Supply Planning Update. Increased Storage, Increased Demands, Increased Transmountain Diversions. Ruedi Water and Power Authority.

Espegren, G.D. 1996. Development of Instream Flow Recommendations in Colorado using R2Cross. Colorado Water Conservation Board, Water Rights Investigations Section, Denver, Colorado.

Instream Flow Council. (2002). Instream Flows for Riverine Resource Stewardship. Instream Flow Council. USA. ISBN 0-9716743-0-2.

Mathews R. & Richter B. (2007) Application of the Indicators of Hydrologic Alteration software in environmental flow-setting. Journal of the American Water Resources Association. 43(6):1400-1413..

Meyer J.L. 1997. Stream health: incorporating the human dimension to advance stream ecology. Journal of North American Benthological Society. 16(2):439-447.

Olden, J.D. & Poff, N.L. 2003. Redundancy and the choice of hydrologic indices for characterizing stream flow regimes. River Research and Applications 19: 101-121.

Poff, N.L. and 7 co-authors. 1997. The Natural Flow Regime: A Paradigm for River Conservation and Restoration. Bioscience 47(11): 769-784.

Poff N.L., Richter B.D., Arthington A.H. et al. (2010). The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology, 55, 147-170.

Poff N.L. & Zimmerman J.K.H. (2010). Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology, 55, 194-205.

Richter, B.D., Baumgartner J.V., Powell, J., and Braun D.P. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology. 10(4): 1163-1174.

Richter, B.D., Baumgartner J.V., Wigington R., and Braun D.P. 1997. How much water does a river need? Freshwater Biology 37:231-249.

Richter, B.D., Roos-Collins R., and Fahlund A.C. 2005. A framework for ecologically sustainable water management. Hydro Review August 2005.

Sanborn, S.C. & Bledsoe B.P. 2006. Predicting stream flow regime metrics for ungauged streams in Colorado, Washington, and Oregon. Journal of Hydrology 325: 241-261.

The Nature Conservancy of Colorado, 2008. Environmental Flows for the North Fork of the Cache la Poudre River (Draft).

Sanderson, J.S., Rowan N, Wilding T, Bledsoe B.P., Miller W.J. & Poff N.L. 2011. Getting to scale with environmental flow assessment: the Watershed Flow Evaluation Tool. River Research and Applications. 2011.

Walker, K.F., Sheldon F. & Puckridge J.T. (1995). A perspective on dryland river ecosystems. Regulated Rivers: Research and Management, 11, 85-104.

Appendix A: Evaluation of Aspen's Proposed Castle Creek Hydro Project

ELOHA/ESWM Framework Implementation

Introduction

As an example, we applied our recommended framework to Aspen's proposed Castle Creek Hydroelectric Plant Project. Since there were already ongoing negotiations between local stakeholders during the framework's development, the steps outlined in this paper were not followed in the exact order described above. However, all elements were considered and the iterative nature of the recommended framework has been proposed for the Project as would be applied to a new diversion.

The Project would include installation of a new hydropower turbine on the spill outlet pipe from Thomas Reservoir. This pipe was recently enlarged and redesigned to function as a hydropower penstock. The new turbine would receive water diverted from Castle Creek and Maroon Creek via Aspen's existing diversion facilities and return it to Castle Creek. Aspen currently has a municipal diversion on Castle Creek and a combined municipal/hydropower diversion on Maroon Creek. Aspen's existing Maroon Creek Hydroelectric Plant currently diverts up to 60 cfs from Maroon Creek upstream of Willow Creek, leaving a minimum of 14cfs in Maroon Creek. Following hydropower generation at the Maroon Creek Plant, water is returned to Maroon Creek. Under Aspen's proposed Project, the first 10 cfs of water available for diversion from Maroon Creek would continue to be delivered to the existing Maroon Creek Hydro plant, but additional available water, up to 27 cfs, would be diverted to Thomas Lake. The trans-basin aspect of Aspen's proposed Project is the diversion of water out of the Maroon Creek basin with return to Castle Creek.

The primary focus of this analysis was the effect of two alternate proposed bypass requirements on Aspen's proposed Maroon Creek diversions.

Step 1: Hydrologic Foundation

a. Collect Flow Data/Modeling

For successful implementation of any quantitative approach to stream health monitoring, it is necessary for streamflow data representative of the proposed project location to be collected, preferably over a long time period. Aspen's proposed Project was a good choice for a stream alteration test case since 25 years of flow records exist for USGS gauges on both Castle and Maroon Creeks at relatively small distances upstream of the Project's points of diversion.

As part of the planning process for Aspen's proposed Project, Aspen's hydrology consultant (Grand River Consulting) created a hydrology model to simulate the diversions, flows and power generation potential for the existing Maroon Creek hydroelectric plant and for Aspen's proposed Project. In addition, the model was set up to provide modeled flows for each of the creeks affected by the proposed Project.

We conducted a statistical streamflow analysis at a point where the transbasin diversion of water from Maroon Creek to Castle Creek caused reduced instream flows in Maroon Creek. We chose the location on Maroon Creek immediately below the existing Maroon Creek hydroelectric plant outlet (called Maroon Outlet Node in this analysis).

b. and c. Creation of Baseline and Developed Hydrographs

In this analysis we compared the pre-impact and post-impact instream flows for Maroon Creek. The pre-impact hydrograph refers to the calculated natural flows in Maroon Creek, assuming there are no significant agricultural, municipal or hydroplant diversions.

Baseline Hydrographs

We created baseline hydrographs using the Grand River hydrology model, which representing natural stream flows at each diversion point and return flow point by applying appropriate factors to the historic USGS gauge data to account for the additional watershed areas between the gauge locations and the analyzed nodes.

Developed Hydrographs

We ultimately considered two post-impact operations scenarios in this analysis. We first considered Aspen's proposed Project operation: a minimum of 14cfs would be left in Maroon Creek, based on an R2CROSS assessment (the 14 cfs scenario).

During our initial review of the Project for the Pitkin County and during our supporting role for the 1-day mediation effort that followed, we developed a more precautionary scenario for the Project's operation (as discussed in more detail in a following section). We proposed that additional and more protective bypass requirements be imposed upon the Project during its initial years of operation and that these bypass requirements be gradually relaxed only to the degree that ongoing monitoring of stream health showed no adverse impacts. Our proposal was refined and amended several times prior to and during the mediation and ultimately contained an additional bypass requirement that daily Project diversions be limited during the period of August 1st through May 15th of each year so as not to cause the resulting stream flow to drop below the greater of the 14 cfs low flow requirement and the historical 25th percentile weekly flow (the "25th percentile" scenario). We used the Grand River hydrology model to generate developed hydrographs for each scenario.

d. Characterize Flow Alteration using Indicators of Hydrologic Alteration

We used the Grand River hydrology model to generate time series output for pre-project flows and for post-project flows for the two alternative scenarios. We input these time series data into The Nature Conservancy's Indicators of Hydrologic Alteration (IHA) software in order to calculate all 33 IHA parameters as well as the Environmental Flow Components (EFC) for each scenario.

Step 2: Flow-Ecology Relationships

a. Flow-Ecology Hypotheses

In the case of Aspen's proposed Project, only limited ecological data was available at the time of our analysis and there was no time for additional data collection prior to the mediation. We developed general hypotheses regarding flow-ecology relationships based upon our experience and expertise with Rocky Mountain streams in similar settings in Colorado. Our initial hypothesis was that stream health on Maroon Creek would be maintained by generally preserving the variable natural flow regime of the Creek.

b. Collect Ecological Data

No additional ecological data was collected prior to setting the initial Range of Variability Approach (RVA) bounds. As part of its proposed Project, Aspen was in the process of developing a draft monitoring plan with the Colorado Division of Wildlife that would provide for additional pre-project and post-project ecological monitoring including data collection for water temperature, stream habitat, macroinvertebrates and hydrology.

c. Anticipated Ecological Responses to Flow Alteration

We evaluated the Project's proposed flow alterations under the initial assumption that, in order to avoid significant impacts to stream health, the allowable range of variability (RV) of the median (50th percentile) values for each IHA and EFC parameter should be bounded by the pre-project 25th and 75th percentiles. If the post-project median value for any given IHA or EFC fell significantly outside of this range, that cell was highlighted in the summary table at the end of this Appendix[5].

Our review of the Aspen's proposed Project operation indicated that diversions would reduce Maroon Creek flows during the ascending and descending limbs and the base flow portions of the hydrograph to a 'flat-lined' minimum flow for several months each year.

We developed a proposal that the Project's operations be "slow-started" in a conservative fashion so that flow-ecology relationships can be established during initial operations rather than causing harm to the stream's ecology and then attempting to repair any damage. Our proposal required the project to operate for an initial period with a bypass requirement that would keep post-project flows above the 25th percentile weekly values during the period of August 1st through May 15th of each year. To the degree that ecological monitoring indicated no adverse effects to stream health after several years of Project operation under this precautionary bypass requirement, these bypass requirements could be gradually relaxed.

The tables at the end of this appendix summarize the resulting change in median flow and the frequency that post-project median flow values fell outside of the RV. It is clear that the 14 cfs scenario had a more significant impact on the stream since more parameters from the 14 cfs scenario fell outside of the RV than the 25th percentile scenario.

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[5] Because Maroon Creek natural flows sometimes fall below the 25th percentile threshold, even the 25th percentile scenario produced post-project flows slightly below the 25th percentile pre-project flow.

We note that the the 25th and 75th percentile boundaries for RV do not necessarily reflect valid flow-ecology relationships. To jump-start the stream health assessment process for this analysis, we bounded the RV to the 25th and 75th percentiles for each parameter. Depending on the parameter studied this range may be appropriate, overly restrictive or not restrictive enough; until further ecological studies are conducted, the appropriateness of these percentiles is not known. The purpose of these initial boundaries is to provide a starting point that can be used as a control point for modifying future operations. As more flow and ecology data are collected, the 25th - 75th percentile RV bounds can be modified for each parameter to determine at what level of modification their effect on local ecology becomes significant.

Step 3: Social/Scientific Process

a-c. Social Values and Water Needs, Acceptable Ecological Conditions and Environmental Flow Standards

In the case of Aspen's proposed Project, social values and water needs, acceptable ecological conditions and flow standards were assessed indirectly and not in the exact order specified in our recommended framework.

Aspen's initial proposal called for the use of the R2CROSS-derived values as the minimum instream flows for Castle and Maroon Creeks. As part of our critical review of the Project for Pitkin County, we proposed that post-project flows on Maroon and Castle Creeks should mimic the variable natural flow regime, particularly during the ascending and descending limbs and base flow portions of the hydrograph, rather than be 'flat-lined' at a minimum instream flow rate for several months each year. We also recommended that the range of variability (RV) of the Indicators of Hydrologic Variability (IHA) and associated Environmental Flow Components (EFCs) developed by Richter should be used as the method to assess the operating standards of the Project.

We discussed our proposal with Aspen's hydrology consultants (who in turn discussed our proposal with Aspen). We collaboratively made several minor changes to our proposal, incorporated suggested changes, developed a letter and proposal for discussion at a one-day mediation that included participation by City of Aspen utilities staff, hydrology and fisheries consultants to the City of Aspen and Pitkin County, local landowners, a representative from Pitkin County, a representative for the Roaring Fork Conservancy. This mediation to some degree served as a multi-stakeholder discussion of the local social and water needs. In other cases it would be more appropriate to include citizens and other stakeholders in this discussion through a more transparent and organized set of negotiation proceedings.

During the mediation, our proposal was discussed extensively. Following the mediation, minor modifications were made to our proposed "environmental flow hydrograph." The changes proposed were designed to give a set of stepwise requirements to modify the instream flow requirements to divert more or less water based on the stream health as a result of the initial set of diversion rules.

Step 4: Precautionary Adaptive Management

a. Standards Implementation Mechanisms

The mediation process resulted in a method to both determine acceptable initial ecological standards for the affected creeks and triggers to implement changes in the Castle Creek Hydroplant's operation.

The mediation plan states that if a statistically significant decrease is detected in any one or more of fish populations, macroinvertebrate populations or aquatic/riparian habitat, the CDOW and Aspen will review the data to determine the cause and, if the cause is determined to be due to Maroon/Castle Creek hydroelectric operations, Aspen will change plant operations to address the decrease in the criteria.

b. Monitor Hydrology and Ecology

A biological monitoring plan was proposed for the Castle Creek Hydroplant to provide continuous feedback for decision making. Elements of the monitoring plan included sampling locations on both Maroon and Castle Creeks, monitoring of stream habitat and water temperature, macroinvertebrate sampling, and gauge installation for hydrologic monitoring.

The mediation group agreed that biological monitoring be conducted by a 3-member team of fisheries/stream health experts, consisting of representatives from Aspen, the Colorado Division of Wildlife, and Pitkin County's Healthy Rivers and Streams Board, who would make the periodic determinations regarding the Project's effects on stream health.

An annual report regarding the monitoring data and the determinations by the 3-member team of experts would be made publicly available.

c. Precautionary Project Operation

Diversions by the Castle Creek Hydroplant would be gradually increased in a stepwise fashion over 3-year monitoring periods only to the degree that monitoring indicated no adverse effects to stream health after several years of Project operation under precautionary bypass requirements. If monitoring showed adverse effects, Project diversion would be decreased.

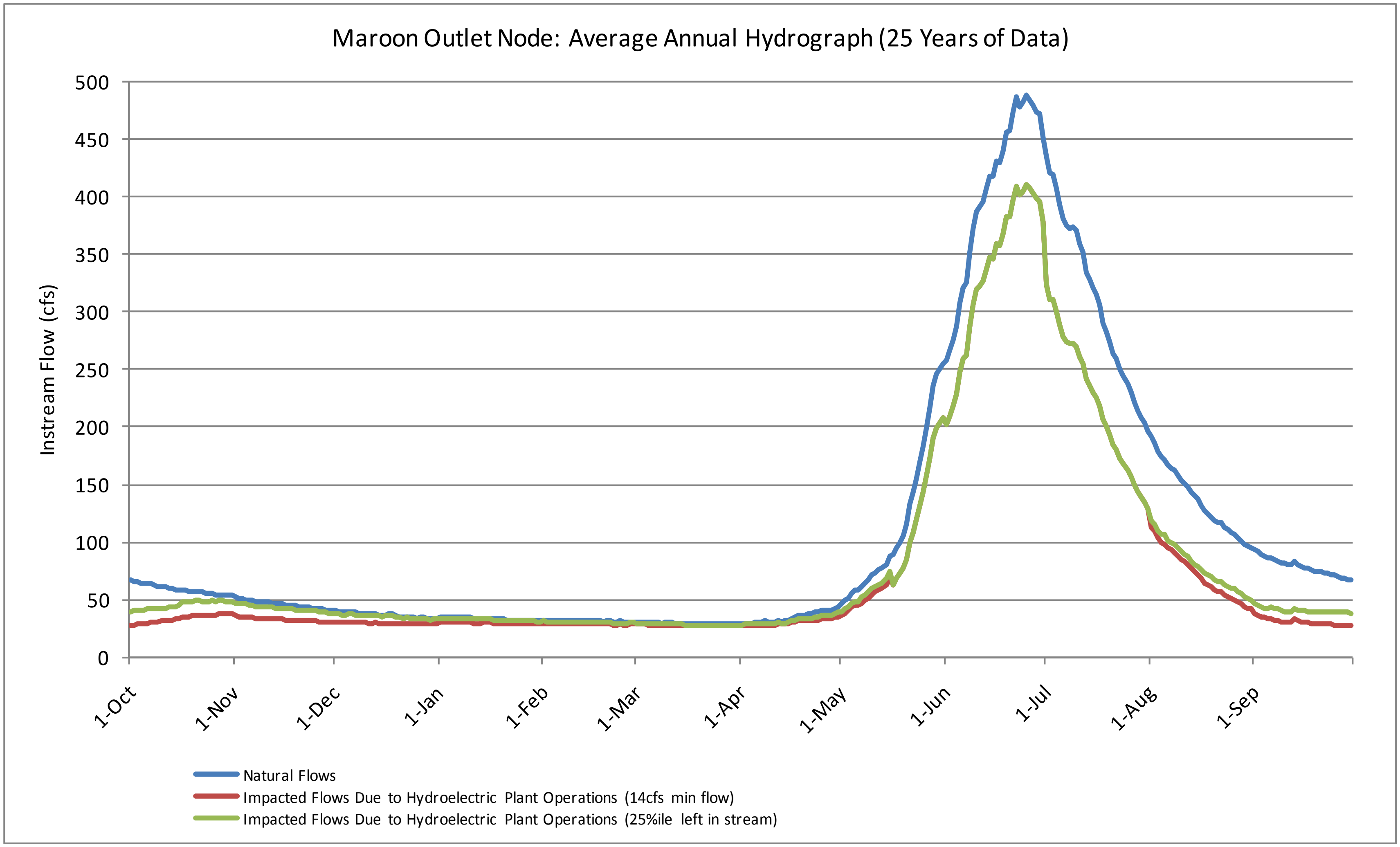


Figure A1 – Maroon Outlet Node Hydrograph

Post-project 50th percentile cells are highlighted if they fall outside of the range of variability (defined by the 25th and 75th percentile pre-project values). Highlighting gradation becomes more red as values fall are farther outside of the range of variability.

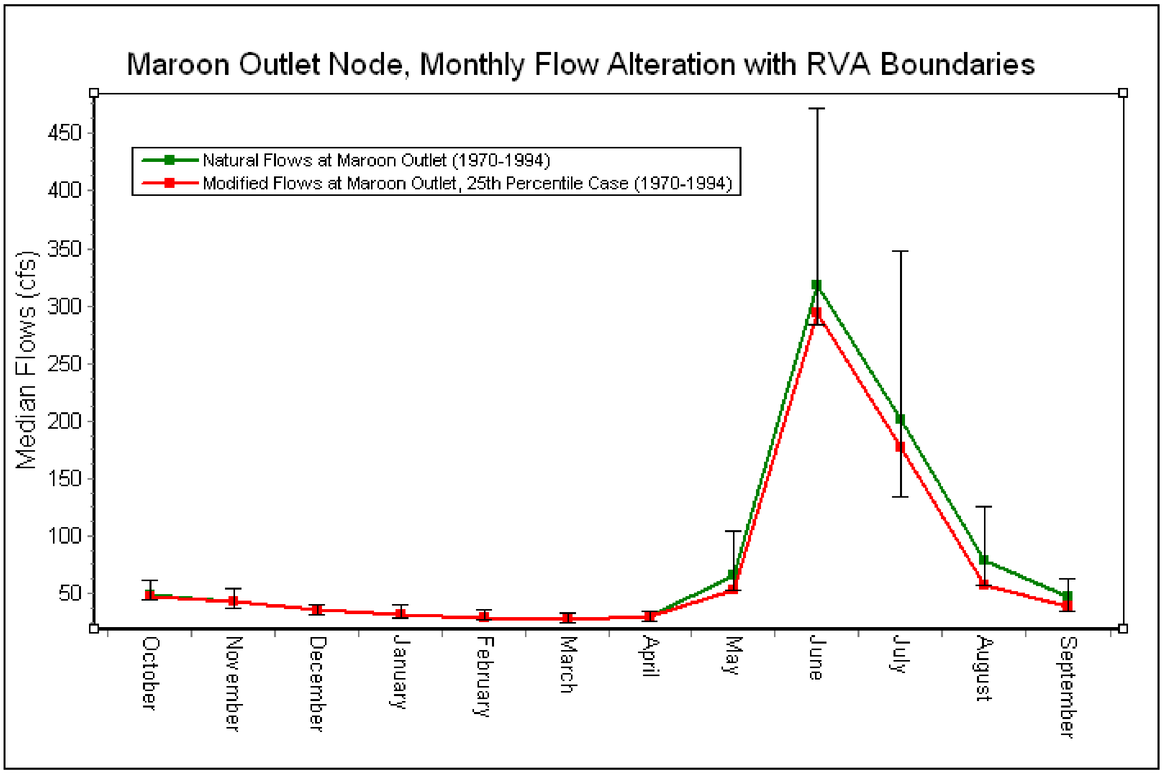
Node	**Maroon Outlet Node**						
	Natural Flows			Aspen Proposal (14cfs min ISF)		20/25%ile Mediation Proposal	
Percentile	Pre-Project 25% (Lower RVA Bound)	Pre-Project 50%	Pre-Project 75% (Upper RVA Bound)	Post-Project 50%	% change in 50 %ile value	Post-Project 50%	% change in 50 %ile value
Parameter Group #1							
October Median Flow	45.3	49.0	62.7	28.6	-42%	47.4	-3%
November Median Flow	38.6	43.8	54.7	31.5	-28%	43.8	0%
December Median Flow	31.8	36.3	41.6	29.7	-18%	35.5	-2%
January Median Flow	29.3	32.3	39.8	30.3	-6%	32.3	0%
February Median Flow	27.4	29.3	36.1	29.3	0%	29.3	0%
March Median Flow	24.8	27.8	32.3	27.8	0%	27.8	0%
April Median Flow	26.3	30.8	35.3	30.0	-3%	29.8	-3%
May Median Flow	53.3	65.7	103.7	41.2	-37%	52.9	-20%
June Median Flow	282.9	318.6	471.9	294.1	-8%	294.1	-8%
July Median Flow	134.7	201.7	348.5	177.2	-12%	177.2	-12%
August Median Flow	57.5	79.4	125.8	54.9	-31%	57.4	-28%
September Median Flow	35.6	47.5	63.2	23.0	-52%	38.6	-19%
Parameter Group #2							
1-day minimum	19.9	24.8	26.8	18.8	-24%	24.8	0%
3-day minimum	21.3	24.8	27.8	19.7	-21%	24.8	0%
7-day minimum	23.3	25.9	28.8	20.1	-22%	25.9	0%
30-day minimum	24.4	26.5	31.4	22.3	-16%	26.5	0%
90-day minimum	25.9	28.1	34.0	27.9	-1%	28.1	0%
1-day maximum	471.2	559.1	716.9	534.6	-4%	534.6	-4%
3-day maximum	459.9	539.5	679.6	515.0	-5%	515.1	-5%
7-day maximum	418.0	494.7	625.0	470.2	-5%	470.2	-5%
30-day maximum	313.2	387.0	496.9	362.5	-6%	362.5	-6%
90-day maximum	198.1	235.1	299.1	210.6	-10%	211.7	-10%
Number of zero days	0.0	0.0	0.0	0.0		0.0	
Base flow index	0.3	0.3	0.3	0.3	-5%	0.3	11%
Parameter Group #3							
Date of minimum	5-Jan	28-Feb	30-Mar	11-Sep	331%	22-Feb	-10%
Date of maximum	14-Jun	22-Jun	27-Jun	22-Jun	0%	22-Jun	0%
Parameter Group #4							
Low pulse count	1.0	4.0	6.0	4.0	0%	3.0	-25%
Low pulse duration	2.9	5.5	20.6	37.0	573%	4.0	-27%
High pulse count	1.0	2.0	2.5	1.0	-50%	1.0	-50%
High pulse duration	10.0	59.0	89.5	69.0	17%	69.0	17%
Parameter Group #5							
Rise rate	1.5	1.5	2.7	0.8	-46%	1.5	0%
Fall rate	-2.5	-2.5	-1.7	-2.4	-1%	-2.3	-7%
Number of reversals	72.0	83.0	101.5	76.0	-8%	93.0	12%

Post-project 50th percentile cells are highlighted if they fall outside of the range of variability (defined by the 25th and 75th percentile pre-project values). Highlighting gradation becomes more red as values fall are farther outside of the range of variability.

Node	**Maroon Outlet Node**						
	Natural Flows			Aspen Proposal (14cfs min ISF)		20/25%ile Mediation Proposal	
Percentile	Pre-Project 25% (Lower RVA Bound)	Pre-Project 50%	Pre-Project 75% (Upper RVA Bound)	Post-Project 50%	% change in 50 %ile value	Post-Project 50%	% change in 50 %ile value
EFC Monthly Low Flows							
October Low Flow	45.3	49.0	62.7	30.8	-37%	47.4	-3%
November Low Flow	38.6	43.8	54.7	31.5	-28%	43.8	0%
December Low Flow	32.2	36.3	42.0	29.7	-18%	35.9	-1%
January Low Flow	30.8	33.8	39.8	30.7	-9%	32.3	-4%
February Low Flow	29.3	29.3	38.3	29.3	0%	29.3	0%
March Low Flow	27.8	29.3	35.3	29.3	0%	28.6	-3%
April Low Flow	29.7	32.3	36.4	30.3	-6%	30.8	-5%
May Low Flow	39.4	51.9	62.4	34.5	-34%	46.9	-10%
June Low Flow	69.1	71.4	73.6	64.2	-10%	64.2	-10%
July Low Flow	52.2	76.6	80.0	73.0	-5%	73.0	-5%
August Low Flow	55.0	63.8	76.4	54.9	-14%	55.3	-13%
September Low Flow	36.1	47.5	58.9	35.0	-26%	38.7	-18%
EFC Flow Parameters							
Extreme low peak	23.3	25.5	26.3	24.4	-4%	24.8	-3%
Extreme low duration	1.0	5.5	32.5	11.8	114%	3.0	-45%
Extreme low timing	8-Feb	13-Mar	23-Mar	21-Mar	11%	9-Mar	-6%
Extreme low freq.	0.5	2.0	4.0	3.0	50%	2.0	0%
High flow peak	89.8	107.0	458.4	337.8	216%	337.8	216%
High flow duration	2.0	4.5	78.0	48.8	983%	48.8	983%
High flow timing	12-Jun	30-Jun	27-Aug	14-Jun	14-Jun	14-Jun	-9%
High flow frequency	0.5	1.0	2.0	1.0	0%	1.0	0%
High flow rise rate	4.5	9.0	12.0	12.5	39%	12.5	39%
High flow fall rate	-8.1	-6.1	-4.6	-8.1	32%	-8.1	32%
Small Flood peak	601.2	669.9	739.4	692.4	3%	692.4	3%
Small Flood duration	79.0	84.0	119.0	76.0	-10%	76.0	-10%
Small Flood timing	18-Jun	22-Jun	26-Jun	23-Jun	0%	23-Jun	0%
Small Flood freq.	0.0	0.0	1.0	0.0		0.0	
Small Flood riserate	13.0	18.4	20.7	20.4	11%	20.4	11%
Small Flood fallrate	-11.8	-10.0	-8.5	-11.7	17%	-11.7	17%
Large flood peak	772.5	808.6	844.7	820.2	1%	820.2	1%
Large flood duration	94.0	98.5	103.0	96.0	-3%	96.0	-3%
Large flood timing	26-Jun	28-Jun	30-Jun	26-Jun	-1%	26-Jun	-1%
Large flood freq.	0.0	0.0	0.0	0.0		0.0	
Large flood riserate	17.5	21.8	26.1	26.0	20%	26.0	20%
Large flood fallrate	-12.5	-11.4	-10.3	-10.9	-4%	-10.9	-4%

Example of IHA graphs for certain parameters

This graph is one of the types of output available from the IHA software. In this case, the data shown is the same as IHA Parameter Group #1 in the table above for the Maroon Outlet Node. The range bars on the pre-impact line indicate the pre-project range of variability (Top and bottom bars refer to 75th and 25th percentiles, respectively). From this graph, the largest impacts are seen from May through September; all flows except May do fall within of the RVA boundaries.



Another example of the outputs of the IHA software is the 1-day minimum flow from IHA Parameter Group #2 for the Maroon Outlet Node using Aspen's 14cfs minimum ISF proposal. This is the parameter within group 2 with the largest % change in the 50th percentile value. The reduction in the median and RVA for the 1-day minimum flow is clear from this graph.