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

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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.

All water diversions cause depletions to stream flows. The amount of depletion is greatest at the location and time of the diversion. If the diverted water is used in a manner that produces return flows to the source stream, the depletive effect of the diversion is reduced by the amount of return flow downstream of the return flow location.

By definition, trans-basin diversions do not produce return flows that return to the source stream. The depletive effects of trans-basin diversions are therefore of particular concern to the HRS Board, because they are 100% depletive to the source stream. 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".

Trans-basin diversions are not the only threat to stream health in Pitkin County. The depletive effects of in-basin diversions can also be significant, particularly when the amount of the diversion comprises a significant portion of the available stream flow.

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 water development 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."

[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.

Scientists have recognized that environmental flow decision-making frameworks such as ESWM and EHOLA can be difficult to implement because of their cost and time requirements, particularly in politically challenging situations such as responding to extreme droughts, legislative mandates or lawsuits (Richter, 2009). They also note that many water developers continue to use "off–the-shelf" estimates of environmental flow requirements that have been shown to be inadequate and would almost certainly cause profound ecological degradation. To address these concerns, scientists have developed simplified approaches for developing presumptive environmental flow standards, that recognize the complex and variable flow regime needed to maintain stream health, for interim use until more definitive site-specific analyses can be done. Two such approaches are the Range of Variability Approach (RVA) and the Percent of Flow (POF) Approach, both of which are described later in this paper.

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.

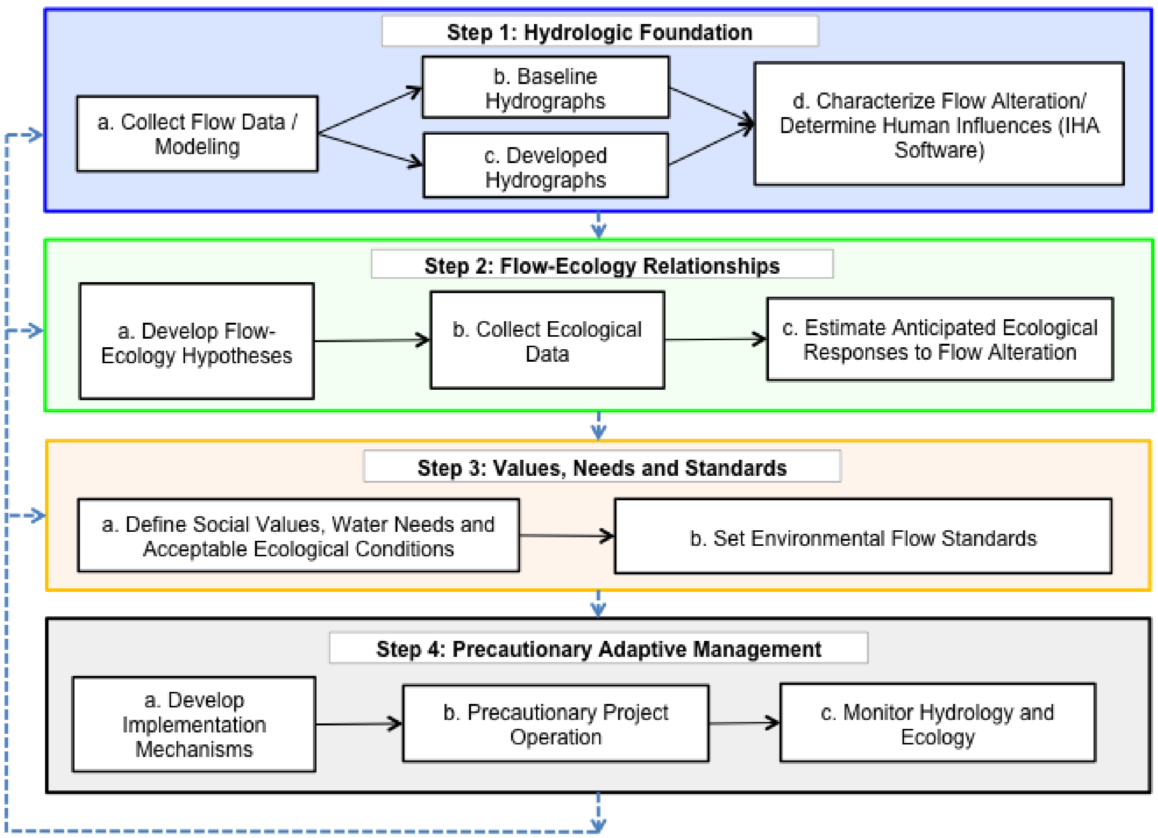

Figure 1: Recommended Decision-Making Framework

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 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 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 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 67 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. "The power of the IHA method is that it can be used to summarize long periods of daily hydrologic data into a much more manageable series of ecologically relevant hydrologic parameters" (The Nature Conservancy 2009).

Olden and Poff (2003) performed a comprehensive review of 171 indices of hydrologic alteration. They acknowledged that some of the 171 parameters they evaluated are difficult to calculate and they found merit in automating these calculations using the IHA software.

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 an initial IHA analysis can establish 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. There may be other quantitative descriptors of natural flow in addition to those included in IHA (such as monthly or seasonal coefficients of variation), that are important for characterizing the healthy aspects of natural stream flow. IHA should be viewed as a useful tool, but not the only tool, for characterizing the ecologically relevant aspects of stream flow.

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 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. 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 2 illustrates the ecological connections between aquatic biodiversity and the natural flow regime as proposed by Bunn and Arthington (2002).

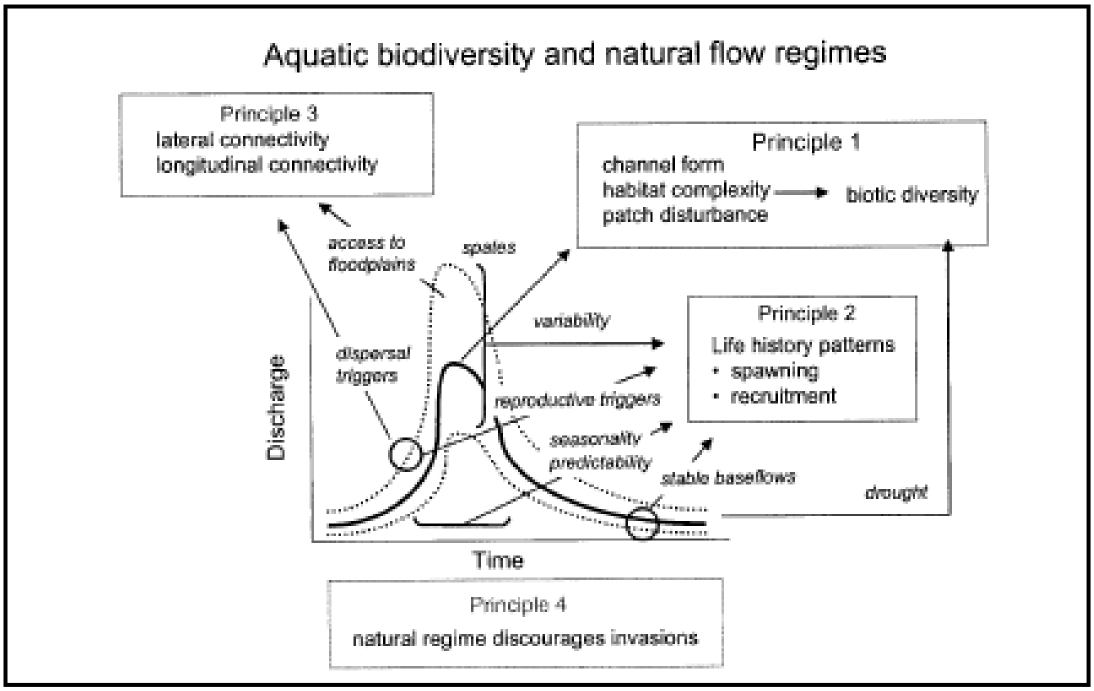

Figure 2. Aquatic biodiversity and natural flow regimes from Bunn and Arthington (2002)

With these general ecological principles in mind and the natural flow IHA analysis in hand, an interdisciplinary team of biologic and hydrologic experts can 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 may rely upon previous experience, literature values, and findings from previous field studies conducted in Pitkin County. Until flow-ecology relationships supported by detailed, site-specific information are developed, the interdisciplinary expert team may also elect to employ one or both of the following statistical methods to craft preliminary ecological flow recommendations for consideration within the social values and precautionary adaptive management steps of our recommended framework.

The Range of Variability Approach

The Range of Variability Approach (RVA) can be used to develop preliminary ecological flow targets by evaluating the magnitude of changes in IHA parameters between natural, pre- and post-project conditions (Richter et al., 1997). The RVA utilizes IHA output to set initial post-project flow management targets as +/- one standard deviation from mean natural values, or alternatively between the 25th and 75th percentiles of natural 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 natural 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.

Of the 67 biologically relevant hydrologic parameters that are calculated by the IHA software, 34 are characterized as "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.
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.

[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.

Olden and Poff (2003) 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 of these parameters (and possibly others) be given consideration as different types of water development projects will alter the natural flow regime differently.

The Percent of Flow Approach

The Percent of Flow (POF) Approach is another method that can be used to establish a preliminary environmental flow recommendation (Richter et al 2011). The POF Approach establishes bands of allowable alteration, called “sustainability boundaries”, which are based on percentage departures from natural daily flows. The POF Approach and sustainability boundary concept are illustrated in Figure 3.

Richter reviewed several case studies and concluded that increased percentages of flow alteration led to lower levels of ecosystem protection (Table 1). For water supply/planning purposes, Richter suggests that “protecting 80% of daily flows will maintain ecological integrity in most rivers”. He goes on to say that “a higher percentage of flow (90%) may be needed to protect rivers with at-risk species and exceptional biodiversity.”

The POF Approach is advantageous because it protects a high level of inter- and intra-annual flow variability. It is also relatively simple to implement and enforce given adequate stream gages and diversion structures.

The RVA and POF Approaches are two scientifically valid, statistical methods for determining preliminary environmental flow recommendations. Protecting the 25th percentile under the RVA approach protects the annual shape of the natural flow regime at a "dry year" condition but does not insure the inter-annual variability associated with wet and average water years. The POF approach protects both the inter- and intra-annual variability associated with the natural flow regime. In our Aspen Hydropower example, we utilized a combination of both the RVA and POF Approaches to develop our initial environmental flow recommendation (see Appendix A). The desired level of preliminary flow protection from either approach would be subject to negotiation and/or optimization through the social values and adaptive management steps of our recommended framework.

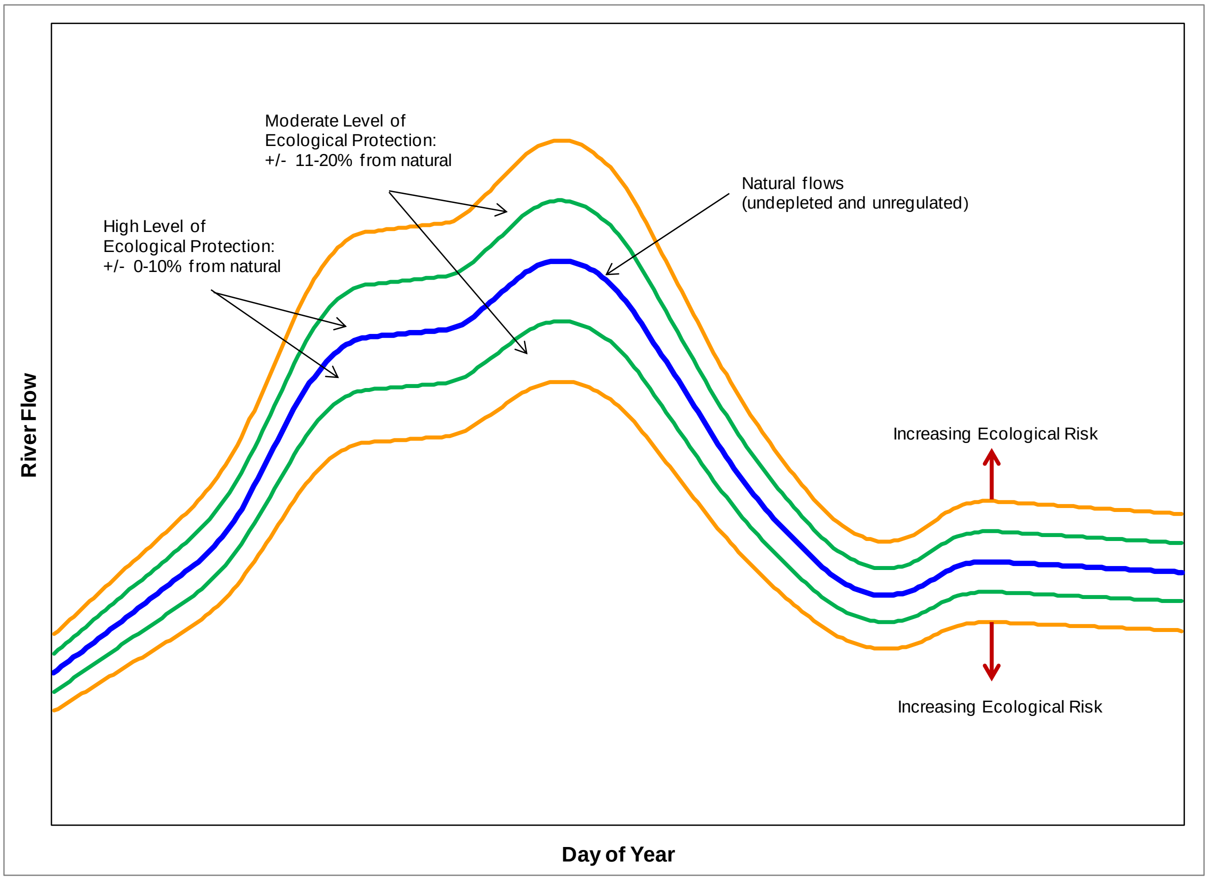

Figure 3: POF "sustainability boundaries" (Richter 2011)

Table 1 Percent of Flow (POF) and levels of protection (Richter 2011)

% Flow Alteration	Level of Protection
< 10%	High – natural structure and function of riverine ecosystem maintained with minimal change
10% to 20%	Moderate – May be measurable changes in ecosystem structure and minimal changes in ecosystem function
➢ 20%	Moderate to Low – Likely to experience moderate to major changes in natural structure and ecosystem function. Greater level of alteration = Greater Risk

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 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 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 or complex, 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.

We believe that the inter- and intra-annual variability of the natural flow regime can be best preserved by utilizing a combination of the RVA and POF techniques to set initial flow standards. Further, we suggest that in the absence of stream-specific, scientific data to the contrary, an initial environmental flow standard that protects stream flows of at least the natural, 25^{th} percentile daily flow and limits diversions to no more than 20% of the natural daily flow will generally provide sufficient environmental protection to initiate a monitoring and adaptive management plan.

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].

[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.

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 over an appropriate time frame[5] 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 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, land use/land cover changes, etc., as well as "treatment" site(s) that are strategically located to capture the potential environmental impacts of the proposed project. 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 expert team should form the core of the monitoring and adaptive management plan committee. The interdisciplinary expert team should consist of individuals with experience in engineering, hydrology, aquatic biology and/or other relevant disciplines. We suggest that in addition to representatives for Pitkin County and the project proponent, the team could include scientists from the Colorado Division of Parks and Wildlife and management agencies (USFS, BLM) for any federal lands that might be affected by the proposed project. In addition, water managers should participate to ensure that recommendations from the core expert team can be implemented.

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.

[5] The time frame necessary to monitor and evaluate whether the initial set of flow standards is adequately protecting aquatic health will vary between streams. This time frame should be determined by the interdisciplinary expert team based on factors such as natural inter- and intra-annual stream flow variability, the magnitude of proposed diversion, and the life history of fish and macroinvertebrate species that are being monitored as indicators of aquatic health.

Summary of Castle Creek Hydropower Plant Case Study

We applied our recommended framework to evaluate the impacts of the City of Aspen's proposed Castle Creek Hydropower Project on Maroon Creek. Water is currently diverted from Maroon Creek for hydropower generation at an existing plant from which return flows go back to Maroon Creek. Under Aspen's proposed project, some of the currently diverted water would instead be conveyed to the proposed Castle Creek plant for hydropower generation and would be returned to Castle Creek; such altered diversions would be considered as trans-basin diversions from the perspective of Maroon Creek. Appendix A contains a full description of our recommended framework application. A brief summary of our findings is as follows.

We used an existing hydrologic model, developed by the City of Aspen and based on 25 years of gaged flows on Maroon Creek, to simulate the operation of the Castle Creek Hydropower Project on Maroon Creek. We ran the IHA software to evaluate the altered flow regime at two different "treatment" site locations (nodes) on Maroon Creek against our "control" site which was located upstream of the Maroon Creek diversion structure. The first "treatment" 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 "treatment" 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. We developed a preliminary flow recommendation for Maroon Creek using both the 25th percentile RVA approach and the 20% POF approach. As a further constraint, hydropower diversions from Maroon Creek were not allowed to reduce the flow below the Colorado Water Conservation Board's 14 cfs decreed instream flow water right. Our 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.

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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 included in our framework were not followed in the exact order described in our paper. 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 would be 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 as affected by the proposed Project.

We conducted a statistical streamflow analysis at a point where the trans-basin 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 baseline (natural flow) and developed hydrographs for Maroon Creek. The baseline hydrograph assumes there are no significant depletions upstream of the existing Maroon Creek diversion point.

Baseline Hydrographs

We created baseline hydrographs using the Grand River hydrology model, which represents natural stream flows at the Maroon Creek 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 location and the analyzed nodes.

Developed Hydrographs

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

During our initial review of the Project for the Pitkin County and as input to the 1-day mediation effort that followed, we developed a more precautionary bypass proposal 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.

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 were collected prior to setting the initial Range of Variability Approach (RVA)/Percent of Flow (POF) bounds. As part of the planning for its proposed Project, Aspen had already collected and provided a significant amount of ecological monitoring data and 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

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

We developed a proposal that incorporated both the range of variability (RV) and percent of flow (POF) approaches discussed in our paper. We proposed 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 bypass requirements that would limit Project diversions from Maroon Creek to 20% of the daily flow available at the diversion structure, subject to the further limitation that Project diversions would not result in a bypass flow of less than the historical 25th percentile daily flow for each day at the return flow structure. 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.

We used the IHA tool to evaluate the Project's proposed flow alterations under Aspen's bypass proposal and under our proposal. In our IHA evaluation, we assumed 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. Our initial IHA evaluation indicated that our proposed diversion limits would not be necessary during June and July when stream flows are relatively high. We therefore modified our proposal to not apply our diversion limits to those months. 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. 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 tables[6]. The tables show that Aspen's 14 cfs bypass scenario would have a more significant impact on the stream since more parameters from the 14 cfs bypass scenario fell outside of the RV than would occur under our proposal.

We note that our proposed 20% of flow/25th percentile flow diversion limits do not necessarily reflect valid flow-ecology relationships. These diversion limits may be appropriate, overly

[6] 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.

restrictive or not restrictive enough; until further ecological studies are conducted, the appropriateness of these percentiles is not known. The purpose of these initially proposed diversion limits is to provide a starting point for Project operations and adaptive management.

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 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 as discussed above, 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, both to Aspen's hydrologic model and to our proposal. We incorporated several changes into our proposal and submitted our proposal for discussion at a one-day mediation, convened by Public Counsel of the Rockies, 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, and 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 and Aspen suggested several modifications to our proposal that would facilitate the implementation of flow bypasses without significantly compromising the protective intent of our proposal. Our proposal is being considered by Aspen and by review and permitting entities as planning for the Project continues.

Step 4: Precautionary Adaptive Management

a. Implementation

As part of its proposed Project, Aspen prepared a draft memorandum of agreement and draft monitoring plan that provided Aspen's view of a basic institutional framework for adaptive management of the Project. The draft monitoring plan called for a 10-year period of biological monitoring that would occur during the fall season of specified years. The draft memorandum of agreement provided that, if a statistically significant decrease is detected in fish populations, macroinvertebrate populations or aquatic/riparian habitat, the CDOW and Aspen would review the data to determine the cause and, if the cause is determined to be due to the Project's hydroelectric operations, Aspen would change plant operations to address the decrease in the criteria.

We reviewed Aspen's draft memorandum of agreement and monitoring plan as part of our critical review for Pitkin County and suggested additional protective elements in our proposal regarding monitoring and adaptive management.

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 Adaptive Management

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.

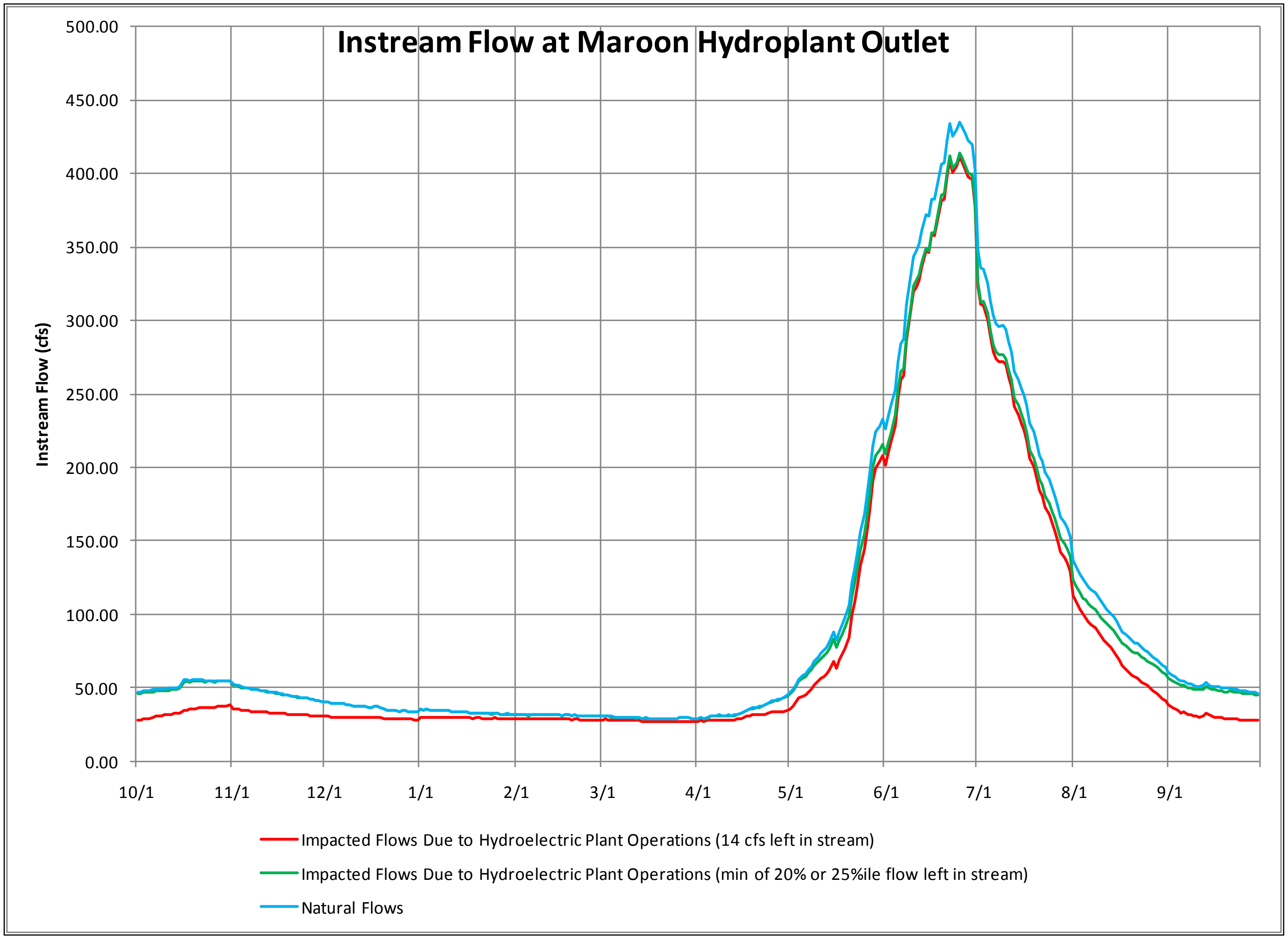


Figure A1 – Maroon Outlet Node Hydrograph

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)							
Node	**Maroon Outlet Node**						
	Natural Flows			Aspen Proposal (14 cfs min ISF)		20/25%ile Flow Limitation	
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%	49.0	0%
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%	65.7	0%
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%	73.4	-8%
September Median Flow	35.6	47.5	63.2	23.0	-52%	47.0	-1%
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%	363.2	-6%
90-day maximum	198.1	235.1	299.1	210.6	-10%	218.7	-7%
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	6%
Parameter Group #3							
Date of minimum	5-Jan	28-Feb	29-Mar	10-Sep		28-Feb	
Date of maximum	12-Jun	21-Jun	25-Jun	21-Jun		21-Jun	
Parameter Group #4							
Low pulse count	1.0	4.0	6.0	4.0	0%	4.0	0%
Low pulse duration	2.9	5.5	20.6	37.0	573%	6.5	0%
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%	64.0	8%
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%	-2.0	-20%
Number of reversals	72.0	83.0	101.5	76.0	-8%	95.0	14%
EFC Monthly Low Flows							

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)

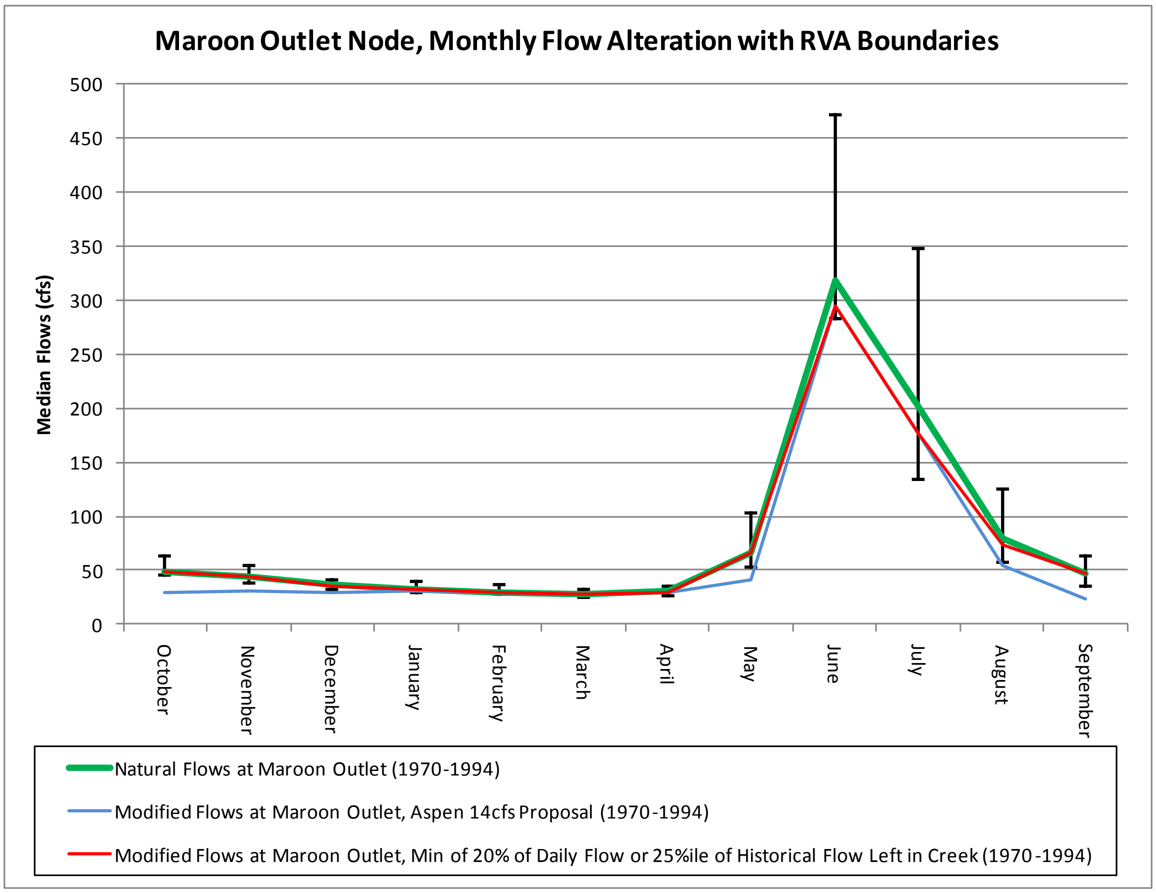
Node		Maroon Outlet Node						
		Natural Flows			Aspen Proposal (14 cfs min ISF)		20/25%ile Flow Limitation	
	Percentile	Pre-Project 25% (Lower RVA Bound)	Pre-Project 50%	Pre-Project 75% (Upper RVA Bound)	Post-Project 50%	% change in 50 %ile value	Post-Project 50%	% change in 50 %ile value
October	Low Flow	45.3	49.0	62.7	30.8	-37%	49.0	0%
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%	33.6	-1%
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%	29.3	0%
April	Low Flow	29.7	32.3	36.4	30.3	-6%	32.3	0%
May	Low Flow	42.0	53.7	82.7	35.0	-35%	53.7	0%
June	Low Flow	78.5	96.9	109.7	92.7	-4%	111.2	15%
July	Low Flow	90.4	105.7	110.7	94.0	-11%	100.9	-5%
August	Low Flow	57.2	77.5	90.4	58.7	-24%	73.4	-5%
September	Low Flow	36.2	48.1	63.7	35.0	-27%	47.1	-2%
EFC Flow Parameters								
Extreme low peak		23.3	25.5	26.3	24.4	-4%	25.5	0%
Extreme low duration		1.0	5.5	32.5	11.8	114%	5.5	0%
Extreme low timing		8-Feb	11-Mar	22-Mar	19-Mar		11-Mar	
Extreme low freq.		0.50	2.00	4.00	3.00	0.50	2.00	0.00
High flow peak		161.2	321.7	497.5	322.7	0%	336.1	4%
High flow duration		5.9	39.3	67.0	41.0	4%	34.5	-12%
High flow timing		10-Jun	26-Jun	23-Jul	15-Jun		14-Jun	
High flow frequency		0.00	1.00	1.00	1.00	0.00	1.00	0.00
High flow rise rate		7.4	14.0	22.0	16.3	17%	15.0	7%
High flow fall rate		-11.5	-8.5	-6.5	-9.2	9%	-8.7	3%
Small Flood peak		601.2	669.9	739.4	692.4	3%	692.4	3%
Small Flood duration		60.0	71.0	101.0	63.5	-11%	65.0	-8%
Small Flood timing		17-Jun	21-Jun	25-Jun	21-Jun		21-Jun	
Small Flood freq.		0.00	0.00	1.00	0.00		0.00	
Small Flood riserate		14.3	20.6	21.2	21.0	2%	20.4	-1%
Small Flood fallrate		-13.2	-12.1	-9.6	-13.0	7%	-12.8	6%
Large flood peak		772.5	808.6	844.7	820.2	1%	820.2	1%
Large flood duration		65.0	78.0	91.0	85.0	9%	87.0	12%
Large flood timing		25-Jun	27-Jun	29-Jun	25-Jun		25-Jun	
Large flood freq.		0.00	0.00	0.00	0.00		0.00	
Large flood riserate		26.1	28.1	30.2	26.3	-6%	25.2	-10%
Large flood fallrate		-14.8	-13.1	-11.3	-11.9	-9%	-11.7	-11%
Coefficient of Dispersion for Monthly Flows								
October			0.36		0.35	-2%	0.34	-3%
November			0.37		0.12	-68%	0.37	1%
December			0.27		0.08	-72%	0.28	2%
January			0.33		0.09	-72%	0.33	0%

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)							
Node	**Maroon Outlet Node**						
	Natural Flows			Aspen Proposal (14 cfs min ISF)		20/25%ile Flow Limitation	
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
February		0.30		0.13	-57%	0.30	0%
March		0.27		0.20	-27%	0.25	-8%
April		0.29		0.16	-46%	0.29	-2%
May		0.77		1.09	42%	0.68	-11%
June		0.59		0.64	8%	0.64	8%
July		1.06		1.21	14%	1.13	7%
August		0.86		1.24	45%	0.78	-10%
September		0.58		0.87	49%	0.53	-9%

Note: For two-period analyses, IHA re-assigns each daily flow value into a new EFC category. Therefore, post-impact EFC magnitude values (e.g. monthly low flows) are not directly comparable to the pre-impact values. To compare pre- to post-impact flow magnitudes, use IHA parameter groups #1 and #2 instead of EFCs.

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 are the same as IHA Parameter Group #1 in the table above for the Maroon Outlet Node. The range bars are associated with the natural flow line and indicate the pre-project range of variability; the top and bottom bars refer to 75^{th} and 25^{th} percentiles, respectively. From this graph, the post-project flows under Aspen's proposed bypass fall below the 25^{th} percentile RVA boundary during May and during August through December. Post-project flows under the 20% of flow/25^{th} percentile flow diversion limit proposal stay within the RVA boundaries during all months.



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.