Halligan-Seaman Shared Vision Planning

An Experiment in Collaborating for Regulatory Decisions

A project supported by the

Colorado Water Conservation Board

Fort Collins Utilities

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About this Report

This is a report from the grantees on a limited, experimental application of a collaborative planning process to one part of a contentious water management issue, an application for a Federal permit to expand two Colorado reservoirs. The report represents the views, observations and conclusions of the authors and not those of the participants in the process.

Government and non-government organizations that have strong, conflicting positions agreed to collaborate on a subset of the permit issues to create this experiment. The willingness to experiment together reflects the lengths participants are willing to go to meet common objectives despite deep divisions on the way to achieve those objectives. However, this report should not be mistaken for consensus on the permit issues or on the merits of the proposed reservoirs.

The authors believe the experiment was a success. One measure of the success of the experiment was that all participants agreed that the collaboration should continue, but the level and type of support varies among participants. Collaboration will bring its own risks and some participants may risk more than others. All participants are now engaged in a debate about whether and how the collaborative process should proceed.

Executive Summary

A multi-year experiment demonstrates the potential for using *Shared Vision Planning*—a well-established method for collaborative planning—to prevent or resolve disputes over permits for water supply projects. The proposed Halligan and Seaman Reservoir expansions are currently under review by the Corps of Engineers, which has permitting authority for such projects under Section 404 of the Clean Water Act. Past cases, such as Two Forks Reservoir in Colorado and King William Reservoir in Virginia, give reason to be concerned that the 404 permitting process will lead to costly, protracted disputes, and so the permit applicants for these projects—the cities of Fort Collins and Greeley, Colorado, and the North Poudre Irrigation Company—decided to test whether *Shared Vision Planning* might helpful for the permitting process. The results are promising and warrant further investigation of using SVP for these projects and other 404 permitting processes.

Shared Vision Planning was developed in the early 1990s as part of the Institute for Water Resources' National Drought Study. It combines three elements:

- A traditional **planning process** based on Federal water planning principles, but expanded to address multiple decision makers and (in some cases) an operational and adaptive management phase;
- A rigorous and efficient form of **public involvement** called "Circles of Influence" that is used to assure that the concerns of the public are addressed; and
- A **shared vision model**, a virtual version of the system to be managed that encompasses all the important impacts of possible decisions. The model is created in a process that engages stakeholders, experts and decision makers.

Shared Vision Planning (SVP) has been used for water management decisions around the country, from the Atlanta Metro Region to the Great Lakes to the Seattle Metro Area, but it has never been used for a permitting decision.

The experiment described here was of limited scope, just large enough to provide a worthwhile test but small enough to fit limited resources and time. It was described as a *play-within-a-play.* The larger play is the experiment to test SVP to see whether applicants, agencies and stakeholders could support eventually using SVP for the permit process. The play within the play is the use of the SVP method to design management strategies that would improve flows on the North Fork Poudre River. The assumption for the inner play was that Halligan and Seaman would be expanded as generally proposed by the permit applicants. The task was to develop environmental metrics and a shared vision model to explore potential refinements of the two enlargements (including down-sizing the proposed enlargements) and to support the design and evaluation of potential strategies for coordinated operations of the two reservoirs to promote environmentally beneficial flows on the North Fork.

This limited scope presented some problems. SVP was conducted separate from the Corps' 404 permitting process, but some participants voiced concerns that the limited scope of SVP would bias the Federal environmental impact study and permit decision because of the focus on only the applicants' preferred alternative (the Halligan and Seaman expansions). Further, there was no guarantee that success in the experiment would lead to success in a full implementation of SVP for the permit decision. Despite these and other issues, participants decided the experiment was worthwhile and remain interested to varying degrees in applying SVP further.

Participants in the experiment included representatives from the following organizations:

- Colorado Division of Wildlife

- Colorado State University
- Colorado Trout Unlimited
- Colorado Water Conservation Board
- Fort Collins Natural Areas Program
- Fort Collins Utilities
- Greeley Water and Sewer
- The Nature Conservancy
- North Poudre Irrigation Company
- Save the Poudre Coalition: Poudre Riverkeeper
- U.S. Army Corps of Engineers
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Forest Service.

One of the key advances from the experiment was the development of an array of environmental metrics related to North Fork Poudre River flows. That quantification makes tradeoffs more explicit and understandable. An environmental workgroup framed a set of environment objectives and developed the metrics to help in the design and evaluation of flow management alternatives. These metrics covered the following:

1. Hydrology, including comparisons of managed flows to natural flows and frequency of flood events.
2. Habitat availability as a function of flow for trout and native fish species.
3. Streambank inundation patterns as a measure of potential impact on riparian habitat.
4. A rough estimate of sediment movement processes.
5. Stream inundation by the expanded reservoirs.
6. Terrestrial inundation by the expanded reservoirs.
7. Flow requirements of the Joint Operations Plan.
8. Estimated impacts to flow on the main stem Poudre River below its confluence with the North Fork.

A shared vision model (SVM) was developed to simulate potential future operations of Halligan and Seaman Reservoirs, as well as operations of several high mountain reservoirs on the main stem, and to simulate the impact of operations on flows, especially on the North Fork. The environmental metrics were incorporated into the SVM and used to drive the design of operational strategies and evaluate the ecological impact of resulting flows.

Several modeling approaches were tested and the result is a set of flow management alternatives that can be expected to improve low flow conditions. The default operations would result in frequent increases of low flows compared to current conditions; the new flow management alternatives would go further in improving low flow conditions. Specifically, the flow management alternatives would virtually eliminate dry river conditions (zero flow) that would otherwise occur in about 50% of years in the reaches below the North Poudre Canal diversion. In addition to eliminating zero flows, the new flow management alternatives would increase flow from the North Poudre Canal to Seaman Reservoir during most of the driest months. For example, in months of July, August and September, tested alternatives would increase river flow from the North Poudre Canal to Seaman Reservoir by at least 50% compared to the default operations. These increases in flow can be important for fish habitat and other ecological functions.

These improvements come with some costs. First, all of the flow management alternatives involve expansions of Halligan and Seaman Reservoir, inundating about 8.7 to 10.6 miles of streams (depending on the exact size of the reservoirs) and about 750 acres of terrestrial habitat for various species.

Further, these larger reservoirs capture high flows and release them during low flow conditions, so the default operations and the new flow management alternatives would decrease some high flows on the North Fork. During the runoff season, which varies from year to year but generally falls between May and July, 10%-20% reductions in flow compared to current conditions will be typical. In Phantom Canyon, flow in the month May would decrease compared to current conditions, sometimes by nearly 40%. This is true for both the default operations and the new flow management alternatives—overall, they are similar in their impact on high flows.

The new flow management alternatives require various levels of coordination, storage sharing and water sharing between the cities of Fort Collins and Greeley. These flow improvements can almost certainly be achieved without sacrificing water supply reliability or yield. As noted above, all of the flow management alternatives would inundate stream and terrestrial habitat. However, one of the alternatives tested suggests that with additional water sharing (to an extent beyond the scope of the SVP experiment), Seaman Reservoir could be expanded to a smaller size than currently proposed with no loss of water supply reliability or yield. This would prevent about 1.9 miles of stream inundation.

While there have been some concerns and problems with this experiment, most participants and stakeholders agree with the results of this SVP experiment. There are still concerns with the projects in general (e.g., water conservation as an alternative, impacts to flow on the main stem Poudre River) but this SVP process has produced some improvements to the default preferred alternative, especially for low flow conditions. The play-within-the-play successfully demonstrated stakeholders' ability to work collaboratively toward a common understanding of issues and to identify opportunities for improving environmental outcomes by changing project design and operation.

What does this mean for the larger play: *can SVP be used successfully for the 404 permitting process?* The results in this experiment suggest that the answer may be "yes." The limited scope of the experiment and the remaining concerns among the participants mean that there are many issues to be resolved before an informed decision can be made about broader SVP. A broader SVP process would include the most difficult issues, such as demand projections and water conservation. So success in this limited test does not guarantee that SVP would be successful for the entire permitting process. The decision of how to proceed is not an easy one.

SVP facilitators recommend a further test of SVP by engaging in a collaborative process to develop a detailed work plan for a full-scope implementation of SVP and to investigate the necessary rules and agreements to set up the process. The work plan would be developed by working through the first iterations of the SVP process in an open and broad, but cursory manner. The point is to raise and discuss all of the key issues in order to describe the level of work that would need to be done to address these issues fully. The products would be scopes of work for each issue, which together would comprise a detailed Plan of Study for the entire SVP process. This would give the participants practical details on how the process would work. The participants would also develop rules of engagement to establish necessary decision-making procedures and roles and responsibilities for each participant. Finally, the participants would describe agreements among organizations that would be necessary to implement full SVP. These products would allow participants to make an informed decision about whether to use SVP for the entire permitting process, or alternatively, SVP could be considered to address limited issues, such as developing mitigation options.

The participants remain interested in further SVP are now seeking grants to support this next test of SVP.

List of Acronyms

APA – Applicants' Preferred Alternative

BATNA – Best Alternative to a Negotiated Agreement

CWCB – Colorado Water Conservation Board

EIS – Environmental Impact Statement

EPA – Environmental Protection Agency

FTC – Fort Collins

HMR – High Mountain Reservoirs

IHA – Indicators of Hydrologic Alteration

LEDPA – Least Environmentally Damaging Practicable Alternative

NEPA – National Environmental Policy Act

NGO – Non-Governmental Organization

NISP – Northern Integrated Supply Project

NPC – North Poudre Canal

NPIC – North Poudre Irrigation Company

SVM – Shared Vision Model

SVP – Shared Vision Planning

Definitions of Flow Management Alternatives:

Default APA – The applicants' default preferred alternative. This is the way in which Greeley, Fort Collins and NPIC would operate their systems without a new approach identified through the SVP experiment.

ModNormLHF – This stands for Modified normal "Low Hanging Fruit." This is the simplest modification of the default preferred alternative, giving FTC storage space in Seaman, when space is available, in order to recapture environmental releases from Halligan so that the water can be used for municipal or other demands later.

ModNormBETTER – This is a more sophisticated modification of the default preferred alternatives. This alternative also involves providing storage space in Seaman for FTC, but it also involves more complicated exchanges and water sharing. The water management features of this alternative may or may not be feasible for water rights, cost sharing or other reasons.

ModNormSMALLSEA – this take "ModNormBETTER" one step further by downsizing Seaman reservoir so that the dam can be built at the existing location, instead of moving downstream. This avoids destroying about 0.90 of the North Fork below the current dam site.

Introduction and Background

This is a report on a limited experimental application of collaborative planning to the regulatory process for obtaining a permit under Section 404 of the Clean Water Act to provide reliable water supply through proposed expansion of urban water supply storage. The hypothesis in the experiment was that shared vision planning (SVP), a specific form of collaborative planning, could produce better outcomes than would otherwise result from following only a standard regulatory decision process. The issues considered in the SVP experiment were a small subset of the issues considered in a 404 application to expand Halligan and Seaman Reservoirs north of Denver, Colorado; the issue set was large enough to provide a worthwhile test and focused enough to fit limited resources and time. The regulatory process continued in parallel while the SVP experiment was carried out; an information "firewall" between the two processes was established so that neither would affect the other prematurely. Primarily, this meant that the Corps did not introduce into the SVP experiment any information from the environmental impact statement (EIS) studies it was conducting for the Halligan-Seaman and other Colorado water supply permits. Most of the participants in the experiment have valued many aspects of this experiment. They have applied for a grant to develop a detailed plan of study to expand SVP to the full permitting process. However, they have not yet all endorsed the use of SVP in the Halligan-Seaman permit process. Some participants saw more reason to use SVP than others, mainly due to the assessments of each party on how well the traditional permit process will serve their objectives. No one is sure that the traditional regulatory process will produce timely or optimal decisions, but a year from now the completion of the draft Halligan-Seaman EIS and the public reaction to it should provide a clearer picture. No one is sure that SVP will shorten the time or produce better solutions, but the development of a detailed plan of study while the permit process plays out will give the participants much needed specifics about what an SVP study would actually entail, allowing the participants to be more confident about the choice for or against using SVP.

The cities of Greeley and Fort Collins, Colorado are planning to expand storage in two existing reservoirs, but doing so requires a permit from the Corps of Engineers. The sequential application of local planning and national regulatory processes has produced unsatisfactory results in other places, with decades-long permit review processes and controversial decisions. Water supply permit applicants face a difficult decision; persist in the highly structured regulatory process because the process is clear even though the results might be problematic, or try something that seems sensible – working with potential project opponents to plan a solution that is mutually agreeable – but has never been tried in this setting. SVP has well established planning and modeling procedures and has been used for about twenty years to address water conflicts, a body of experience which has not only improved the method but also helped make clear when it will not work. Over the last two years, the cities have worked with other interested parties, including non-governmental organizations critical of the reservoir expansions to apply SVP to an artificially constrained subset of expansion issues, essentially test driving the process to see whether it might work on the full issue set. The results have been encouraging, but the choice between regulation as usual and collaboration is still not obvious. This report summarizes the experiment and lays out the pros and cons of the decision facing all participants now.

Overview of 404 and the purpose for this SVP effort

Section 404 of the Clean Water Act of 1972 directs the Secretary of the Army to regulate the discharge of dredged or fill material into navigable waters of the U.S. In all but two states, the program is run by the U.S. Army Corps of Engineers (Corps) with oversight by the U.S. Environmental Protection Agency (EPA). A 404 permit is typically needed to expand municipal water supply systems because some component of that infrastructure must often be placed in a stream or other regulated body of water. The Corps expects 900 applications for permits by 2011 (Barry and Brumbaugh, 2007), a daunting number given the current methods and capacity for handling these applications.

As part of the permitting process, the Corps must ensure all permit actions comply with the Section 404(b)(1) guidelines as well as make a determination that the proposal is not contrary to the public interest. At times, the process has produced no solutions after decades of review and tens of millions of dollars of study. Two of the more notable examples are the Two Forks Dam project for Denver, Colorado, and the King William Reservoir project for Newport News, Virginia. The Two Forks Dam permit was granted by the Corps after a $37 million EIS process but was then vetoed by the EPA Administrator (Luecke, 1999). A decade later, the Norfolk (Virginia) Corps district denied the King William Reservoir permit, the denial was reversed by the Corps North Atlantic Division, but finally, a Federal Court ruling overturned the permit approval in 2009 after finding the Division and EPA approval of the permit “arbitrary and capricious” (Hirschauer, 2009). Newport News ended its pursuit of the project in 2009 after more than two decades and $54 million in costs (Hirschauer, 2009).

Background on Water Needs and the Halligan-Seaman Proposal

Colorado’s population is expected to double from 4.8 million in 2005 to between 8.7 and 10.3 million in 2050 (CWCB, June 2009).

The cities of Fort Collins and Greeley initially proposed the Halligan Seaman Water Management Project in partnerships with the North Poudre Irrigation Company (NPIC) and three water districts collectively known as the Tri-District, including North Weld County Water District, the Fort Collins-Loveland Water District, and the East Larimer County Water District. Tri-District decided to withdraw from the project in 2009.

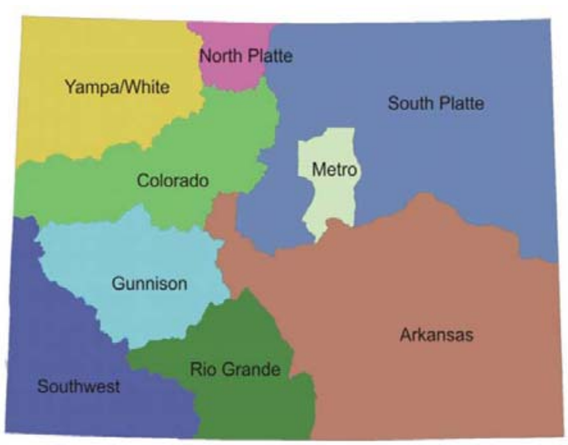


Figure 1 Colorado Water for the 21st Century Basin Roundtables

The project involves the expansion of two existing reservoirs: Halligan (owned by Fort Collins) and Milton Seaman (owned by Greeley) Reservoirs. Fort Collins and NPIC propose to expand Halligan from 6,428 to 22,318 acre feet; Greeley proposes to expand Seaman from 5,008 to 53,000 acre-feet. The proposed expansion of Halligan would serve as annual supply and drought protection for the city of Fort Collins and provide additional irrigation water storage for NPIC. The proposed expansion of Seaman would serve anticipated growth and for drought protection for Greeley, which has grown from 38,902 in 1970 to over 100,000 in 2005.

Overview of Environmental Concerns and Overall Objectives

Under the baseline operating plan in the applicants' preferred alternative, releases would be made from the upper reservoir (Halligan) into the North Fork of the Poudre when needed for water supply. The irrigation water would be diverted just below Halligan into the North Poudre Canal (NPC), the Fort Collins water would pass down the river and through the lower (Seaman) reservoir on its way to Fort Collins' water treatment plant. Because the releases would be timed according to water use demands and because much of the water is diverted at the NPC, the North Fork Poudre River between the reservoirs may not have much flow in many months (the flow rates and timing are designed to meet the urban and agricultural demand patterns, not to meet riverine environmental flow needs). The hypothesis tested in the SVP experiment was that if Halligan releases could be caught and stored in Seaman, then Halligan releases could provide NPIC demands and North Fork environmental flows, the latter stored in Seaman and released when needed to meet demands that would normally be met by either Halligan or Seaman.

There were many questions surrounding the hypothesis:

- There were no clearly defined, uncontested environmental demands for riverine flows.
- The Nature Conservancy has developed indices of hydrologic alternation (IHA), and these can be used as a preliminary guide when designing streamflow regimes. The premise of using IHA is that the existing riverine ecosystems developed in response to historic flow patterns, mostly formed before the large diversions, and that flows closer to the natural, unregulated and undiverted flows will be better for that ecosystem.
- In this case, it is probably infeasible to create the full flows that existed before water was diverted out of the river. The scope of the SVP experiment was constrained by the assumption that the applicants' forecasted demands would be assumed true and would have to be met. Because the NPIC demands were withdrawn from the North Fork between Halligan and Seaman, the flows between the NPC and Seaman would need substantial augmentation to be restored to the natural streamflow conditions present in that reach before there were large diversions.
- There would probably be conflicts among environmental objectives. For example, what would be better: scenario A which indicates a 50% improvement in native fish habitat below the North Poudre Canal and a 15% reduction in Preble's meadow jumping mouse habitat, or scenario B which indicates a 20% improvement for fish and a 10% reduction for Prebles? In addition to comparing scenarios, we will also want to understand tradeoffs in order to develop guidelines for model optimization.

Testing the hypothesis would require defining environmental flow needs.

Implementing Results and Adaptive Management

Participants referred to the experiment as having a "play within a play" structure such as was used in "The Taming of the Shrew" in which the play is about actors who put on a play. In this case, the larger play is an experiment in which the participants in the Halligan-Seaman permit process try SVP to see whether they would support the process. The play within the play is the attempt to design flow management strategies that would improve North Fork flows.

In the outer play, participants were able to observe first-hand how well some of the requirements for successful SVP would be met – things like the extent to which applicants were willing to change their preferred alternative or stakeholders were willing to tradeoff environmental and water supply performance. Discussions of how the true SVP process would be conducted allowed participants to judge the degree to which the purpose and need in the permit would be revisited. Based on what was learned in the outer play, participants supported going ahead with the next step in SVP, the development of a detailed plan of study. But while there was agreement to go ahead, the experience also allowed participants to develop a keener sense of what could go wrong. In the last SVP workshop, participants discussed problems that could arise if SVP would extend the time required for Greeley and Fort Collins to obtain water supply solutions and if other projects—especially the Northern Integrated Supply Project, or NISP—using the traditional permitting approach were awarded more expeditiously. In this case, the Greeley-Fort Collins evaluation might suffer, working under the assumption at that point that there would be less water to share with the environment and that the least expensive mitigation options would have been used by the other permittees.

Because of the limited scope used in this experiment, the improved operating plans for Halligan and Seaman Reservoirs are too preliminary to be implemented or adaptively managed. Lessons learned from the experiment may be applied to improve the applicants' preferred alternative, and the experience in attempting to rank plans using conflicting environmental metrics could well serve the development of an adaptive management plan to modify releases based on actual environmental results.

The shared vision model estimates future flows and reservoir levels, relating water flows and levels to various outcomes based on the best available understanding of that relationship. But what if future water supplies and demands are different from those in the model? What if the relationships modeled in the SVM between flow and environmental quality are substantially wrong? If the SVP process were extended and did provide operating rules and reservoir configurations, an uncertainty analysis would be completed that showed the sensitivity of the conclusions to those uncertainties. An adaptive management plan would be developed to address the key uncertainties and that plan would be part of the permit. A monitoring program would be designed to collect hydrologic and biological data when necessary to provide more information to support or reject the modeled relationships. Possibilities for these approaches are highlighted later in this report.

The SVP Process

The particular form of collaboration used in this experiment is called Shared Vision Planning, or SVP. SVP is a modified form of traditional water resources planning that includes new approaches to public involvement and the use of computers for planning and decision making. Since its development in the early 1990s, shared vision planning has been used in many water conflicts – usually in situations that had defied resolution using other means.

General background on SVP

Decisions about how water is controlled and distributed are made using a combination of approaches including markets, legislation, regulation, adjudication and administrative policy making. Planning - broadly, the consideration of consequences before making a decision – is typically used to evaluate and justify investments in water projects and changes in the operation of existing projects. Federal water project investment planning is conducted according to a highly detailed set of rules called Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (the P&G) that is supported by decades of practical experience and numerous books, reports and papers with consistent and sound advice on the application of the guidelines.

SVP is a particular type of water resources planning. It was designed during the National Drought Study by the Corps of Engineers' Institute for Water Resources as a way to develop tactical drought response plans – ready, on the shelf responses to a future, temporary water shortage that could happen at any time - when there were multiple decision makers and conflicting decision criteria. But the design of SVP lends itself to any sort of planning and it has been applied for other purposes in numerous studies since. It was used in the Comprehensive Study of the Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa River Basins (1993-1996) to address long term water supply planning and basin reservoir systems management. In 1997, it was used to demonstrate that a robust decision about whether or not to pump water from Devils Lake, North Dakota could be made confidently despite irreducible uncertainty about future flooding. The St. Paul District of the Corps of Engineers used SVP to simultaneously consider short and long timestep issues (flooding and reservoir water supply management) on the Upper Mississippi River. SVP was used on the International Joint Commission (IJC) study of Lake Ontario levels and is currently being used with more sophisticated climate risk approaches on the IJC study of Upper Great Lakes levels. Peruvian SVP studies under World Bank and Inter-American Development Bank loans will extend SVP public involvement methods to stakeholders who are more separate and disenfranchised than any to date.

There are three essential attributes of shared vision planning:

- A traditional **planning process** based on Federal water planning principles, but expanded to address multiple decision makers and (in some cases) an operational and adaptive management phase;
- A rigorous and efficient form of **public involvement** called "Circles of Influence" that is used to assure that the concerns of the public are addressed;
- The **shared vision model**, a virtual version of the system to be managed that encompasses all the important impacts of possible decisions. The model is created in a process that engages stakeholders, experts and decision makers.

Three works from the 1940s, 1950s and 1960s are arguably the most influential on water resources **planning**; Gilbert White's 1942 thesis, *Human Adjustment to Floods* and Arthur Maass' two books, "*Muddy Waters*" (1951) and the "*Design of Water Resources Systems; New Techniques for Relating Economic Objectives, Engineering Analysis, and Governmental Planning*" (1962) a textbook by participants in the Harvard Water Program which Maass led. White is considered the father of *floodplain management*, based on the insight that engineers should not control water if adjusting behavior provides a better result. In *Muddy Waters*, Professor Maass argued that a Federal executive branch agency was obliged to design water projects that served the President and national interests rather than (just) the desires of special interests and individual Congressmen. *Design of Water Resources Systems* suggested an analytic approach and likely national objectives for that design. Professors White and Maass and other participants from the Harvard Water Program worked in and outside government to develop practical planning guidelines that operationalized their principles. There is a traceable path from their work to the P&G. SVP uses the same basic planning process except that it includes methods to determine and apply the decision criteria of multiple decision makers and it goes beyond the recommendation phase and can be used operationally or in adaptive management.

The **Circles of Influence** approach to public involvement begins with the traditional attempt to identify impacted parties, but actively seeks to engage the parties using existing relationships such as professional and trade societies to build trust and reduce costs. If there is a central idea to Circles of Influence it is to win the trust of those who are trusted and respected rather than trying to create trust directly in the agency management team.

The **shared vision model** is a single computer model of the system being studied that decision makers, experts and stakeholders all use to test new management ideas and investments. Models like this were imagined by C.S."Buzz" Holling (1978) when he wrote about adaptive management in the 1970s. Richard Palmer used an interactive simulation model to help resolve conflicts over how to supply water to the Washington, D.C. metro area in 1980 (Palmer et al, 1982), and it was he who introduced the idea of the shared vision model to the National Drought Study team more than a decade later.

Summary of the Scope of Work

This work focused on five of the seven steps of the shared vision planning process:

- Building a team, identifying problems and opportunities;
- Developing a baseline and metrics for comparison of plans;
- Formulating alternatives;
- Evaluating individual alternatives using the metrics mentioned above; and
- Comparing alternatives.

Because the experiment was artificially constrained with no attempt to produce an actionable preferred plan, less emphasis was placed on ranking plans and adaptive management of the selected plan.

Building a team, identifying problems and opportunities. The participants took pains to include all parties with a voice in the permitting decision. Because of the constrained scope of the experiment, some recognized problems were not considered, but where possible, the participants tried to extend the experiment to address concerns outside the scope of the experiment that were important to participants. For example, the scope of experiment did not include flow on the mainstem of the Poudre River below its confluence with the North Fork, but some attempt was made to estimate impacts of Halligan and Seaman on mainstem flows.

Developing a baseline and metrics for comparison of plans. The shared vision model (SVM) was modified to more accurately and fully produce the levels and flows of the applicants' preferred alternative as represented in their system models, built in MODSIM and Excel. Donnie Dustin and Paul Weiss ran the system models and provided background information to make the translation from those models to the SVM (built in Excel) possible. This became the baseline for comparing new plans. In addition to the water supply metrics (reliability, vulnerability and resilience) the Environmental Work-Group developed metrics for a variety of animal and plant species. John Sanderson led the development of a family of environmental metrics.

Formulating alternatives. Mark Lorie developed an array of alternative reservoir sizes and operating policies using an "Unconstrained" version of the model (see below). He and Bill Werick developed this version, acting on a suggestion by Lee Rozaklis. In the Unconstrained condition, all storage and all water was considered sharable among the participants. Halligan Reservoir was used to store water for NPIC demands and North Fork environmental flows and Seaman Reservoir was used to store water for deliveries to both Fort Collins and Greeley.

Evaluating individual alternatives and comparing them. Mark Lorie and John Sanderson combed through successive versions of many alternatives, reformulating to improve plan performance using the full suite of metrics.

All of this work was presented as it was developed in two major workshops (December 2009, April 2010). The participants worked together electronically and in several committee workshops, small group meetings and several teleconferences.

Relationship to the Permitting Process

This was an experiment to determine whether SVP could be used to collaboratively design a future that addresses all stakeholder interests around water supply and the environment, thereby providing a better outcome than the traditional processes used to meet National Environmental Policy Act (NEPA) and Clean Water Act requirements. There have been a few instances in which Clean Water Act permits for water supply projects have taken decades to resolve, some leading to denials (Shabman and Cox, 2004).

On November 24, 1990, EPA Administrator William Reilly vetoed the Corps permit of the Two Forks Reservoir for Denver water supply. The permit had been granted by the Corps after a nearly $40 million environmental impact study. However, EPA found that the potential for meeting future population needs through water conservation had not been adequately investigated and that Two Forks Reservoir imposed unacceptable impacts to the aquatic ecosystem. One practical consequence of the veto was that Denver suburbs which could have received water from the Two Forks dam had to address their own water supply needs, and had to consider how to avoid an EPA veto after years of study.

Fifteen years later, Mark Lorie, representing Corps planners investigating the 404 water supply issue approached four 404 applicants in the Denver area (Denver Water, Northern Colorado Water Conservancy District, Fort Collins and Greeley) with the idea of using SVP. The cities of Fort Collins and Greely considered it for a time, but then in April, 2006, decided they were not ready to experiment with SVP. The cities said they might use it in the final stages of the permit, to design an operating policy and tailor a mitigation plan to the final design.

Meanwhile, The Nature Conservancy (TNC) had been attempting to engage in the planning of the proposed water supply system for Fort Collins and Greeley, because they recognized both a risk and an opportunity with the project. The risk was that the project would impact the remaining natural aspects of flows in the North Fork. The opportunity was to improve winter flows and to demonstrate an improved approach to water supply planning. Heather Knight, the Laramie Foothills Project Director for TNC, had independently learned about SVP and she facilitated acceptance of the approach by the cities. In May, 2007 the city of Greeley, speaking on behalf of all players in the Halligan-Seaman EIS, told the Corps they were willing to consider an SVP process, but as an experiment in parallel to the permitting process and on a limited subset of the problem, restoring flows in the North Fork of the Poudre River between the expanded Halligan and Seaman reservoirs.

The Corps had just started the Western States Watershed Study and agreed to support an investigation of SVP for Halligan-Seaman. This was the first phase of the study. It was designed as a proof of concept, showing that the SVP approach was technically feasible.

The potential participants in the SVP experiment met in a June 3-4, 2008 workshop designed to make a final decision on whether to proceed with the shared vision planning experiment. Participants at the workshop included the Sierra Club, TNC, the cities of Greeley and Fort Collins, US Forest Service, Colorado State University, the Western States Water Council and others. A primary objective of that workshop was for participants to consider and answer five triage questions (Werick and Palmer, 2004) to determine whether SVP was likely to help. The five triage questions are:

1. How could SVP improve management if it lived up to expectations?
2. Would the SVP effort be overridden by another process?
3. What issues about open disclosure would weaken the SVP approach?
4. Would the SVP address the real issues that will drive decisions in this basin?

5. What are the practical concerns (money, time, talent, etc.) that would have to be resolved for this to work?

The participants divided themselves into three sub-groups to create three independent responses to the five questions, but the collective answers were consistent and positive. The participants themselves believed that the conditions which would cause SVP to fail were not a serious threat to this case study. In sum, the participants answered the first question by saying that SVP could produce a reservoir design that was better for the region and at the same time provide experience with a process that was better for managing permit decisions. None of the three subgroups believed that the SVP would be overridden by another process (typically, markets, lobbying, adjudication, and legislation) although there was awareness that another project in the region, NISP, was more controversial and its permitting process could affect the working relationships of people who worked on NISP as well as Halligan-Seaman. There was no collective response from the sub-groups about any one party not participating in an open planning process for fear of exposing secrets about their water systems. On the fourth question, participants agreed that the SVP experiment was actually designed to avoid some larger issues, such as whether the applicants' preferred alternative was the best solution to their water supply needs, but all agreed to that compartmentalization and felt that within that compartment, the analysis would be realistic, dealing substantively with water supply and instream flow requirements. Finally, the participants all worked on how they could fund their participation. For some, participation would have to involve a minimum of expense and activity (participation in the major workshops, but nothing else). But the cities and TNC began to consider how they could get funding support and establish their own project manager for the work. The workshop ended with an agreement to move forward with the SVP experiment. Since the workshop, the Colorado Water Conservation Board awarded the city of Greeley a $102,000 grant for the project.

In the second phase of the study supported by the CWCB grant, from September 2008 through June 2010, the cities and NGOs led the development and modeling of more alternatives and more detailed and comprehensive ecosystem metrics. This phase included four large workshops and many smaller meetings of individual workgroups.

The Rules of Engagement

During a November 2008 workshop that began the North Fork experiment, all participants agreed to be bound by *rules of engagement* governing personal behavior with regards to the collaborative effort. Bill Werick presented examples of rules used in different conflict resolution processes and provided a starter list of rules. The partners in the experiment refined and expanded these rules at the November 2008 workshop, agreeing to this rule set:

1. *Do unto others as you would have them do unto you.*
2. *Facilitators can offer expert advice but must remain neutral on all issues and decisions.*
3. *While participating in the SVP, participants should not act outside the process to undermine SVP. However, participants are expected to withdraw from the collaboration if and when their BATNA (Best Alternative to a Negotiated Agreement) better serves their objectives and constituents than would further collaboration.*
4. *Participants should share information that would change others' decision about the best alternative or withdraw from SVP.*
5. *Participants must honor laws and policies about privacy, proprietary information; if you can share, share, if not express your concern and negotiate a solution with other participants or withdraw.*

6. *Newcomers are welcome if they follow the rules and get up to speed so they don't hold people up.*
7. *Exits may be crippling, so participants should let others know as soon as possible and see if it can be avoided.*
8. *Check with others before issuing press releases. Greeley's PR firm will be used for press releases for the entire SVP group. A review group for all press releases will be formed. This group will review drafts of press releases before they go out.*
9. *We want consensus; in fact there is a concern that to not achieve it would be defined as a failure of the collaboration.*

Enforcement of the Rules

1. *If you are breaking the rules, stop.*
2. *If you find out someone is breaking a rule,*
   a. *confront the individual about the issue yourself;*
   b. *If you don't want to confront the person or if it doesn't work, go to the Enforcement Committee (Chandler Peter, Gene Riordan, Heather Knight);*
   c. *Finally, take the issue to Bill Werick and he will make it public to the whole group.*

Participants and the Workgroups

Representatives from the following organizations participated in this SVP experiment:

- Colorado Division of Wildlife
- Colorado State University
- Colorado Trout Unlimited
- Colorado Water Conservation Board
- Fort Collins Natural Areas Program
- Fort Collins Utilities
- Greeley Water and Sewer
- The Nature Conservancy
- North Poudre Irrigation Company
- Save the Poudre Coalition: Poudre Riverkeeper
- U.S. Army Corps of Engineers
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Forest Service

Participants were organized into five workgroups:

- Modeling workgroup – develop the SVM and make it consistent with the applicants' system models; formulate flow management alternatives;
- Environmental workgroup—develop objectives and metrics for evaluating the environmental impacts of flow management alternatives;
- Water rights & operations workgroup—review the SVM and flow management alternatives to ensure feasibility given water law, available water rights portfolios, and operational constraints;
- Dam design workgroup—investigate and document dam design issues presented by environmental objectives and flow management alternatives;
- Adaptive management workgroup –investigate and describe potential adaptive management programs for Halligan-Seaman.

General Timeline

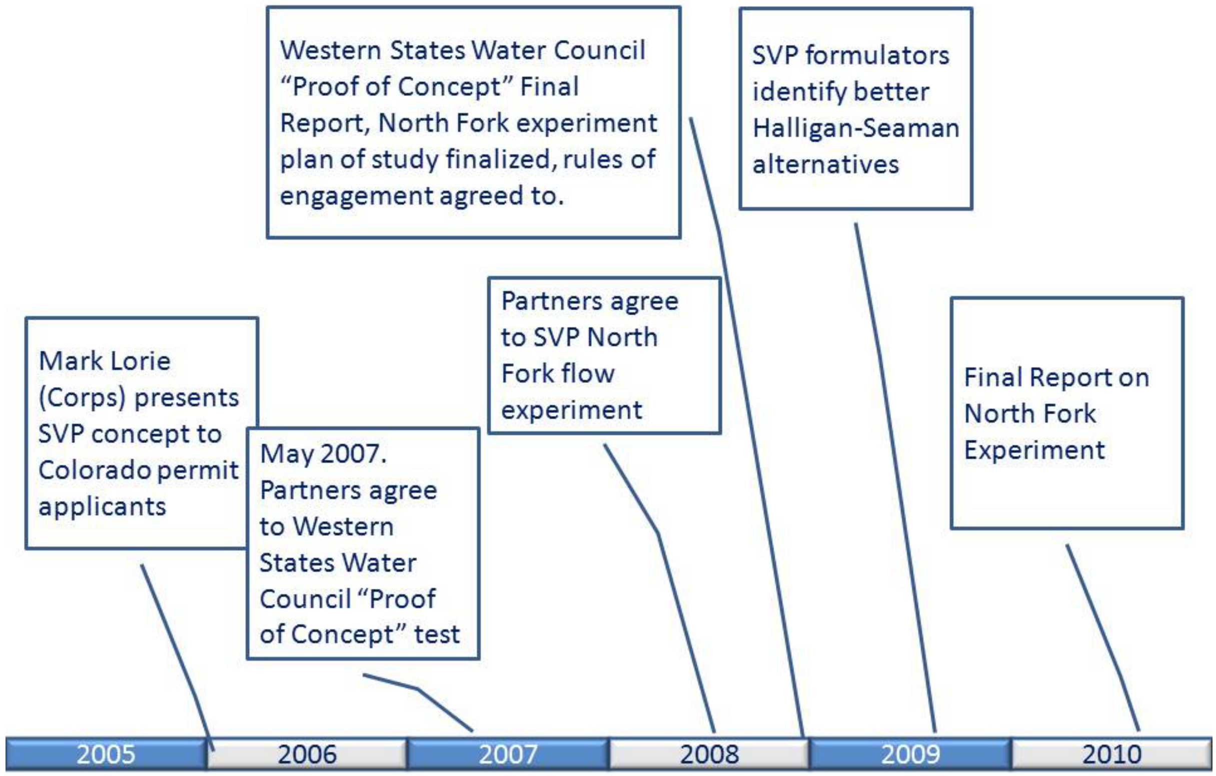


Figure 2 Timeline of the Halligan Seaman SVP Experiment

Figure 2 depicts the significant milestones in the SVP experiment, including events leading up to this study.

Problems and Issues

There is little reason to believe that SVP will make Fort Collins and Greeley water supply planning easy or certain. The "triage" questions identify, from experience, conditions that must be met for SVP to be successful, and these conditions are not always present. SVP can help resolve differences about facts but is not meant to resolve value or belief differences. Beyond these general concerns, there were specific issues that gave different participants pause:

- The Save the Poudre Coalition, a non-governmental organization, noted that the experiment was so constrained it could not consider a full range of alternatives (conservation of water to meet future supply needs, for example) nor would it distinguish changes in impacts to the main stem Poudre River. At the same time, the limitation of the SVP experiment to modifications of the applicants' preferred alternative might work against those who wanted a fair comparison of all alternatives by making the applicants' preferred alternative good enough environmentally to be permitted while there were better environmental alternatives not favored by the applicants that would be dismissed.
- The Corps and EPA were supportive of shared vision planning despite the challenges it presented for them. For the Corps, SVP is more work for an already over-worked regulatory

staff. For both EPA and the Corps, SVP requires a new set of responsibilities that might make their standard responsibilities more difficult. Specifically, both the Corps and EPA have a regulatory and decision-making role in the 404 process. The Corps district hears all sides and then decides what will be permitted; EPA may review and may even over-rule the Corps. As decision-makers they must be involved in the SVP process, which means they will articulate specific decision criteria and participate in preliminary evaluations to clarify, even in a trial and error process, what is permittable and what is not. Their decisions during the process could be used in an adversarial action if the SVP experiment does not produce the results desired.

- For all parties, the openness of the SVP process can become a liability if the SVP process fails and the process becomes adversarial again – openness in one context is discovery in another.
- For the applicants, who bear much of the cost of the EIS process, SVP offers both the promise of expedited solutions if it is successful and the threat of costly delays if it is unsuccessful. In a region with multiple, sometimes overlapping water supply projects in review, permitting delays may make it more difficult to get a permit, for two reasons. First, if other projects are permitted to take water out of rivers impacted by Halligan-Seaman, those earlier permitted withdrawals may make the environmental consequences of the incremental Halligan-Seaman withdrawals more significant. Second, once the least environmentally damaging practicable alternative (LEDPA) is selected, it may still be necessary to mitigate the damage even if it is less than other alternatives. In some cases the first to mitigate may mitigate more cheaply.

The participants supported the development of a plan of study to do SVP despite these concerns. In part that is a measure of faith participants have in one another and in the process, in part it is because the specter of a two-decade-long permit review ending badly hangs over the decision.

The Shared Vision Model

Purpose and Scope

The Shared Vision Model (SVM) was developed to test flow management alternatives for the North Fork. Based on the scope of the SVP experiment, the SVM models a future scenario (a projection for the year 2050) in which Halligan and Seaman Reservoirs are expanded, as currently proposed by the permit applicants. The future scenario in the SVM also includes projected future water rights yields and future water demands for each applicant.

The SVM includes the following water resources features for Fort Collins (FTC), Greeley and NPIC:

- The North Fork from Halligan Reservoir to its confluence with the mainstem Poudre, modeled as four lumped reaches: Below Halligan (including Phantom Canyon), Below the North Poudre Canal (NPC), Above Seaman (below tributaries), and Below Seaman;
- Halligan Reservoir, FTC, TriDistricts and NPIC storage;
- FTC, TriDistricts, and NPIC storage rights for Halligan Reservoir;
- Bypass flow on the North Fork at Halligan Reservoir;
- The NPC, including releases from NPIC storage in Halligan and direct flow rights;
- Seaman Reservoir, Greeley storage; FTC and TriDistricts storage for testing coordinated operations alternatives;
- Greeley storage rights for Seaman Reservoir;
- Joe Wright Reservoir (FTC's High Mountain Reservoir on the mainstem Poudre);
- FTC storage rights for Joe Wright Reservoir;

- Greeley's High Mountain Reservoirs on the mainstem Poudre, aggregated into three lumped storage quantities for modeling simplicity;
- Greeley's storage rights for the High Mountain Reservoirs;
- Greeley's planned exchange and pump of excess HMR yields to Seaman; and
- Converted agricultural water rights on the lower mainstem and exchanges to Halligan and Seaman.

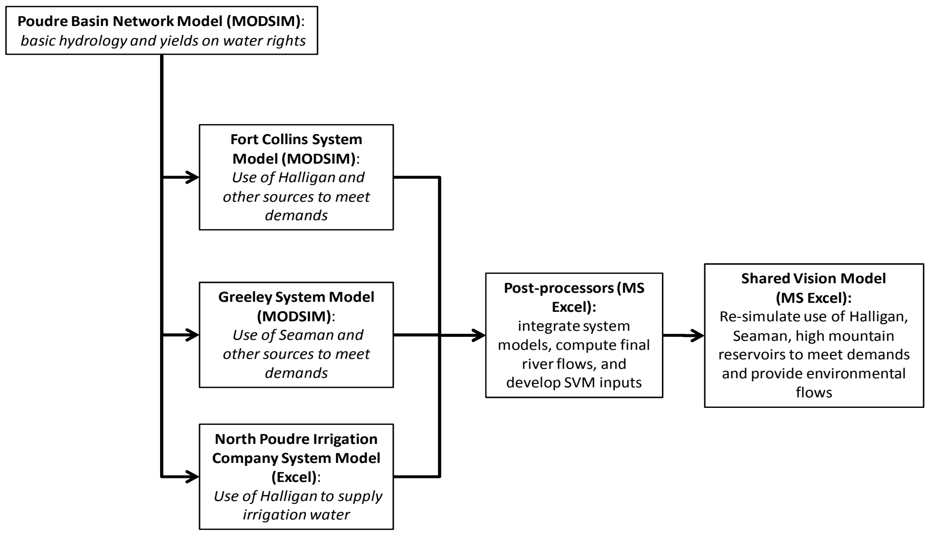
Note that during the SVP process, TriDistricts dropped out as a partner in the Halligan project. The original SVM was designed when TriDistricts was part of the project. Those parts of the SVM dealing with TriDistricts' share of the project were left in the final version of the SVM but they were made inactive so they have no impact on the results. For example, TriDistricts' share of storage is set to zero; their shares of converted agricultural rights are assumed to back to the ditch of origin.

The SVM integrates a suite of other models built in MODSIM and Excel: the Poudre Basin Network Model (MODSIM), Fort Collins system model (MODSIM), TriDistricts system model (Excel), NPIC system model (Excel), and Greeley system model (MODSIM). Those models are used to simulate future water rights yields and to determine how each applicant will use their systems. Some of each applicant's simulated future need is met from sources outside the SVM (e.g., water from the Colorado Big Thompson project, direct diversion on the mainstem Poudre). The SVM re-simulates water that comes only from sources on the North Fork and the HMR, and exchanges to the North Fork reservoirs. In other words, the system models determine the portions of the applicants' yields and needs that come from the North Fork and HMR systems, and the SVM is used to retime how these selected sources are used in order to meet the selected portions of the applicants' demands while also meeting environmental flow objectives. Since the system models are run largely independently, the SVM is the only tool capable of testing coordinated operations among the applicants, even though it simulates only portions of the applicants' systems.

General Documentation of the SVM

The SVM is a basic water balance model built in Microsoft Excel. The core of the model is a simulation of the future scenario in which Halligan and Seaman Reservoirs are expanded. The model uses time series of water rights yields, minimum required releases from each reservoir, and total water deliveries required from the North Fork and HMR sub-systems. These time series come from output from the applicants' system models. The main part of the SVM re-simulates how Halligan, Seaman and HMR are used to meet specified portions of the applicants' demands. The model runs on a monthly time-step and simulates a period of 86 years. Part of the simulation is based on historic stream gage data, but it also includes 30 years of stochastically generated streamflow data. The historic and synthetic data are strung together to allow for one continuous simulation.

Figure 3: Models and connections for Halligan-Seaman Shared Vision Planning (TriDistricts not shown)



The SVM uses inflows, demands, and environmental target flows to calculate releases from each reservoir for each month in the simulation. Using simple mass balance calculations (including estimates of evaporation), end-of-month storage for each reservoir and each compartment in each reservoir (e.g., NPIC and FTC storage in Halligan) is calculated for each month. The SVM was designed in part to mimic the results of the applicants' system models. The base simulation uses several rules to balance between use of Halligan, Seaman, and the HMR in order to replicate results of the system models.

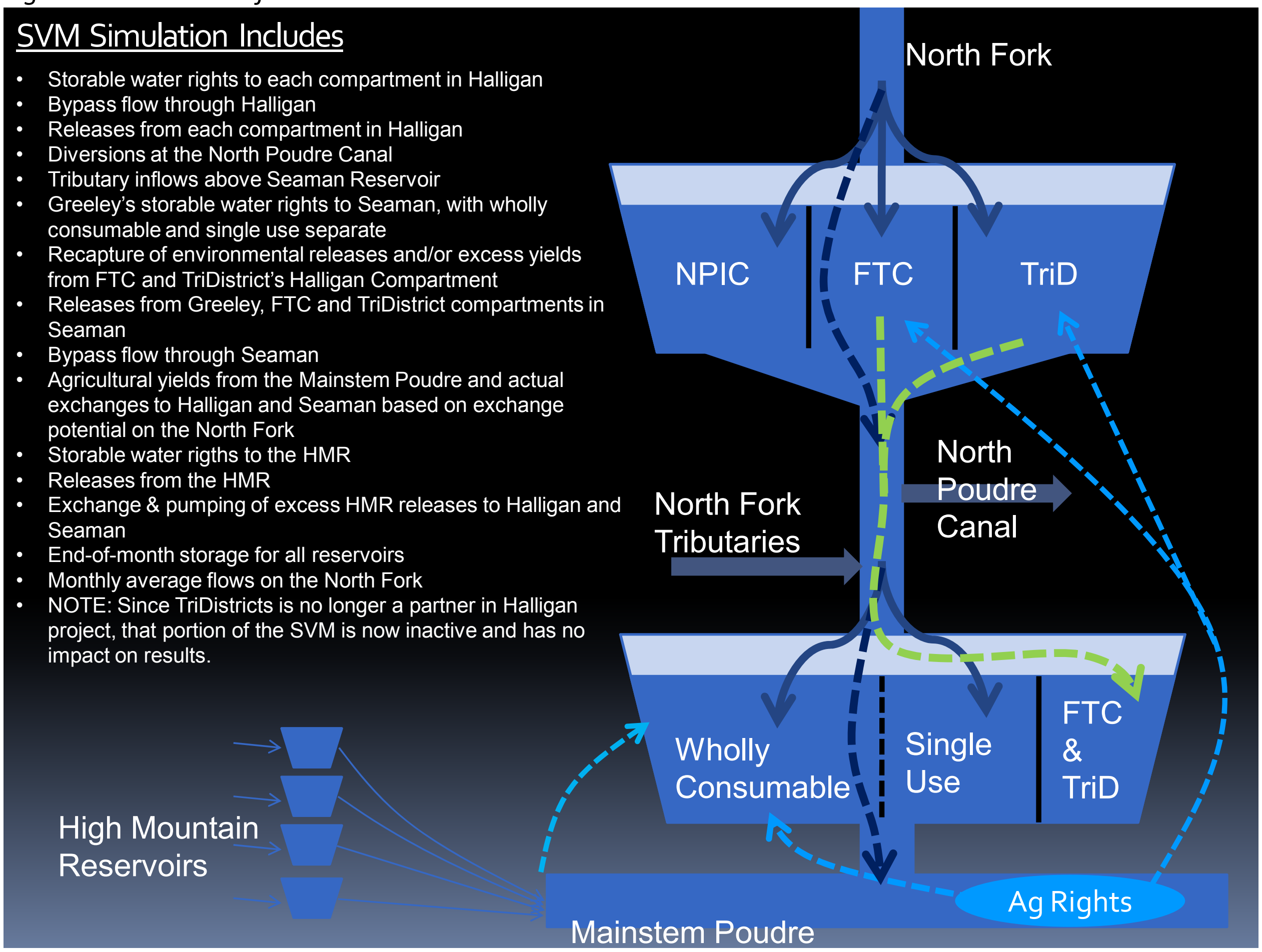
Once the SVM could successfully replicate the applicants' models, tools were added to modify the operations and test alternatives. The final version of the SVM allows for the following changes to test alternatives:

- Size of FTC's storage compartment in Halligan (NPIC is not changed);
- Total size of Seaman;
- Option to provide storage space for FTC in Seaman and an option to set the size of that space (otherwise FTC is given access to space available each month);
- Option to exchange HMR excess releases to Halligan; and
- Option to share yields on converted agricultural water rights.

Other options were tested throughout the study. For example, various means for storing Greeley's North Fork water rights in Halligan were investigated. The final list of options shown above were those that provided the most benefit in terms of managing for environmental flows on the North Fork.

The SVM (and the system models) run on a monthly time-step, calculating end-of-month storage values for reservoirs and monthly average flows or water rights yields on the river. This is appropriate for water supply planning, but less so for planning to meet environmental flow needs. But developing a model with daily or smaller time-steps was not feasible given available resources. To address this need, a method was developed to estimate daily high and low flows within each month. The method was based on statistics of past daily flow variations about the monthly average flow within each month of the record. The estimated daily flows were labeled "probable daily high flow" and "probably daily low flow" and were used to gage potential impact of daily flows on environmental metrics. A link to the description of this method and how it was used can be found in Appendix 5.

Figure 4: Schematic of the SVM Simulation



<u>Environmental Goals and Metrics for Halligan-Seaman</u>

We identified seven general categories of river resources that need to be evaluated:

1. Fish, including native fish and trout;
2. Aquatic macroinvertebrates, particularly in Dale Creek which supports a high-quality community;
3. Riparian and wetland plant communities;
4. Preble's meadow jumping mouse;
5. Fluvial geomorphic functions, including sediment transport, erosion, and deposition;
6. Water quality, including temperature and nutrients; and
7. Terrestrial habitats for game species, as they are impacted by inundation and fragmentation.

Desired outcomes for these resources were expressed in the following goals:

1. Maintain a conservation area for transition-zone native fishes that are likely to continue disappearing from the northern Front Range with increased water use and climate change. Examples could be *Iowa and johnny darter*, creek chub, longnose sucker, common shiner, stoneroller minnow, and *longnose dace*. Species in *italics* have been recorded from the North Fork Poudre River.
2. Maintain self-sustaining trout populations that support a fishery. However, trout populations may be managed in deference to the goals of maintaining a native fish conservation area.
3. Maintain a complex riparian habitat by allowing for adequate water supplies, floods that regenerate habitat and sediment supplies that support plant recruitment and soil health. This riparian habitat supports numerous terrestrial species, including Preble's meadow jumping mouse, while also supplying litter and invertebrates to the river, which in turn support native fish and trout. Riparian vegetation also supplies large woody debris, maintains shoreline complexity that may buffer native fishes from trout predation, and provides shade that influences temperature regimes.
4. Maintain geomorphic and sediment transport processes. For example, ensure periodic flows suitable for scouring gravels needed by trout and native fish for spawning and invertebrate production.
5. Maintain viable populations of critical terrestrial species, including Preble's meadow jumping mouse and game species such as mule deer and elk.
6. Minimize inundation of streams (especially the North Fork and Dale Creek) caused by reservoir expansion.
7. If possible, improve Joint Operations Plan flows and mitigate impacts on mainstem flows.

Metrics for Evaluating Flow Management Alternatives

To evaluate changes to the seven resource categories listed above and to gain insight into the project's capacity to meet the above stated goals, we developed explicit quantitative metrics that could be evaluated using the SVM. These metrics do not address all aspects of desired environmental outcomes and their evaluation. Rather, they allow some perspective on each resource in a quantitative manner that can be compared across multiple future scenarios. Available resources constrained the depth and breadth of the analyses.

Each quantitative metric (see Table 1 below) was calculated for natural conditions (i.e., no water infrastructure on the river), current conditions, the Applicant's Preferred Alternative (APA), and three variations on the APA. Temperature was not explicitly modeled, but was described in detail with recommendations as it may affect native fish reproduction and growth (Appendix 4). Results for each of the metrics are presented in tables and charts that allow comparison across scenarios (Appendix 1).

Hydrology-Based Metrics

Flow is a master variable related to all river ecosystem function (Poff et al. 1997). In the absence of detailed and specific knowledge about ecosystem response to flow patterns, the natural flow regime (Poff et al. 1997) can be assumed to support all native species and ecosystems in and along a river. General knowledge of species and ecosystems as well as fundamental ecological principles can be used to infer ecological changes that may occur in response to changes in various aspects of the flow regime (see Appendix 3). For example, reductions in peak flows can lead to less sediment movement and reductions in baseflows reduce total available habitat for aquatic species.

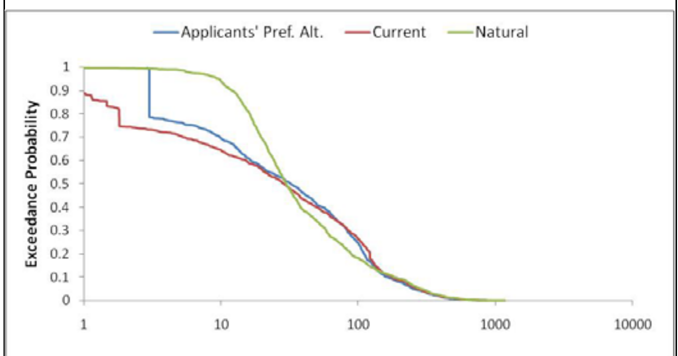
Figure 5 shows four perspectives on hydrologic changes that were included in the SVM and used for evaluations of alternatives. Appendix 1 provides the charts and tables shown in Figure 5 for all of the alternatives described later in this report.

Table 1: Categories of Environmental metrics with quantitative results

1) Hydrology-based metrics
2) Stream temperatures for native fish (descriptive only)
3) Stream temperatures for trout (descriptive only)
4) Fish habitat availability (trout and native)
5) Sediment transport and channel maintenance
6) Streambank inundation by high flows
7) Stream inundation by reservoirs
8) Terrestrial habitat inundation by reservoirs
9) Interactions between brown trout and native fish
10) Improvement of JOP flows
11) Main-stem minimums below the confluence

Figure 5. Examples of four primary perspectives on hydrologic change. Charts/tables for all alternatives can be found in appendix 1. (a) A flow duration curve, showing the probability of flow exceeding a certain value. All alternatives decrease the probability of flows less than about 10 cfs. (b) Percentiles of average monthly flow throughout the simulation: minimum, 5th percentile, median, and 95th percentile by month (months top to bottom are Jan-Dec). Blue indicates higher flows compared to a reference condition (in this case, current conditions); orange indicates lower flows—typically occurring during runoff in May and June. (c) A hydrograph showing monthly patterns over the entire simulation. The green band shows current conditions. The black line shows mean monthly flows under a given scenario, and the dashed blue lines show the range of probably daily flows under that scenario. (d) The proportions of exceeding (blue), meeting (green) and falling short of (red) environmental flow recommendations presented by The Nature Conservancy at the beginning of the SVP process (see Appendix 3).

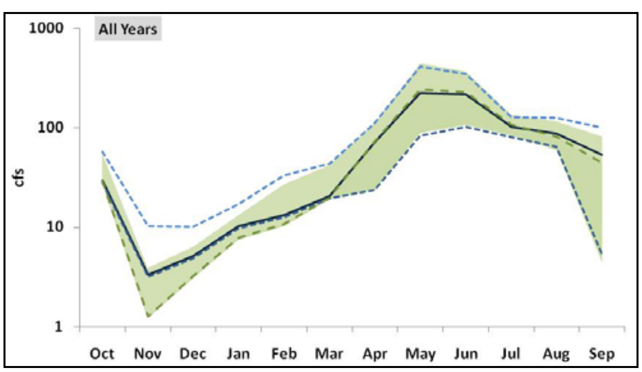
(a)



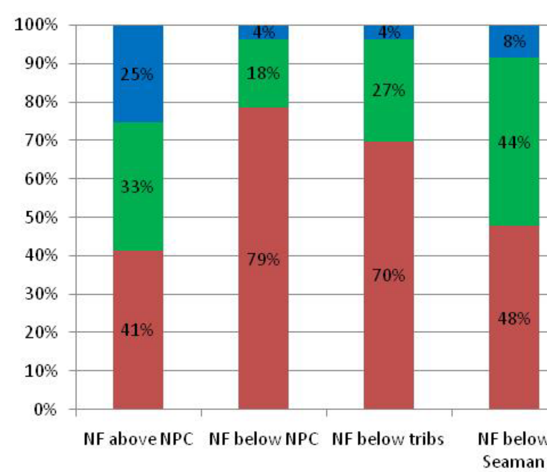
(b)

	Applicants' Pref. Alt.			
	Min	5th Percentile	Median	95th Percentile
Jan	3.8	7	12	46
Feb	4.9	8	15	44
Mar	5.2	9	22	66
Apr	7.3	14	58	196
May	14.1	29	147	701
Jun	8.6	21	159	535
Jul	2.3	6	28	75
Aug	0.0	5	13	66
Sep	4.3	6	13	31
Oct	9.1	14	23	63
Nov	6.6	8	12	22
Dec	7.1	8	11	22
	0 months with zero flow			

(c)



(d)



The charts shown above describe average monthly flows and provide some information on the daily variation that can be expected. They say little about large floods (1500 cfs) and very large floods (~7500 cfs), which can strongly influence long-term structure and function of aquatic and riparian habitats. Very large floods occur over a matter of minutes and hours, not months. Analysis of similar events from other Front Range stream gage records suggests that such an event on the North Fork will require about 10,000 af of spillway outflow in a month. By analyzing the size and frequency of Halligan spill events under proposed scenarios, it was determined that, in principle, large and very large spills could be accommodated (more on this in the section on results and Table 4). However, this may not be easy, because the reservoir may attenuate the flow and reduce the peak. There may also be significant liability issues if flood damages result. See the Outstanding Issues section for more on this topic.

Stream Temperatures for Native Fish

Stream temperatures can limit populations by affecting individuals at any time during their lives. We did not attempt to quantify stream temperatures that would result under various flow management alternatives. Rather, Nate Cathcart and Kurt Fausch of Colorado State University analyzed what is known about the thermal biology of native transition zone fish (i.e., those found in the North Fork Poudre River) in order to understand what temperatures should be achieved to allow native fish to persist (see Appendix 4 for a summary of temperature issues).

For most native transition-zone fish, it is minimum rather than maximum temperature that limits survival, growth, and survival. Eggs, larvae, and juvenile stages of fishes are the most sensitive to temperature, and these life stages are critical for populations to persist. Most native fish in the North Fork require at least 10°C to initiate spawning (data were available for eight of nine species), and this represents an important thermal limit for these native fishes. Stream temperatures need to reach about 15 ºC for all species to hatch successfully. Moreover, Cathcart and Fausch inferred from the limited data on the existing thermal regimes in the North Fork, and those for the main stem Poudre River in Fort Collins (where the same assemblage of fishes is native), that average daily temperatures will need to reach at least 20ºC for a month or more to allow sufficient growth of fish larvae to achieve high overwinter survival (i.e., recruitment) for many of these native species. Temperature samples of inflows to Halligan Reservoir suggest that under natural conditions, summer temperatures in the low 20s were frequently achieved. Limited data on the existing reservoir indicate that early summer temperatures are suppressed by the reservoir, but from late July through September the typically low reservoir pool allows higher natural stream temperatures to be maintained or even increased as the water passes through the pool. A larger reservoir that is not drawn down as often may not naturally provide this dynamic thus temperatures would have to be more actively managed. If a conservation goal for the North Fork Cache la Poudre River is to maintain suitable habitat for the assemblage of native fish species, then their thermal requirements will need to be a primary consideration.

Multi-level outlet works on the new dams are imperative to allow stream temperature management. However, temperature needs for native fish requirements and those for trout may at times conflict, and there may also be legal conflicts between a cold-water and warm-water stream designation. The North Fork and all Front Range streams where they flow from the mountains to the plains are *transition zone* streams where both cold-water species and warm-water species share the habitat, both near their limits of thermal tolerance. One aspect of stream temperatures on the North Fork that may assist in the management for both native and trout species is that the water typically warms as it is released from Halligan and travels down the river. Dr. Bill Miller (a member of the SVP environmental work-group) modeled changes in the North Fork using the Stream Reach Model and found that at 80 cfs stream temperature can be expected to increase approximately 5 degrees Celsius as it travels from Halligan dam outlet to Seaman Reservoir. For example, temperature released from Halligan at 16ºC will be around 21ºC when it enters Seaman Reservoir.

Stream Temperatures for Trout

Temperature needs for trout are well established. Colorado's current temperature standards for the North Fork include two guidelines. Chronic thermal stress to trout is avoided by ensuring that maximum weekly average temperature does not exceed 18.2°C. Acute thermal stress is avoided by ensuring that the maximum temperature in any two-hour period does not exceed 23.8 °C. As mentioned in the previous section, both biological and legal conflicts may exist between native fish and trout. Targeting temperatures near the maxima that allow healthy trout should allow the full range of species to meet their temperature needs. In addition, trout temperature needs could be met upstream at 20°C as possible. Dealing with the legal conflicts will require a special permit for the North Fork.

Fish Habitat Availability (trout and native)

Nine species of native fish have been sampled in the North Fork since 1959 (Cathcart and Fausch, 2010). Presumably the native greenback cutthroat trout would also have lived in this river and would have been the top predator. The rainbow trout that are present have hybridized with native greenback cutthroat, and may fill an ecological niche similar to the cutthroat. In contrast, brown trout fill a top-predatory role that did not naturally exist in the North Fork. Brown trout are known to be strong predators on native fish. Anecdotal evidence suggests that native fish populations are currently substantially reduced due to the presence of brown trout (K. Fausch, personal communication).

For all species of fish, flow rates determine the amount of habitat potentially available. Fish habitat availability was modeled using River2D results provide by Dr. Bill Miller. Five locations were modeled: below Halligan Dam, Phantom Canyon, below the NPIC diversion, below the tributaries (above Seaman Reservoir), and below Seaman Dam. Modeling was done for two species of trout (rainbow trout and brown trout), and for three life stages for each of species (fry, juveniles, and adults). Modeling was also done for large-bodied and small-bodied native fish, based on longnose sucker and longnose dace, respectively.

Modeled monthly flows were used to estimate monthly available habitat for each species and life stage. Using estimates of daily departures of flow from monthly values mentioned above, potential daily low and high values for available habitat were also simulated. Normalized scores (percent of maximum possible habitat) were used to compare the APA and the other alternatives to modeled current and natural conditions. The time series of monthly average and potential daily and high low available habitat were analyzed in various ways to provide summary metrics. Averages and minima of available habitat were calculated for each species, life stage, river reach and alternative and collated into large tables (see pages 18 and 19 of appendix 1). Table 2 shows an excerpt from the larger tables provided in the appendix. The SVM includes others displays, such as seasonal charts of average conditions.

Table 2. Examples of habitat availability results for one flow management alternative (ModNormSMALLSEA, details in following sections of this report). (a) average normalized (0-1 scale) habitat availability by species, life stage (for Brown and Rainbow Trout), and river reach compared to current conditions using monthly average flows. The entire table can be found in appendix 1.

	Brown Trout			Rainbow Trout			Longnose	Longnose
	Fry	Juv.	Adult	Fry	Juv.	Adult	Dace	Sucker
Below Halligan	0.71	0.18	0.05	0.70	0.19	0.08	0.15	0.17
Phantom Canyon	0.46	0.14	0.02	0.45	0.16	0.01	0.15	0.15
Below NPC	0.24	0.12	0.00	0.25	0.12	0.09	0.04	0.05
Below Tributaries	0.60	0.44	0.09	0.62	0.39	0.20	0.32	0.28
Below Seaman	0.69	0.28	0.03	0.51	0.30	0.15	0.19	0.19

Color Coding Key				
	Better than Current	>25% better	15% to 25% better	5% to 15% better
	Worse than Current	>25% worse	15% to 25% worse	5% to 15% worse

Sediment Transport and Channel Maintenance

Sediment transport, deposition and scour are significant processes for maintaining channel form in a dynamic equilibrium, with lateral and longitudinal diversity of in-stream habitats, clean substrates for invertebrate production and fish spawning, and adequate channel conveyance. However, erosion and deposition patterns have changed since the construction of Halligan Reservoir in 1909.

Since that year, very little coarse load (gravel and larger) has passed in the reach below Halligan. This reach is now well-armored and the channel appears to be in quasi equilibrium. A new reservoir of any size will likely continue the pattern of coarse sediment capture that currently exists unless some type mechanism is in place to transport coarse sediments through the reservoir. Lack of coarse sediments can limit spawning habitat for several fish species.

Fine sediments (up to 2 mm) currently deposit in the reservoir near the existing Halligan dam, potentially due to prevailing wind, fetch and reservoir orientation (Sara Rathburn, personal communication), and are regularly flushed out of the reservoir. A much larger reservoir will have greater capacity to capture fine sediments and flushing these fine sediments out will be more difficult, unless dam and reservoir design and operations allow for fine sediment management.

The sophisticated modeling necessary to assess sediment transport and geomorphological changes was not possible with the limited SVP budget, but we were able to calculate a coarse metric that allows for relative comparisons of expected increases or reductions in that amount of sediment work that the river will do over time. To make the desired comparisons, we calculated:

Cumulative bedload transport potential = $\sum(\tau_* - \tau_{*critical})^{1/2}$

where:

τ_* = dimensionless shear stress

$\tau_{*\,critical}$ = dimensionless critical shear stress.

Cumulative bedload transport potential was calculated for each month using the expected median daily flow for that month for all sub-alternatives and for each of the two reference conditions (current and natural). Then ratios of each alternative to each reference condition were calculated. A resulting ratio greater than one indicates that cumulative bedload transport would increase in that scenario, and a ratio less than one indicates it would decrease. For example, a ratio of 0.85 indicates that bedload transport and therefore geomorphological function has decreased by approximately 15%. The SVM includes charts of these ratios and the charts for the alternatives discussed below are shown in Appendix 1.

Several caveats apply to this analysis. Perhaps the most important is that the value of this analysis is greatly reduced by not having daily flow estimates. Many of the most significant sediment transport dynamics occur at a sub-monthly time step. For example, in the North Fork the flow rate that is most effective at sediment transport is exceeded, on average, for about 2 weeks in five years out of ten. Using a monthly flow estimate to calculate sediment transport potential does a poor job of capturing the dynamics around this two-week period.

Streambank Inundation by High Flows

It is well-established that the ecological function of streambank (riparian) vegetation is strongly related to high streamflows (see Merritt 2002 and Merritt and Wohl 2006 for more detailed information on this dynamic). Merritt (2002) demonstrated that the vegetation below Halligan Reservoir differs substantially from that above the reservoir, suggesting that the reservoir has had an impact on the riparian vegetation. High flows perform multiple functions in riparian areas. Among other dynamics, they transport water, sediments, nutrients, and seeds to riparian areas, they recharge floodplain aquifers, and they provide suitable conditions for seedlings. Prolonged inundation leads to anoxic conditions which influences species distribution and affects nutrient cycling. Very high streamflows—those that occur only a few times each century—have an important role in maintaining riparian habitat diversity. For example, these very high flows move late-successional areas of the riparian areas back to early successional stages, thereby opening habitat for species that need, for example, abundant sunlight.

Details of the many relationships between high flows and riparian vegetation are among the most poorly known aspects of the ecology of many streams, including the North Fork Poudre River. As such, we were unable to specifically describe riparian changes as they may relate to flow. However, inferences concerning whether or not substantial changes could be anticipated under various scenarios could be made based on patterns of riparian inundation.

To understand the dynamics of vegetation inundation, we used topographic data and modeled total wetted area for five stream reaches collected by Dr. Bill Miller to estimate amount and frequency of vegetation inundation at six different classes of high flows. Water begins to inundate vegetation along much of the North Fork at 80 cfs. The flood with a 2-year recurrence interval is about 320 cfs. Dr. Miller's modeled wetted area was calculated for a maximum of 700 cfs. These points define obvious breaks in the distribution of high flows, and we added a few more breaks to be able to discern where changes in inundation by flows were occurring.   The SVM includes histograms of inundation events (frequency of flows in the ranges noted above) and charts of cumulative inundation over the entire simulation. These charts can be seen in appendix 1.

Stream Inundation by Reservoirs

Expanded reservoirs will cause inundation and a direct loss of stream habitat. If expanded, both Halligan and Seaman Reservoirs will inundate and destroy several miles of stream. Analysis using Geographic Information Systems estimated the relationship between reservoir size (for both reservoirs) and stream loss. The SVM displays miles inundated of various streams under each alternative and these values can be seen in the summary table on page 3 of Appendix 1.

Terrestrial Habitat Inundation by Reservoirs

As with stream habitats, inundation of terrestrial habitats (including riparian areas) causes a direct impact to an existing habitat by transforming it into a different habitat that does not support the species using the former habitat. To gain a basic understanding of relative impacts across scenarios, total acres inundated under each scenario where calculated for all Colorado Division of Wildlife Activity Maps for nine species. In addition, a relative measure of connectivity impacts was also determined.

Of particular interest is the Preble's Meadow Jumping Mouse (PMJM), a federally listed threatened species. The mapped overall range of PMJM extends across and beyond the entire project area. The mapped occupied range of PMJM occurs above Halligan Reservoir. The Critical Habitat for PMJM as defined under the Endangered Species Act occurs on the North Fork and its tributaries between Halligan and Seaman Reservoirs.

Absolute area impacted and qualitative effects on connectivity were assessed along with game species impacts (results in Appendix 1). Length of Critical Habitat impacted is captured under stream miles inundated. The total Critical Habitat impacted by the reservoirs as shown under stream inundation is the sum of "NF Miles – Seaman (above)" and "Other Stream Miles."

Table 3. Species assessed for terrestrial impacts.

Bighorn Sheep
Black Bear
Elk
Mountain Lion
Mule Deer
Preble's Meadow Jumping Mouse
Pronghorn
River Otter
Turkey

Interactions between Brown Trout and Native Species

Brown trout are strong predators on native fish. Keeping those native fish viable is among the top desired conservation outcomes on the North Fork. All flow management alternatives analyzed would likely lead to increased habitat availability over time for native fish, with only a marginal increase in habitat for trout. However, we cannot say how these changes in habitat will translate into changes in abundance of either native fish or trout. It is conceivable that brown trout abundance would increase to a level that adversely impacts native fish abundance, despite increases in available habitat. If this happens, management of brown trout numbers may be warranted. If the infrastructure proposals are implemented, yearly monitoring will be necessary to ascertain population impacts.

There are two known methods of managing trout populations, if necessary, while maintaining a healthy sport fishery. The first method is to harvest adults. This can be done by allowing or encouraging "catch and keep" in lieu of "catch and release". Bag limits can also be increased when greater harvest is required. The second method is to limit brown trout reproduction. This would be done in the following steps:

1. Determine through data collection when spawning occurs (probably October)
2. Use River2D to map habitat where flows ~ 1 ft/sec (these are preferred spawning locations).

3. Determine through data collection when eggs hatch (probably Feb/Mar); calculate number of growing-degree days for reference; also, identify window when eggs have hatched but fry are not free-swimming (4-8 weeks after eggs hatch).
4. During post-hatch window, dramatically reduce spawning area (should equate to dropping flows 75-90% from spawning flows).
5. Manage reproduction in 4 of 5 years; 1 in 5 good reproduction years supports robust trout population.

Flow under the Joint Operating Plan

In order to satisfy an agreement with U.S. Forest Service, Fort Collins, Greeley, and the Water Supply and Storage Company operate their high mountain reservoirs to release 10 cfs to the Cache la Poudre River at or above Barnes Meadow Reservoir from November 1 through March 31. Since the SVM includes operations at the HMR, it is possible that flow management alternatives could change the frequency with which these flow requirements are met (either for the better or worse). The SVM reports the frequency of meeting the 10 cfs requirement. In general, this was seen a high priority objective and so all flow management alternatives described below provide 10 cfs in November through March in all simulated years.

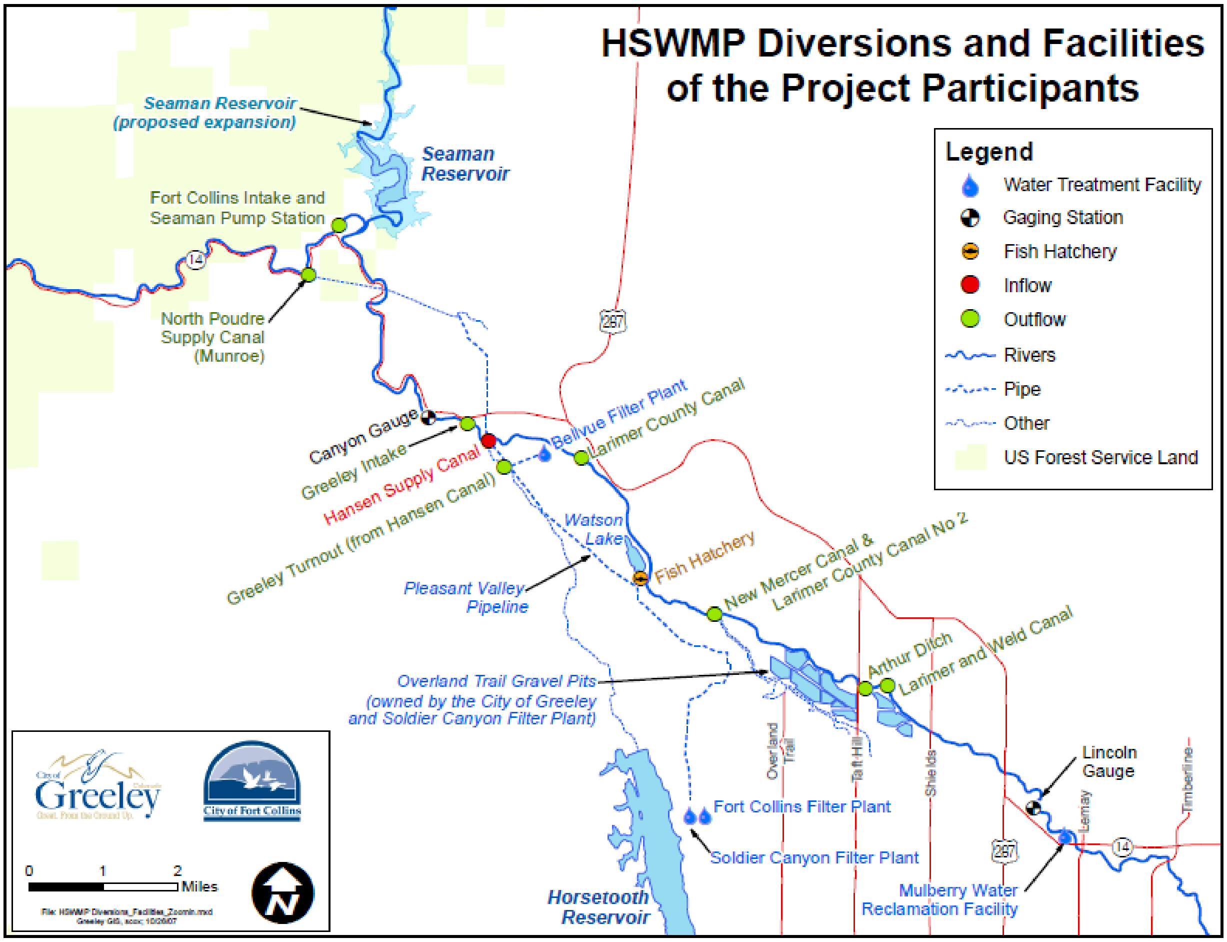
Flow on the Main-stem Poudre River below the North Fork Confluence

The Halligan-Seaman project was proposed to provide water supply. By definition, providing water supply with reservoir storage results in diminished streamflow somewhere in the river network. Streamflow impacts on the North Fork will consist mostly of changes in timing of flows, with increased low flows and decreased high flows. Impacts on the main stem of the Cache la Poudre River downstream of the mouth of the North Fork will occur to both timing and quantity of flows. Any benefits to the North Fork that accrue from enlarged Halligan and Seaman Reservoirs must be viewed in the context of flow changes on the main stem (as well as habitat inundation by the expanded reservoirs). A full analysis of flow changes on the main stem were not considered in the development of flow management alternatives for the North Fork.

However, a method was developed to estimate mainstem flows for the APA and other flow management alternatives. The main impact of Halligan-Seaman operations on the main stem would come from the exchange of converted main-stem agricultural water rights up to the reservoirs. These converted agricultural rights originate from several diversions along the main stem (see Figure 6), so modeling main-stem flow would require work that was deemed outside the scope of this SVP effort. A simpler method was developed. It is relatively straightforward to calculate flow in the main stem at its confluence with the North Fork because all of the converted agricultural rights originate below this point. So all changes to the timing and magnitude of exchanges would impact flow at this location. Similarly, it is relatively straightforward to calculate flow in the main stem at the Lincoln Gage because all of the converted agricultural rights originate above this point. For this location, changes to the timing and magnitude of exchanges would have little or no impact because the water would be diverted above here anyway (at the original ditch).

In between those two locations, it is much more complicated—it depends on the exact location of the original ditch. To simplify the analysis, a floating minimum flow for the stretch of river between the North Fork confluence and the Lincoln Gage was calculated using output from the applicants' system models. The floating minimum flow is the lowest flow occurring in that stretch in each month. The minimum may (and probably does) occur in a different reach each month. Depending on the location of the floating minimum and the location of the converted yields, an exchange may or may not impact the floating minimum flow. If the exchanged water comes from a ditch below where the floating minimum occurred in any given month, the exchange will reduce the floating minimum. If the exchanged water comes from a ditch above where the floating minimum occurred in any given month, the exchange will not reduce the floating minimum. Using this logic, the SVM calculates a range of potential floating minima for each month, but does not specify the location (for a slideshow on this topic, see link provided in Appendix 5). Statistics on the resulting range of floating minima are reported.

Figure 6: Mainstem Poudre River and Diversions



Flow Management Strategies

The Basic Idea

Storage at Halligan Reservoir, diversions at the North Poudre Canal and other factors significantly impact the hydrology of the North Fork Poudre River. Flow in Phantom Canyon regularly drops down to 3 cfs and occasionally approaches zero. Flow in the stretch just below the NPC is regularly near zero during the growing season when the NPIC is diverting large quantities of water for irrigation purposes. The tributaries between NPC and Seaman moderate these impacts somewhat, but even that reach is often significantly depleted.

The basic idea behind this SVP effort is that Fort Collins and Greeley could coordinate their operations in order to improve flow conditions on the North Fork between Halligan and Seaman Reservoirs. It would require releasing water from Halligan, allowing that water to flow down the North Fork, and recapturing that water in Seaman for municipal use later on. Several changes to the applicants default configuration and operations would be required. At the very least, coordinated operations would require sharing of storage space in Seaman Reservoir in order to recapture environmental releases from Halligan and store it for FTC's use later on (otherwise these releases would significantly reduce yield and water supply reliability for FTC). Significantly augmenting flow from Halligan storage may reduce water supply reliability, but it is possible that other operational changes could mitigate this. Sharing space in Halligan might be helpful, in order to store some of Greeley's water higher in the basin, but tests in the SVM showed limited benefits of this (more below).

Sharing water rights may also increase overall efficiency and allow for more flow augmentation without sacrificing water supply reliability. Both FTC and Greeley will use converted agricultural water rights from the mainstem Poudre River. They will use some of these converted agricultural rights directly, diverting the water to their treatment plants, and some of it they will exchange up the North Fork to Seaman and Halligan Reservoirs. In some cases, due to limited exchange potential or limited available space in the reservoirs, FTC or Greeley may not be able to use all of their converted agricultural water. In these cases, it may be beneficial to trade or share that water with the other entity—e.g., when FTC has excess yields of agricultural water, Greeley can use it for direct diversions or exchange it to Seaman.

The Unconstrained Experiment

The system modeled in the SVM is complicated, requiring a significant amount of accounting of different types of water and a fairly complicated rule structure to balance use of the various reservoirs. The normal, constrained simulation captures the complicated accounting and rules. This makes it difficult to test options for enhancing environmental flows on the North Fork while maintaining water supply reliability because the options require modifications of the many rules and calculations intended to simulate all the accounting and operations.

To simplify the problem, an Unconstrained version of the simulation was developed. The Unconstrained version lumps all of the water rights, all of the storage compartments in reservoirs, and all of the demands (except NPIC's system, which remains separate and independent within the Unconstrained simulation).

The Unconstrained simulation represents, essentially, complete integration of FTC and Greeley North Fork and HMR operations. Functionally, it would mean that FTC and Greeley share all of their North Fork and HMR storage space and all of their North Fork and HMR water in meeting their demands. For example, with the Unconstrained, both Greeley and FTC water is stored in Seaman but the ownership is not tracked. When there is a demand from either city that must be met from Seaman, water is released without tracking who originally owned the stored water. It is important to note that the Unconstrained does not exceed the total water available with the applicants' expected water rights portfolios. It just blurs the lines of ownership.

This level of integration and water sharing is not typical in Colorado, but may be well within the bounds of Colorado water law for some of the North Fork water rights. A detailed discussion of the implications of the Unconstrained simulation for water rights and water law can be found in Appendix 2. While the legal issues may be surmountable, full implementation of something like the Unconstrained version of integration and sharing would complicate cost-sharing and project management. There are similar examples elsewhere in the U.S. that could be instructive for cost-sharing and project management if FTC and Greeley choose to investigate this level of integration (ICPRB, 2008).

Barring complete integration of the North Fork and HMR systems of Greeley and FTC, benefits identified with the Unconstrained version of the SVM had to be recreated in the normal simulation, with all of the accounting and complicated rule structures. Results of the Unconstrained experiment helped identify which specific elements of the full integration should be recreated as particular flow management strategies within the normal simulation. Recreating these in the normal simulation provides descriptions and tests of how these strategies would actually work with Greeley and FTC keeping their systems separate and independent.

The Unconstrained SVM showed promising results for the following strategies:

- Providing dedicated, flexible storage for FTC in Seaman Reservoir and using that to recapture environmental releases and excess yields from FTC's storage in Halligan;
- Storing more water in Halligan when available, since it is higher in the watershed; and
- Sharing unused water rights to increase and/or preserve water in storage when possible.

Specific Flow Management Strategies

Dedicated Storage for Fort Collins in Seaman Reservoir

The most fundamental feature for successful coordination of operations is to provide storage space in Seaman for Fort Collins. This allows Fort Collins to release stored water from Halligan Reservoir to meet environmental targets on the North Fork and recapture that water in Seaman so the water can be used for municipal purposes later on. This maintains FTC's storage capacity on the North Fork but shifts the water from Halligan to Seaman at times when it would be environmentally beneficial.

Several versions of this strategy were tested. The most obvious version is to carve out a piece of Seaman capacity and use that piece only for FTC water. For example, if Seaman total capacity is 53,000 af, Greeley might have a dedicated storage compartment of 45,000 af and FTC might have a dedicated storage compartment of 8,000 af. Neither entity could exceed their compartment's capacity. This version is the simplest and may be the easiest to implement and manage, but it is the least efficient because it is the least flexible. For example, tests showed that there would be times that one entity would be spilling (e.g., bypassing some flow because their compartment is full) while the other entity has free space. The available space should be shared as much as possible to maximize efficiency.

A more flexible approach is to share storage capacity as it is needed and as it is available. In other words, allow FTC to store water in Seaman to the extent that space is available in any given month. The reservoir would have a maximum capacity, but neither FTC nor Greeley would be limited in the amount of water they could store. The storage of each city would change each month based on their water rights yields, demands and the amount of water released from Halligan for environmental purposes.

The flexible approach does involve a few rules and limitations. First, there must be a means for allocating spill when Seaman reaches capacity. If both FTC and Greeley have enough stored water and storable inflow to cause Seaman to reach capacity, whose water will spill first? One cities' water can be prioritized over the other, or there can be a rule for allocating spill between them (i.e., both spill some water). In general, Greeley's water supply reliability is a little more sensitive to this rule. Therefore, it is better to give Greeley's water priority and spill FTC's water from Seaman when the reservoir fills. It is also possible to place minimum limitations on FTC's storage space in Seaman (i.e., a small dedicated block of storage capacity that is not shared). This was shown to be helpful for meeting safety factor storage requirements in one alternative.

Greeley Storage in Halligan

A second option for sharing storage space is to store some of Greeley's North Fork water rights in Halligan first. Greeley has three storage rights on the North Fork. Some of this water originates hydrologically above Halligan Reservoir and some originates below Halligan. The portion that originates above Halligan can be stored at Halligan. This option was tested but proved to offer very little benefit in meeting environmental flow targets or water supply needs. This is because the bulk of Greeley's North Fork water rights yield during high flow years and months. This does allow Halligan to be topped off in some months, reaching full capacity slightly more often. But that extra water makes only a marginal difference in augmenting critical low flows in later years.

Exchange Excess Yield from High Mountain Reservoirs to Halligan

Most of the HMR need to be drawn down before winter each year, because winter ice makes operational changes at the HMR difficult. So the HMR are drawn down and set at a steady outflow to meet requirements of the Joint Operations Plan (JOP). The water that is released during drawdown may not always be needed for municipal or other uses, so it may be wasted. Greeley plans to store unused HMR drawdown releases either by exchanging the water to Seaman when there is exchange potential, or by pumping the water to Seaman (they plan to install a pump, likely of 50 to 75 cfs capacity, near the current FTC diversion just above the confluence). Storing excess HMR releases in Seaman will allow Greeley to use that water for water supply or other purposes in later months and years.

A similar exchange to Halligan might provide more opportunities for augmenting low flow on the North Fork, without hurting water supply reliability. This option was tested both in the unconstrained experiment and the normal simulation. In the unconstrained version, because it represents complete integration of operations, exchange to Halligan of FTC HMR drawdown releases and Greeley's HMR drawdown releases was tested. In the normal simulation, the exchange to Halligan of only FTC HMR releases was tested (for reasons of model simplicity). Exchanging Greeley HMR as well would slightly increase the amount of water available for augmenting flow in certain periods.

Water Sharing

One specific strategy for water sharing was modeled and tested: using FTC's excess agricultural rights on the mainstem to meet Greeley's demands. As noted above, both FTC and Greeley plan to make use of agricultural water rights from the mainstem Poudre River. Much of this agricultural water will be exchanged up the North Fork to Halligan and Seaman Reservoirs. In many cases, there will not be sufficient exchange potential (i.e., flow remaining in the river after other operations) for them to make the exchanges up the North Fork. In these cases, the water would normally go unused by Fort Collins (and often rented out to other parties). Some of that unused water yields in months during which Greeley has increased demands which would normally be met by making releases from Seaman or the HMR. Therefore, transferring those unused agricultural yields from FTC to Greeley and using that water to meet Greeley's demands in those months preserves storage in Seaman and/or the HMR. In the SVM simulation of the default preferred alternative, there is the possibility for this kind of sharing over 11% of the time, with the total amount of water available being over 84,000 af.

The Unconstrained simulation implies other kinds of water sharing as well—water is stored where ever possible and demands are met with available water, regardless of who owns it. No other water sharing strategies were tested in the normal simulation, but analysis and comparison of alternatives suggests how much water would be necessary for water sharing and potential sources of this water.

Rules to Simulate and Meet Flow Targets

Several approaches to simulating environmental flow targets were tested. The first approach was developed for the Unconstrained experiment and relied entirely on the preliminary flow targets published by The Nature Conservancy in 2008 (The Nature Conservancy, 2008). Those targets seek to mimic historical natural conditions by specifying a range of acceptable flow for each month of the simulation based the year type (dry, average, or wet) and a few other factors. Because they are based on natural flows, these targets require a great deal of water. In fact, early tests with the Unconstrained model showed that it is impossible to meet those targets without significantly reducing water supply reliability.

Various rules to reduce those flow targets based on monthly simulated storage conditions were tested. While these rules helped, it was pointed out that it would be more efficient to augment the lowest flows first, and then promote natural-type flows when there is sufficient water in storage. Several versions of this “bottom-up” approach were tested for both the normal and unconstrained simulation. In general, two kinds of targets are used: a static base target and the dynamic targets based on modeled natural conditions as cited above. Storage thresholds are used to modify these targets and switch between them. The final version used for testing alternatives is documented below.

1. Set base target flow (values between 3 and 10 cfs were tested and used for different alternatives)
2. Adjust base target flow based on Beginning-of-Month storage in FTC Halligan as a percentage of capacity. In other words, if beginning-of-month storage is 80% of capacity, the target is reduced by 20%.
3. Determine whether any reach of the North Fork between Halligan and Seaman will fall short of the adjusted base target flow (from step #2) without a release from FTC Halligan and determine the shortage.
4. Determine whether any reach of the North Fork between Halligan and Seaman will fall short of the larger TNC environmental flow targets (there is a different target for each reach because of different hydrology) without a release from FTC Halligan and determine the shortage. The largest shortage may become the target release, depending on adjustments in the steps below.
5. Set two cutback thresholds based on storage in FTC Halligan (as a percent of capacity as in Step #2); the larger threshold is used to reduce the dynamic targets as a function of storage; the smaller threshold is used to trigger a switch from the much greater dynamic targets, to the smaller base target. Values between 30% and 80% were tested for the larger threshold, while values between 5% and 50% were tested for the smaller threshold.
6. If beginning-of-month storage in FTC Halligan (as a percent of capacity) is less than the larger cutback threshold, reduce the target according to storage. For example, if the cutback threshold is 70% and if storage that month is at 60%, the target is reduced by 40%.
7. Determine if the target set in step #6 will exceed the upper end of the acceptable range of flows according the TNC flow targets cited above. This can happen if the target is set to release a lot of water to augment flow below NPC, where the NPIC diversion often depletes flow significantly. The big release might exceed the upper end of the acceptable range in Phantom Canyon (above NPC). If the target is too large, adjust it by the amount of excess so that it does not exceed the upper end of the acceptable range.

8. If beginning-of-month storage in FTC Halligan (as a percent of capacity) is less than the smaller cutback threshold, use the adjusted base target set in step #2 instead of the target calculated in step #7. Otherwise, use the target from step #7.

There is one significant shortcoming of this approach that will need to be addressed for any SVP alternative to be implemented. Determining the dynamic environmental flow targets (those based on the 2008 manuscript by The Nature Conservancy) requires knowledge of the year-type (i.e., dry, average, or wet year) in advance at the start of the water year (October 1st). This is not realistic. The impact of this assumption is small for winter months, because the winter flow targets do not vary significantly across year types. The impact is very large during the runoff period and through the summer and early fall months, when the flow targets vary a lot across year types. It is quite likely that measures of snowpack could be used to identify the year type by April of each year. This has not yet been tested for the Halligan-Seaman system.

Flow Management Alternatives

Different versions of the strategies described above were combined as complete alternatives and tested in the SVM. For each alternative, the thresholds for adjusting and switching flow targets were modified in an informal optimization to find the best possible results against the metrics described above. In all cases, water supply reliability was maintained as much as possible. Five alternatives and the key results are described below. Detailed results on the metrics for each alternative are shown in Appendix 1.

The Default Preferred Alternative

The applicants' system models represent the starting point for designing flow management alternatives. These model scenarios were developed with the single objective of maximizing firm yield and the applicants expected to improve these operations for purposes of streamflow or other objectives. In the SVP process, the results of these operations were labeled the default applicants' preferred alternative, or APA. The objective of SVP is to develop a set of coordinated operations that are better than the default APA for environmental objectives. The SVM had to mimic the applicants' modeling of the default APA in order to have an accurate baseline for comparing other alternatives.

In terms of flow conditions, the default APA has mixed results. FTC has planned for a minimum release of about 3 cfs during the winter months. This would represent an improvement over current conditions and would certainly improve habitat conditions for native fish and trout. However, the default APA does allow 53 months (out of 1032 total months in the simulation) of zero flow ("sweeps"), all but one of which occurs below the NPC. And in general, the default APA allows for many months with extreme low flows. Improving these low flows was the primary goal in designing alternatives. In addition, the default APA causes inundation of significant stretches of the North Fork and other streams because of the larger reservoir pools. With the proposed expansions, the following stretches of river would be inundated and lost:

- North Fork Poudre River above the current Halligan Dam – 2.37 miles
- North Fork Poudre River above the current Seaman Dam—2.93 miles
- North Fork Poudre River below the current Seaman Dam—0.90 miles
- Other streams around the proposed Halligan Reservoir—2.71 miles
- Other streams around the proposed Seaman Reservoir—1.65 miles.

So the proposed expansions would result in the loss of a total of 6.20 stream miles of the North Fork Poudre River, and 4.36 miles of other streams around the two reservoirs. Some of these streams are demonstrated habitat for the Preble's Meadow Jumping Mouse, a threatened species under the

Endangered Species Act. When the TriDistricts were part of the project, Halligan was to be expanded to nearly 40,000 acre-feet. This size would have inundated a significant stretch of Dale Creek, and ecologically important stream. With TriDistricts out, the current proposed expansion to just over 22,000 acre-feet will not inundate Dale Creek at all.

Flow Management Alternative #1 – Low-Hanging Fruit

A few simple modifications to the default APA allow for significant improvements to flow conditions on the North Fork. This alternative was labeled ModNormLHF, shorthand for modified normal simulation – low-hanging fruit. ModNormLHF includes only one flow management strategy: provide recapture storage for FTC in Seaman. FTC is given use of whatever space is available in Seaman on a monthly basis, sometimes none if Greeley has filled the reservoir. Greeley water takes priority, so FTC water spills first when Seaman reaches capacity. Releases from FTC Halligan are made primarily for environmental purposes using the targets described above. Those releases, as well as any excess yield from FTC Halligan, is captured in Seaman for FTC's use later on. Both reservoirs are kept at their default sizes of 22,318 af for Halligan (10,890 af for FTC) and 53,000 af for Seaman.

Just this modification shows promising results. The SVM shows that this alternative can eliminate sweeps (months with zero average flow). That alone is a significant improvement over the default APA and current conditions. Further, ModNormLHF shows increases in flow during many of the driest months of the simulation, especially in reaches of the North Fork below NPC and above Seaman. Overall, the North Fork streamflows resulting from ModNormLHF do slightly better against the dynamic streamflow targets, indicating more natural flow conditions on the North Fork compared to the default APA. These flow improvements result in some significant improvements to fish habitat when compared to the default APA. However, ModNormLHF is quite similar to the default APA for sediment movement and terrestrial vegetation inundation metrics. Water supply reliability under ModNormLHF is equivalent to the default APA, and the alternative successfully meets flow requirements of the JOP in all months.

Flow Management Alternative #2 – Better than Low-Hanging Fruit

Additional improvements over the default APA are possible with new exchange and water sharing strategies. ModNormBETTER adds the following features to ModNormLHF:

- Exchanging HMR to Halligan – excess yields from FTC's HMR (Joe Wright) are exchanged to Halligan Reservoir when space in the reservoir and river flows allow (i.e., when there is sufficient exchange potential);
- Sharing agricultural water rights – when FTC has excess agricultural water rights on the Mainstem Poudre (i.e., agricultural water that it cannot use because of limited space in Halligan or limited exchange potential on the North Fork), that water is used to meet Greeley demands.

These two strategies would allow for augmentation of flow on the North Fork for environmental purposes and improvements to water supply reliability. The flow augmentation benefits are at least as good as with ModNormLHF—some scores are slightly better, some are slightly worse, but overall the scores are similar. ModNormBETTER definitely brings an improvement in flow conditions compared to the default APA. At the same time, ModNormBETTER performs just as well for water supply for Greeley and FTC as the default APA. The default APA and ModNormLHF result in three months of shortages for Greeley, with a total shortage about 1,000 af. Because of the water sharing strategy, ModNormBETTER eliminates these shortages. For FTC, as with the default APA, ModNormBETTER brings no shortages or violations of safety factor storage. JOP flow requirements are met under ModNormBETTER.

Flow Management Alternative #3 – Smaller Seaman

There is interest in reducing the size to which Halligan and/or Seaman might be expanded. This possibility was explored using the SVM. Downsizing Halligan (compared to the default APA) has a direct impact on the ability to augment flow on the North Fork, so no alternatives involve a smaller Halligan. Downsizing Seaman does not significantly impact ability to manage North Fork flows, but it does impact Greeley and, in some cases, FTC water supply reliability. The main purpose in testing an alternative with a smaller Seaman is to determine the impact on water supply reliability metrics.

ModNormSMALLSEA takes the configuration used for ModNormBETTER, except that Seaman reservoir is set at 42,000 af. Expanding Seaman Reservoir to 43,000 af or more will require Greeley to move the dam site downstream by 0.90 miles. Decreasing the size of the proposed Seaman expansion to 42,000 acre-feet is significant because it would allow Greeley to build the dam at the existing site, which would preserve 0.90 miles of North Fork compared to the default APA.

Reducing storage capacity by 11,000 af has impacts. ModNormSMALLSEA does allow for improvements to North Fork flow conditions--the results against the environmental metrics are similar to the results for ModNormBETTER. However, the reduced storage capacity results in less water supply reliability for Greeley and violations of FTC's safety factor storage requirement. Greeley's reliability under ModNormSMALLSEA drops to 99.2% (compared to 99.7% under the default APA and 100% under ModNormBETTER); the total shortage is 5411 acre-feet (all of which occurs during one drought event of the simulation). FTC's safety factor is violated 4 times over the simulation, twice during the critical design drought. This alternative would be attractive because of cost savings (a smaller dam at the existing site) and avoidance of some stream loss. To be feasible, FTC and Greeley would need to acquire more water rights (probably more senior water rights) in order to avoid the shortages and safety factor violations.

Summary of Flow and Environmental Results

Table 5 shows summary metrics for each resource metric across the four alternatives discussed here. A similar table can be found in appendix 1. Green shading in the table indicates an improvement for that metric compared to the Default APA; red shading indicates worse performance. The table shows that each of the alternatives presented in this report result in small but meaningful improvements to environmental metrics that are most dependent on low flows. The flow management alternatives would virtually eliminate dry river conditions (zero flow) that would otherwise occur in about 50% of years under the default APA in the reaches below the North Poudre Canal diversion. In addition to eliminating zero flows, the new flow management alternatives would increase flow from the North Poudre Canal to Seaman Reservoir during most of the driest months even more so than under the default APA. For example, in months of July, August and September, the new alternatives would increase river flow from the North Poudre Canal to Seaman Reservoir by at least 50% compared to the default operations. As a result of improved low flow conditions, absolute minimum fish habitat scores for trout and native species are generally higher for the new flow management alternatives compared to the default APA.

All of the alternatives, including the default APA, would be worse than current conditions on metrics that depend on high flows. Essentially, with additional storage compared to current conditions, the reservoirs would store more water during periods with high flow and release that water (for environmental purposes, municipal purposes, or both) during periods with low flow. During the runoff season, which varies from year to year but generally falls between May and July, 10%-20% reductions in flow compared to current conditions will be typical. In Phantom Canyon, flow in the month May would decrease compared to current conditions, sometimes by nearly 40%. This is true for both the default operations and the new flow management alternatives—overall, they are similar in their impact on high flows (see charts on pages 3-16 of Appendix 1). The impact of this can be seen by comparing riparian vegetation and sediment movement metrics under the alternatives with those metrics under current conditions. All of the alternatives would result in reductions (about 1%-6%) of cumulative bedload transport potential (see page 17 of Appendix 1) compared to current conditions. Similarly, all of the alternatives, including the default APA, would result in changes in patterns of inundation of riparian (see pages 21-42 of Appendix 1). There would be fewer large inundation events and overall less cumulative inundation over time compared to current conditions. Some of the changes in vegetation inundation are small and others are large, and changes in riparian ecology could be similarly variable over time.

Except for ModNormSMALLSEA, the alternatives would result in the same amount of stream loss due to inundation, up to about 10.5 miles. These results were noted above and can be seen in Table 5. ModNormSMALLSEA includes a smaller version of Seaman Reservoir than the default APA, reducing the loss of North Fork stream miles by 0.90 miles. In addition, the alternatives would all cause losses of terrestrial habitat because of larger reservoir pools, totaling about 750 acres.

All alternatives perform equally well in meeting requirements of the Joint Operating Plan. All the alternatives provide the required 10 cfs release to the mainstem in November-March of all years.

The alternatives may differ in their ability to cause the very large flood events described earlier. These events will be associated with spill events at Halligan Dam. As noted earlier, analysis of other Front Range streams suggests a spill event with at least 10,000 acre-feet of outflow would be required. The following table shows the frequency and magnitude of spill events for each alternative. Over the period modeled in this study, this type of event would be expected in the range of 2-4 times.

Table 4: Halligan Spill events across four flow management alternatives

Metric	**Default APA**	**ModNorm-LHF**	**ModNorm-BETTER**	**ModNorm-SMALLSEA**
Number of Spill Events	10	4	2	2
Largest Spill Event (af/month)	43,153	42,136	30,941	32,010
Smallest Spill Event (af/month)	14,083	19,969	23,826	23,863

One issue that is of keen interest to many stakeholders in the region is flow and resulting ecological conditions on the mainstem of the Poudre River below the Poudre Canyon. Generally, the stretch of the Poudre below the canyon was outside the scope of this experiment, but a rough method for estimating potential impacts was developed (described above). This method shows that the alternatives presented here will result in slightly less flow (compared to the default APA) on the mainstem during the runoff period (generally, May through July) because of increased exchanges of converted agricultural water rights originating from main stem ditches. No comparison was made to current or natural conditions.

The results can be summarized as follows. All of the alternatives described here include reservoir expansions (since that was the premise of this experiment) and so all of them result in losses of up to 10.5 stream miles and 750 acres of terrestrial habitat. The default APA would often increase low flows compared to current conditions but results in 53 months (out of 1032 total in the simulation) with zero flow, most of which occur below the NPC. Coordinated operations represented by the three

modified alternatives (ModNormLHF, ModNormBETTER, and ModNormSMALLSEA) would improve low flow conditions even more, virtually eliminating dry river conditions and increasing many of the lowest flows by up to 50% compared to the default APA. The low flow improvements come with some diminishment of high flows: 10%-20% less compared to current conditions, especially during the runoff periods. All of the alternatives would decrease the frequency of moderately high flows compared to current conditions. ModNormSMALLSEA provides the low flow benefits, with slightly less stream loss and slight reductions in water supply reliability for Greeley (i.e., more shortages) and violations of FTC's safety factor storage (not shown in the table).

Table 5: Summary metrics for each resource and alternative

= Better than Default APA   =Worse than Default APA

Metric	Default APA	ModNorm-LHF	ModNorm-BETTER	ModNorm-SMALLSEA
Water Supply Reliability				
Greeley	99.7%	99.7%	100.0%	99.2%
Fort Collins	100.0%	100.0%	100.0%	100.0%
Frequency of Meeting Original Environmental Flow Targets*				
Above NPC	33%	36%	38%	36%
Below NPC	18%	20%	23%	22%
Above Seaman	27%	30%	33%	32%
Below Seaman	44%	44%	44%	44%
Months with zero flow on North Fork	53	0	0	0
Fish Habitat, Avg Score				
Overall Average Score	0.51	0.52	0.53	0.54
Average minimum score	0.15	0.26	0.25	0.25
Freq. of departure from natural	42%	42%	40%	40%
Reservoir Inundation Impacts				
NF Miles - Seaman (above)	2.93	2.93	2.93	2.34
NF Miles - Seaman (below)	0.90	0.90	0.90	0.00
Dale Creek – Halligan	0.00	0.00	0.00	0.00
NF Stream Miles - Halligan	2.37	2.37	2.37	2.37
Other Stream Miles	4.35	4.35	4.35	3.99
Vegetation Inundation				
Average return interval	0.92	0.91	0.91	0.91
Average max return interval	3.23	3.42	3.42	3.25
Cumulative % diff with natural	-29%	-28%	-27%	-28%
Sediment Movement				
Cumulative Transport Potential, ratio to current	0.97	0.96	0.96	0.96
Cumulative Transport Potential, ratio to natural	0.59	0.58	0.58	0.58

*These are the targets originally published in a report by The Nature Conservancy (2008); they are intended to mimic natural conditions and are used together with baseflow targets to design flow management alternatives (see description above).

NOTE: Metrics for the JOP required flows are not shown here because all alternatives meet these requirements all the time; the JOP metrics are shown in the table in Appendix 1.

Implementation and Adaptive Management

The specific alternatives discussed above are meant to represent general options that the applicants may consider in formulating their final preferred alternative for the EIS and permit evaluation. These alternatives demonstrate that there are significant opportunities for changing the default APA in order to enhance environmental flow conditions on the North Fork. Since the SVP process was kept separate from the NEPA and permit evaluation process, integrating SVP results into the NEPA process will require additional work.

First, more work is needed to fine tune the alternatives discussed above, or even formulate a new alternative based on the results and strategies discussed. Modelers continue to identify new issues and inconsistencies between the SVM and applicants' system models. For example, recent comparisons of the models showed differences in the way that releases from Seaman Reservoir are balanced with exchanges and pumping of HMR excess yield. The SVM includes more exchanges and pumping and more releases from Seaman. Greeley's system model offset releases by using the HMR excess yields directly, and therefore exchanges and pumps less. The practical result is that the SVM shows more flow in the North Fork below Seaman by pumping HMR water to Seaman and releasing water from Seaman at the same time. This operation would be costly, so it is not likely to be implemented as modeled in the SVM. Further work is needed to evaluate this impact and modify the alternatives.

While it is impossible to know now whether the Halligan and Seaman projects will be permitted by the Corps, it is worth considering some general implementation issues. There are number of issues the applicants will have to address for successful implementation and some of these issues were mentioned earlier. The applicants will certainly have to work through any water rights issues associated with the alternatives developed in SVP. This will mean changing existing decrees or filing for new decrees so that they allow for necessary operational strategies and water sharing. In addition, the alternatives have implications for cost sharing and project management. The applicants will need to negotiate appropriate agreements to handle these issues. For example, will the costs for Halligan and/or Seaman be shared by FTC and Greeley given the integrated operations? And if so, how will the shares be calculated?

More important for this report is to describe how the operational strategies might be implemented collaboratively. While the SVM includes some state of the art data and analysis done by leading experts on riverine ecology, it is not a perfect prediction of how the North Fork basin will respond to the proposed reservoir expansions and operations. Adaptive management will be crucial for success if Halligan and Seaman are built as proposed and one of the operational strategies presented here is implemented. Successful adaptive management requires collaboration among experts, managers and stakeholders (Lee, 1993).

Adaptively managing coordinated operations for the proposed Halligan-Seaman expansions will require a formal standing committee with representatives from several organizations that have responsibility for and/or expertise in relevant areas. Potential implementation may be many years away, so it is difficult to speculate exactly which organizations should be involved, let alone specifying individual people. In general, the applicants should seek to partner with the same organizations (or types of organizations) that have been involved in SVP (e.g., The Nature Conservancy, Trout Unlimited, Colorado Division of Wildlife etc.). The description of the applicants' eventual preferred alternative will need to describe how this committee will be established and, generally, how it will work. The committee should have a formal charter and rules of engagement to govern its actions and decision-making procedures.

Adaptive management requires specifying hypotheses about uncertain outcomes of an alternative and monitoring to test these hypotheses in real time (Holling, 1978). SVP has a natural connection with adaptive management (Lorie, 2006). The SVM represents a set of hypotheses of how the reservoirs can be operated and the likely ecological responses of those operations. These hypotheses can be formalized and monitoring programs can be implemented to test them. The exact hypotheses selected for an adaptive management program will depend somewhat on exactly which operational alternative the applicants select for implementation (assuming the reservoirs are permitted and expanded). The following hypotheses are examples for potential implementation of an adaptive management program for the proposed Halligan and Seaman expansions if one of the alternatives presented here (or another, very similar alternative) is selected for implementation.

1. **Hypothesis**: Population of native fish species (especially Longnose Dace and Longnose Sucker) will increase because of (1) general increase of low flows compared to current conditions; (2) elimination of sweeps (months, days with zero flow); (3) improved water temperature management of Halligan outflows conducive to native fish (NOTE: temperature management was addressed only partially within SVP but this is expected to be a condition of an eventual permit); (4) control of Brown Trout populations so that predation on native species is limited; and (5) frequency and magnitude of high flows sufficient for maintaining and creating physical habitat needed by native fish.

   Monitoring:
   i. Continuous water temperature and flow gaging below Halligan Reservoir and somewhere below the NPC.
   ii. Periodic (at least annual) fish population surveys in representative reaches of the North Fork.
   iii. Periodic (about every five years) field surveys of the amount and quality of available physical habitat for native fish species in representative reaches of the North Fork (this should be done if and when populations are not responding as hypothesized).

2. **Hypothesis**: A stable, reproducing population of Brown and Rainbow Trout will be maintained because of (1) general increase of low flows compared to current conditions; (2) elimination of sweeps (months, days with zero flow); and (3) frequency and magnitude of high flows sufficient for maintaining and creating physical habitat needed by Brown and Rainbow Trout.

   Monitoring:
   i. Continuous water temperature and flow gaging below Halligan Reservoir and somewhere below the NPC.
   ii. Periodic (at least annual) fish population surveys in representative reaches of the North Fork.
   iii. Periodic (about every five years) field surveys of the amount and quality of available physical habitat for native fish species in representative reaches of the North Fork (this should be done if and when populations are not responding hypothesized).

3. **Hypothesis**: Brown Trout populations will be limited (to control excessive predation on and competition with native species) by (1) periodically (roughly, 1 in 2 years on average) dropping Halligan outflows after Brown Trout have spawned to freeze and desiccate eggs and (2) shifting the stream temperature regime slightly upwards in favor of native fish but still within generally acceptable ranges for trout.

Monitoring:

i. Continuous water temperature and flow gaging below Halligan Reservoir and somewhere below the NPC.
ii. Periodic (at least annual) fish population surveys in representative reaches of the North Fork.

4. **Hypothesis**: The quality of riparian habitat for terrestrial species, especially Prebles meadow jumping mouse, will remain at least as good as under current conditions because of sufficient frequency and magnitude of a range of high flows to inundate riparian areas and maintain adequate sediment movement processes.

   Monitoring: Periodic surveys of riparian habitat to assess diversity and overall habitat quality.

The suggestions above do not comprise a comprehensive description of an adaptive management program for the proposed Halligan and Seaman expansions. They do represent the key hypotheses driving the design of the alternatives presented in this report and provide illustrative examples for eventually designing a robust adaptive management program. Once the applicants decide on specific flow management strategies for their new preferred alternative, they can begin to formalize plans for adaptive management.

Outstanding Issues

The work represented in this report does not address all of the issues that should be considered during comprehensive environmental evaluation of this project. This section describes several items identified as needing further analysis, but where time and resources were insufficient to complete the analysis. This short list should not be considered exhaustive of all the issues that ought to be considered for a complete environmental assessment of the project.

Impacts on the Mainstem Poudre River

Effects of project design and management on the North Fork cannot be viewed in isolation from the main stem. Average monthly flows on the mainstem at two specific locations and one generalized location were estimated, and these were compared across scenarios. However, the scope of the SVP did not permit a thorough analysis of mainstem impacts. Such impacts should be analyzed in detail during comprehensive environmental impact assessment of this project. Also, these impacts should be viewed in a cumulative manner, including with the assumption that the Northern Integrated Supply Project will be implemented as proposed.

Detailed Sediment, Geomorphological, and Riparian Modeling

The only explicit metric related to sediment (cumulative work over time) is very general. Much more sophisticated work should be conducted on sediment transport and stream geomorphology.

The key general questions that should be addressed are:

- How is channel morphology and behavior currently changing (time scale ca. 50 years)? How is the riparian corridor currently changing (time scale ca. 50 years)?

- Will the channel morphology and behavior continue on this same trajectory and range of variability in the future? Will the riparian corridor continue on this same trajectory and range of variability in the future?
- Will the new flow regime increase the potential for future channel changes? Is the potential for future change / alternative trajectories significant in terms of channel form, processes, and stream / riparian habitat?

Detailed Investigation on Dam Design Issues

Temperature management

It is assumed that multi-level outlet works will be a permit condition, allowing flexibility around management of temperature and water quality aspects of reservoir releases. However, in order to be able to anticipate water quality impacts, dynamics in the reservoirs and in the stream need further investigation. These dynamics can be modeled, but no attempt was made to do so in the SVM. Stream water quality—particularly temperature—has substantial impacts on aquatic life. It is strongly recommend that stream temperature be managed in a manner that maximizes benefit to native fish while minimizing impacts to trout.

Sediment management

Sediment supply, transport, erosion, and deposition all play important roles in stream ecosystem function. Emulating natural sediment dynamics below reservoirs is preferable for maintaining a healthy river. There now exist basic principles for ecological sediment management in reservoirs, and tens of case studies where sediment is managed for the environment.

The ideal management scenario moves sediment through the reservoir in real time. The next best is to move all sediment through without abrupt dumps. Multiple approaches to sediment management for environmental outcomes exist, such as:

- Manage the dam as run-of-the river when possible. Run-of-the-river reservoirs trap less sediment than those with large seasonal storage.
- Minimize dam height and storage area.
- Employ low-level sediment sluices, diversion channels, or tunnels to transport sediment through the dam.
- Employ low-level outlets to flush sediments, while employing mid- and high-level outlets to maintain water quality during sediment flushing. As with the existing Halligan Reservoir, flushing can be expected to release fine sediments, but rarely coarse sediments.

Large (ten-year) and very large (25-year) floods

Large and very large flood events have important ecological functions. Floods of this size may be out of management control, and may occur regardless of intent. If not, they will have to be managed for if they are to occur. Our analysis indicates that spills of sufficient size to provide flows of this magnitude will occur.

If spills are sufficiently large to supply flood events, the hydraulics of the spillway will need to be designed to accommodate a large flood, particularly because a large inflow will be attenuated as it passes through the reservoir, perhaps even if the reservoir is full. If spills are not sufficiently large, dam designers should to investigate mechanisms for creating these events with a bladder, collapsible spillway, or similar structure. These structures may add significant costs to the projects. In addition, creating large flood events could impose significant liabilities because of resulting damage downstream. These cost and liability factors also require additional investigation.

Time Lag between Expansion of Halligan and Seaman Reservoirs

Under the current project proposal, the new Halligan Dam may be constructed a decade or more before the new Seaman Dam. The joint management of the proposed reservoirs and the water they contain is central to the improvements to the APA demonstrated in this experimental SVP effort. An expanded Halligan in the absence of a larger Seaman will almost certainly limit the ability to achieve the environmental flow benefits demonstrated during the experimental SVP. No attempt was made to understand these limits. Analyzing what can and cannot be done to achieve environmental flows during the period between the two proposed reservoir expansions is an essential step for future work.

Climate change

According to Ray et al. (2008), "The scientific evidence is clear: the Earth's climate is warming. Multiple independent measurements confirm widespread warming in the western United States; in Colorado, temperatures have increased by approximately 2°F between 1977 and 2006. Increasing temperatures are affecting the state's water resources." Climate models project Colorado will warm 2.5°F by 2025, relative to the 1950–99 baseline, and 4°F by 2050. These warmer temperatures will result in more precipitation falling as rain and less as snow, increased crop irrigation demand and increased evapotranspiration from native vegetation, and earlier snowmelt.

No attempt was made to factor climate change into the analysis presented here. A thorough analysis of the Halligan-Seaman projects to achieve both water supply and environmental goals should consider climate change. Proposals for next steps, if funded, will begin to scope needs for factoring climate change impacts into the SVP process.

Next Steps

SVP is labor-intensive, requiring more meetings and workshops, and more analyses (data gathering and modeling to address the range of issues introduced by stakeholders). This means that compared to the traditional process for producing an EIS and permit decision, using SVP will require more up-front investment of time and money by the permit applicants and the stakeholders. As described earlier, the permitting process often explodes into controversy, resulting in repeated rounds of technical, administrative and legal reviews. This can be extraordinarily expensive, especially for permit applicants. The hope is that SVP will yield widely supported solutions and limit this controversy. If it can limit controversy, SVP would be a very wise investment.

The purpose of this SVP process was to provide a limited test of SVP for the permitting of water supply projects under the 404 program. The test was largely successful—the participants were able to collaborate on developing alternatives for potential Halligan-Seaman operations that will clearly improve environmental flow conditions compared to current conditions and compared to what we would expect with the applicants original, default operations. This success does suggest that SVP could be a very useful tool for the permitting process. However, the test had a very limited scope and there are still serious concerns about the Halligan-Seaman project among many stakeholders. A broader SVP process would include the most difficult issues, such as demand projections and water conservation. So success in the limited test does not guarantee that SVP would be successful for the entire permitting process. Therefore, the decision of how to proceed is not an easy one.

SVP facilitators described four potential options for what to do next.

1. No further SVP;
2. Expand the scope of SVP to include a few additional issues, such as flow on the mainstem Poudre or mitigation options, but keep the process separate from the EIS and permitting processes;
3. Expand the scope to include everything within the scope of the EIS and permit process, but keep it separate from the Corps' EIS and permit process.
4. Replace the current EIS and permit process with an SVP process.

Most participants would like to see some form of SVP continue in this case. Option 3—running a full-scope SVP process in parallel to the Corps' traditional process—carries a lot of risks because it will be difficult to keep the two processes consistent. So the choice is between Option 2 (additional SVP with a limited scope) and Option 4 (doing the entire EIS and permit process with SVP). Option 2 is relatively easy to scope out, but may not offer substantial benefits because it may not be able to address all of the important issues. Option 4 holds the most promise for minimizing eventual controversy, but it is difficult to envision exactly how this would work.

SVP facilitators recommended testing Option 4 by engaging in a collaborative process to develop a detailed work plan for Option 4 and the necessary rules and agreements to set up the process. The work plan would be developed by working through the first iterations of the SVP process in an open and broad, but cursory manner. The point is to raise and discuss all of the key issues in order to describe the level of work that would need to be done to address these issues fully. The products would be scopes of work. For example, the participants would debate and discuss water use projections and would produce a scope for how we would analyze and predict water use rates within a full SVP process. The many scopes of work developed would comprise a detailed Plan of Study for the entire SVP process. This would give the participants practical details on how the process would work. The participants would also develop rules of engagement to establish necessary decision-making procedures and roles and responsibilities for each participant. Finally, the participants would describe agreements among organizations that would be necessary to implement full SVP. These products would allow participants to make an informed decision about whether to do Option 4, and would also provide needed information for implementing various versions of Option 2.

The participants are now seeking grants to support this test of Option 4.

Conclusions

This SVP experiment yielded several key results.

First, facilitators, applicants and stakeholders were able to collaborate in developing positive results. A shared vision model of the system was developed and it incorporated key metrics to reflect environmental objectives for the future of the North Fork Poudre River. Strategies for coordinated operations of Halligan and Seaman were developed to improve low flow conditions on the North Fork (both compared to the default operational alternative and compared to current conditions). These potential improvements would not make the proposed reservoirs expansions environmentally benign. Several miles of the North Fork and other streams would be permanently lost, destroying demonstrated habitat for the threatened Preble's Meadow Jumping Mouse, and terrestrial habitat for game and other species would also be lost. However, **if** the reservoirs are expanded, the flow management strategies presented here would improve environmental conditions on the North Fork compared to how the reservoir owners would operate the dams without these strategies.

Second, although the limited scope of this experiment reduced the stakes involved, the experiment provides a demonstration of the potential feasibility of using a collaborative process like SVP to design and evaluate water supply alternatives under the 404 permitting program. As described earlier, the nature of 404 permitting process for water supply projects often leads to controversy and protracted disputes (Shabman and Cox, 2004). Nationwide, the Corps expects about 900 new applications for permits for water supply projects and many of these will require EISs (Barry and Brumbaugh, 2007). There are six significant projects under review in Colorado alone, including the Halligan-Seaman project that was the focus of this experiment. Large controversies on even a small number of these projects will be very costly and it is likely that the results will be less than optimal. There are signs that opposition to projects in the Poudre River basin, potentially including Halligan and Seaman Reservoirs, might lead to significant controversy and a long-term battle over the fate of those permit applications (see Wockner, 2010).

Rigorous collaborative approaches, like SVP, offer a way to prevent or resolve such costly disputes over permits for water supply projects. Since there is no track record of using SVP for regulatory decisions, there is no guarantee it would work, but the experiment described here offers hope for both the local issues and the national problem. For the Halligan and Seaman proposals, the experiment has clearly demonstrated that the applicants and stakeholders (including responsible agencies) can collaborate in an open and honest manner. The participants developed and agreed to a set of rules to govern this process. Thorny, complicated issues were raised repeatedly during the process and, to the extent possible given the limited scope, these issues were addressed head on through productive debate and changes to the analysis as much as possible. The results, while limited to the constrained scope of modifying the Halligan-Seaman alternative, are generally accepted by most participants as accurate descriptions of the likely future impacts of the proposed reservoirs.

Finally, the positive results in this experiment have encouraged the permit applicants, responsible agencies and other stakeholders to seriously consider using SVP for the entire EIS and permit evaluation process. They also are considering further use of SVP on a limited basis, perhaps focused only on designing mitigation options for the projects. Either would be a significant step, so they are investigating options by initiating a follow up test that will be more comprehensive than the experiment described here. The results of this next test will provide detailed descriptions of how SVP would function and proceed if it were used for the full EIS and permitting process. Some participants have applied for a Federal grant to support this work and may seek other sources of funding as well. This work would allow participants in the Halligan-Seaman process to make an informed decision about SVP. The work will also identify and describe larger policy issues that will help the Corps in testing and potentially implementing SVP in future 404 permitting cases.

References

Barry, J. and R. Brumbaugh. 2007. Water Supply and Corps Regulatory. IWR Issue Paper. 8 pgs.

Cathcart, C. N. and K. D. Fausch. 2010. Implications of a depressed thermal regime on native fish species of the North Fork Cache la Poudre River. Colorado State University, Department of Fish, Wildlife, and Conservation Biology. Fort Collins, CO.

Colorado Water Conservation Board, June 2009. Colorado's Water Supply Future. State of Colorado 2050 Municipal and Industrial; Water Use Projections. Prepared by: Camp Dresser & McKee, Inc. Harvey Economics (Draft Report)

Hirschauer, Sabine. August 16, 2009. "King William Reservoir: How did Newport News spend $51.2M?" Daily Press, 7505 Warwick Blvd., Newport News, VA 23607.

Holling, C. S. (ed) (1978). *Adaptive Environmental Assessment and Management*. John Wiley & Sons, New York.

Interstate Commission on the Potomac River Basin (2008). Webpage on CO-OP History. http://www.potomacriver.org/cms/index.php?option=com_content&view=article&id=98&catid=47&Itemid=141 (accessed June 3, 2010).

Lee, Kai N. (1993). *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Island Press, Washington, D.C.

Lorie, Mark (2006). "Shared Vision Planning and Adaptive Management: Lessons for Better Water Management." Paper Presented at the American Water Resources Association Specialty Conference on Adaptive Management of Water Resources. Missoula, MT. June 26-28, 2006.\

Luecke, D.F. (1999). "Two Forks: The Rise and Fall of a Dam." Natural Resources and Environmental 14(1), 24-28.

Merritt, D. M. 2002. Maintenance of riparian woodlands along mountain stream channels: roles of historic disturbance and hydrologic variability. Colorado State University. Report submitted to The Nature Conservancy of Colorado Fort Collins, CO.

Merritt, D. M. and E. E. Wohl (2006). Plant dispersal along rivers fragmented by dams. River Research and Applications 22:1-26.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks and J. C. Stromberg (1997). "The natural flow regime." BioScience 47:769-784.

Ray, A. J., J. J. Barsugli, K. B. Avery, K. Wolter and M. Hoerling (2008). Colorado climate change: a synthesis to support water resource management and Adaptation. NOAA-CU Western Water Assessment. Report for the Colorado Water Conservation Board.

Palmer, R.N., J.A. Smith, J.L. Cohon, and C.S. ReVelle (1982). "Reservoir Management in the Potomac River Basin." Journal of Water Resources Planning and Management 108(1):47-66.

Shabman, L. and W. Cox (2004). "Urban Water Supply Planning and the Environment: Extending the Reach of Section 404 of the Clean Water Act", Virginia Journal of Environmental Law, Spring 2004.

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

Wockner, Gary (2010). ”Last Stand on the Poudre: The fight for Colorado’s Cache la Poudre River could be ground zero for the next round of water wars in the Western U.S.” *Waterkeeper Magazine*, Winter 2010, 24-27.

Appendix 1 – Compendium of SVM Output

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Definitions:

Default APA – The applicants' default preferred alternative. This is the way in which Greeley, Fort Collins and NPIC would operate their systems without a new approach identified through the SVP experiment.

ModNormLHF – This stands for Modified normal "Low Hanging Fruit." This is the simplest modification of the default preferred alternative, giving FTC storage space in Seaman, when space is available, in order to recapture environmental releases from Halligan so that the water can be used for municipal or other demands later.

ModNormBETTER – This is a more sophisticated modification of the default preferred alternatives. This alternative also involves providing storage space in Seaman for FTC, but it also involves more complicated exchanges and water sharing. The water management features of this alternative may or may not be feasible for water rights, cost sharing or other reasons.

ModNormSMALLSEA – this take "ModNormBETTER" one step further by downsizing Seaman Reservoir so that the dam can be built at the existing location, instead of moving downstream. This avoids destroying about 0.90 of the North Fork below the current dam site.

Overall Results: Summary metrics for each resource and alternative

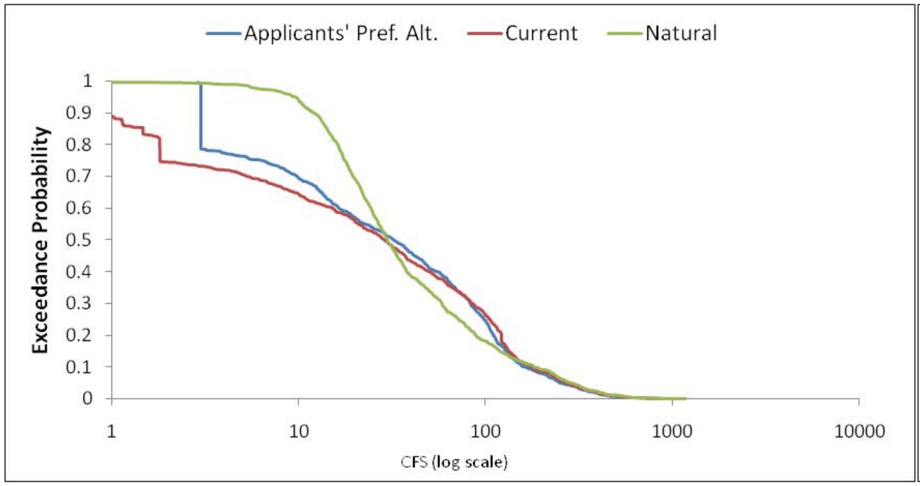
[green] = Better than Default APA   [red] =Worse than Default APA

Metric	Default APA	ModNormLHF	ModNorm-BETTER	ModNorm-SMALLSEA
Water Supply Reliability				
Greeley	99.7%	99.7%	100.0%	99.2%
Fort Collins	100.0%	100.0%	100.0%	100.0%
Frequency of Meeting Env. Flow Targets				
Above NPC	33%	36%	38%	36%
Below NPC	18%	20%	23%	22%
Above Seaman	27%	30%	33%	32%
Below Seaman	44%	44%	44%	44%
Months with zero flow on North Fork	53	0	0	0
JOP, Frequency of total release less than 10 cfs				
Oct HMR	0%	0%	0%	0%
Nov HMR	0%	0%	0%	0%
Dec HMR	0%	0%	0%	0%
Jan HMR	0%	0%	0%	0%
Feb HMR	0%	0%	0%	0%
Mar HMR	0%	0%	0%	0%
Apr HMR	99%	98%	99%	99%
Fish Habitat, Avg Score				
Overall Average Score	0.51	0.52	0.53	0.54
Average minimum score	0.15	0.26	0.25	0.25
Freq. of departure from natural	42%	42%	40%	40%
Reservoir Inundation Impacts				
Eagles Nest Open Space (acres)	0.00	0.00	0.00	0.00
Wetlands Impact (acres)	0.00	0.00	0.00	0.00
NF Miles - Seaman (above)	2.93	2.93	2.93	2.34
NF Miles - Seaman (below)	0.90	0.90	0.90	0.00
Dale Creek - Halligan	0.00	0.00	0.00	0.00
NF Stream Miles - Halligan	2.37	2.37	2.37	2.37
Other Stream Miles	4.35	4.35	4.35	3.99
Vegetation Inundation				
Average return interval	0.92	0.91	0.91	0.91
Average max return interval	3.23	3.42	3.42	3.25
Cumulative % diff with natural	-29%	-28%	-27%	-28%
Sediment Movement				
Cumulative Transport Potential, ratio to current	0.97	0.96	0.96	0.96
Cumulative Transport Potential, ratio to natural	0.59	0.58	0.58	0.58

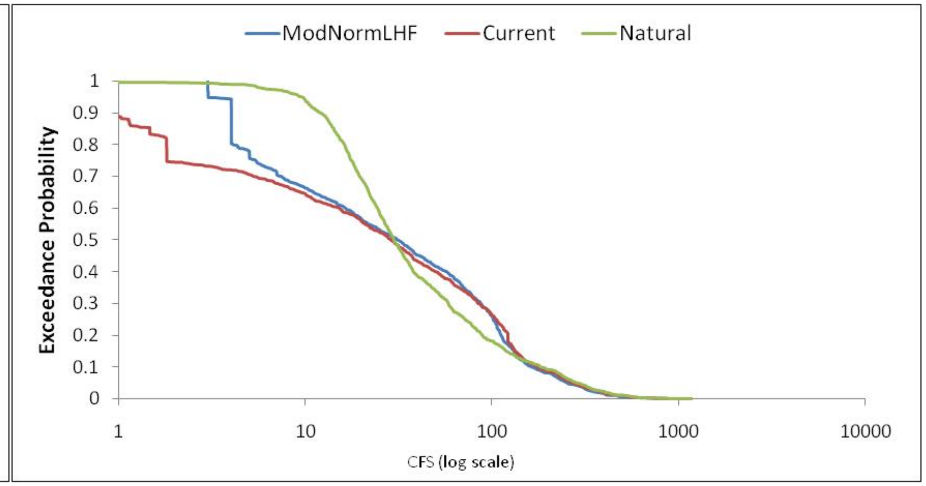
Flow Duration Curves

North Fork below Halligan (Phantom Canyon), flow duration curves for alternatives, current conditions and natural conditions

Default APA



ModNormLHF



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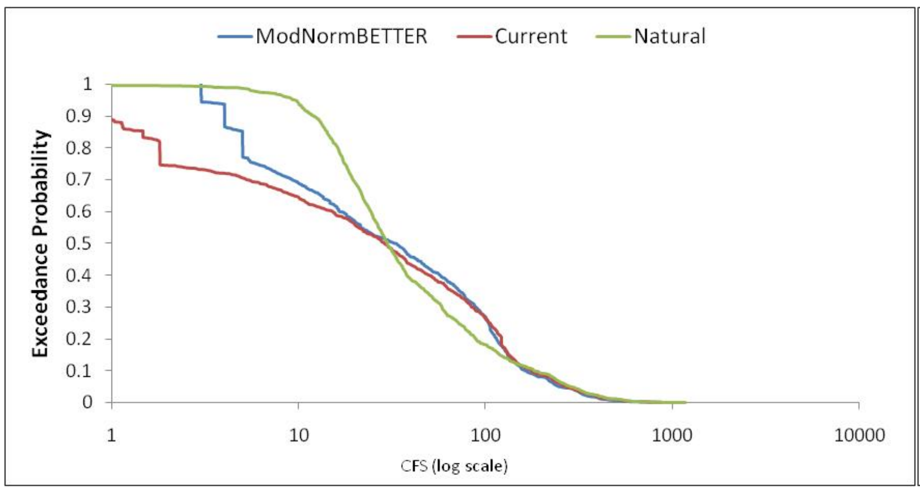
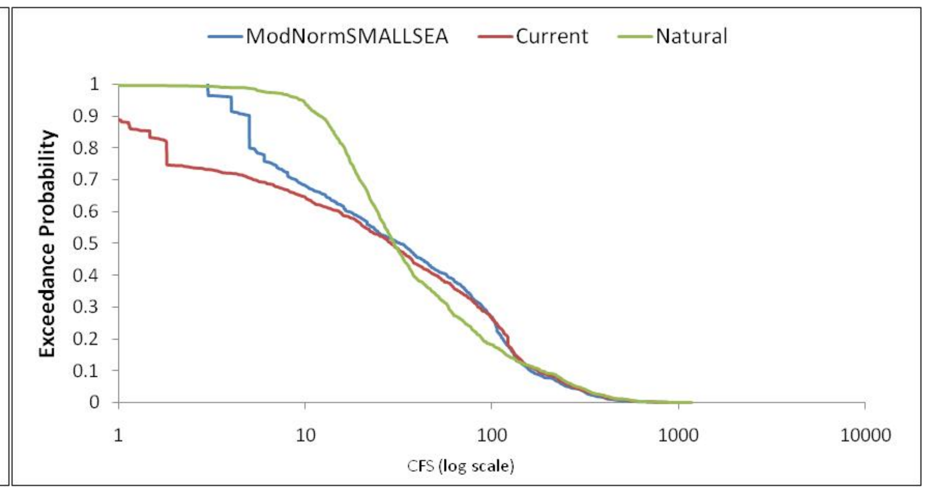
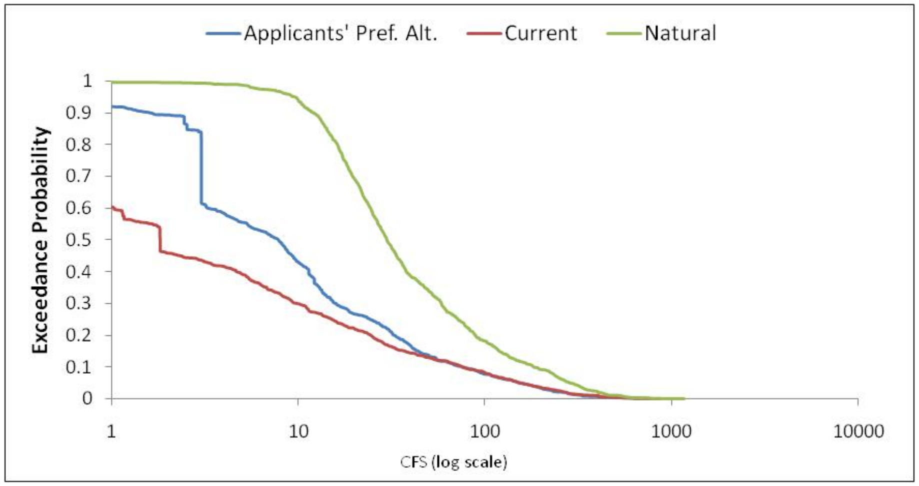


ModNormSMALLSEA



Flow metric: North Fork Below North Poudre Canal, flow duration curves for alternatives, current conditions and natural conditions

Default APA



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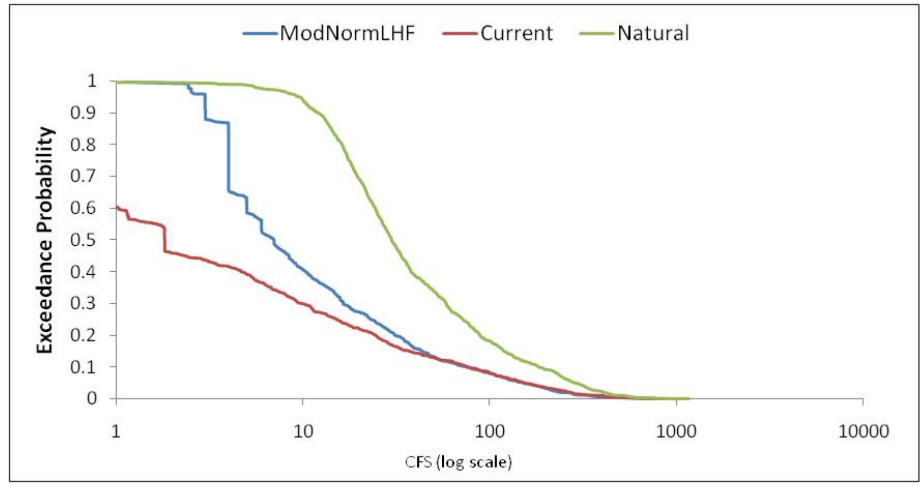

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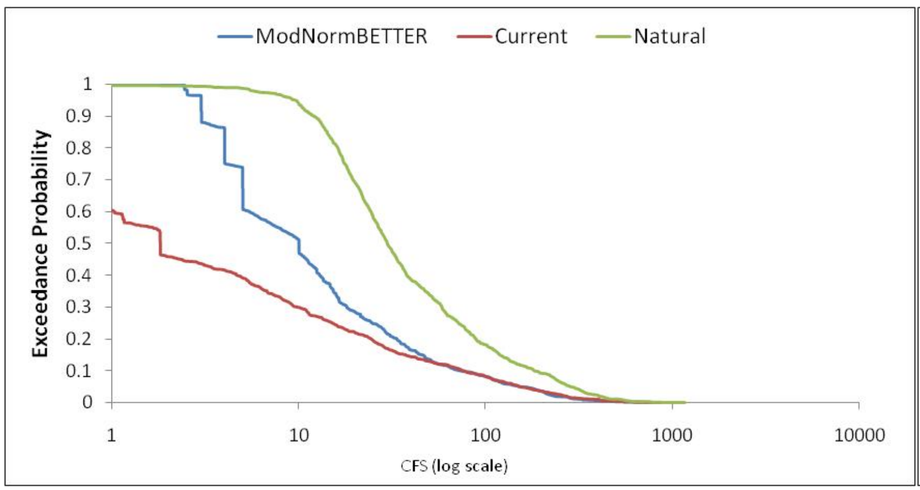

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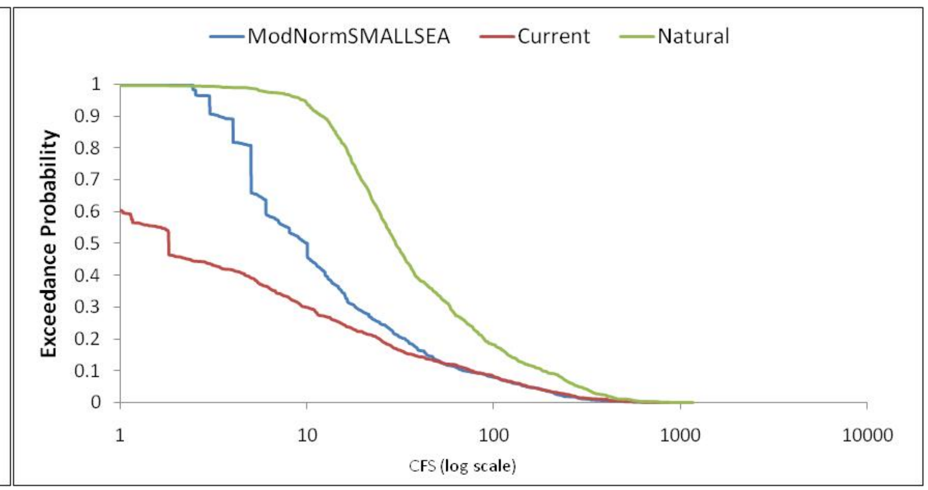
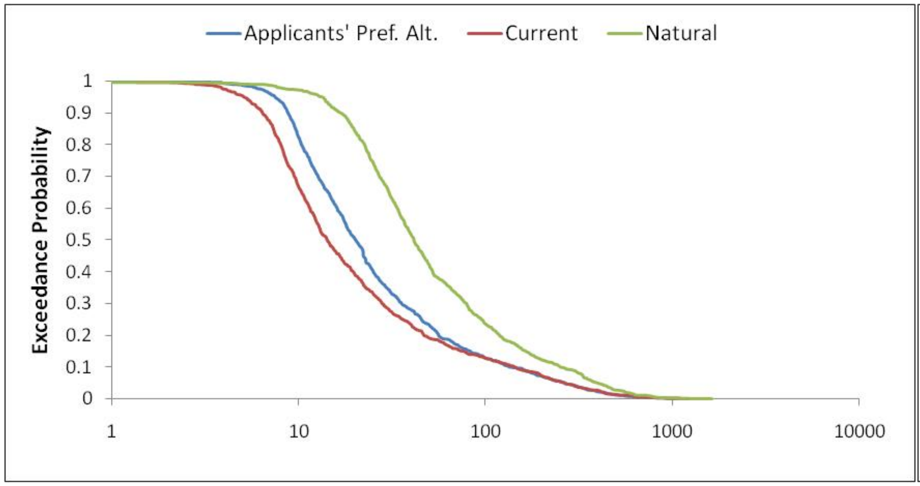


Flow metric: North Fork Below Tributaries/Above Seaman, flow duration curves for alternatives, current conditions and natural conditions

Default APA



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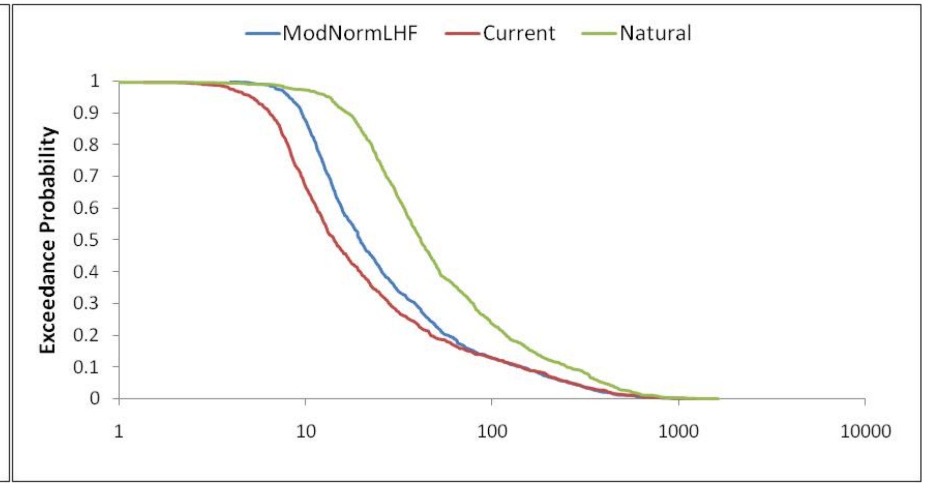

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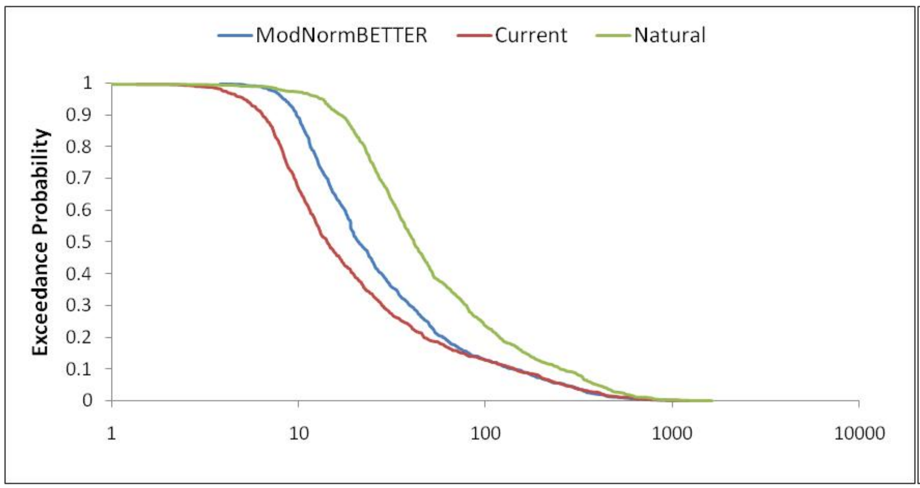

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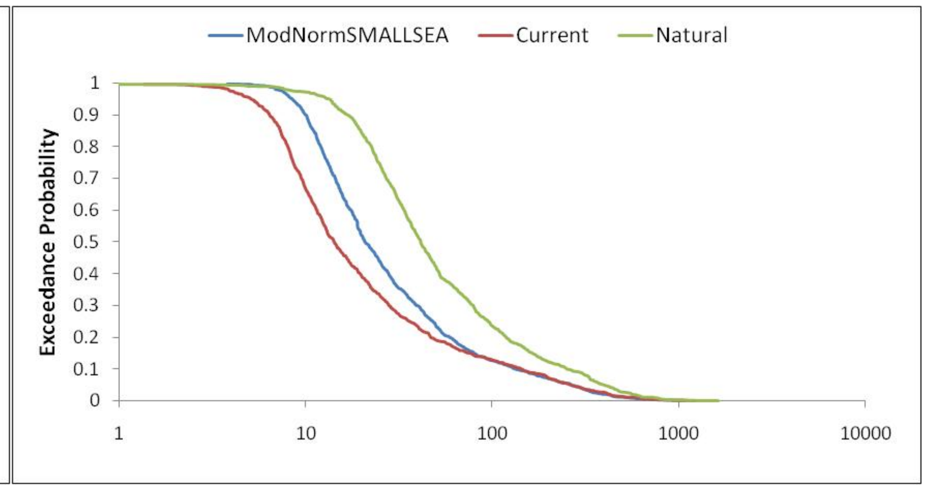
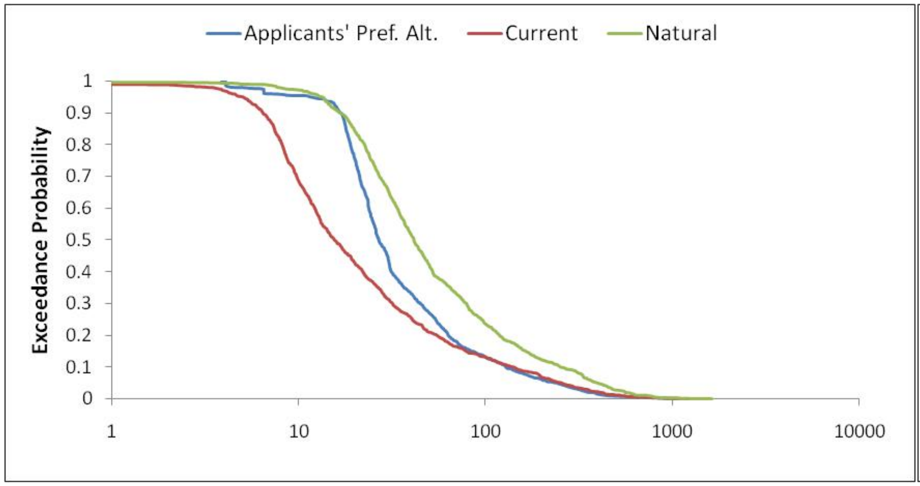


Flow metric: North Fork Below Seaman, flow duration curves for alternatives, current conditions and natural conditions

Default APA



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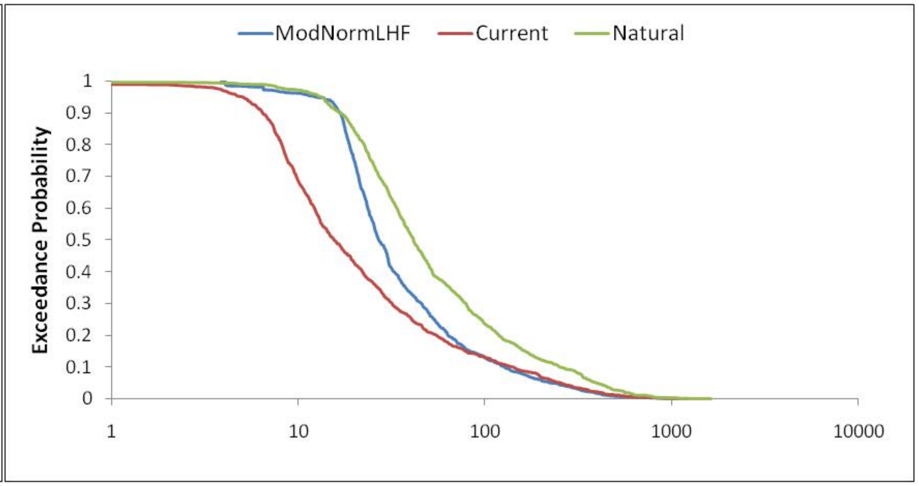

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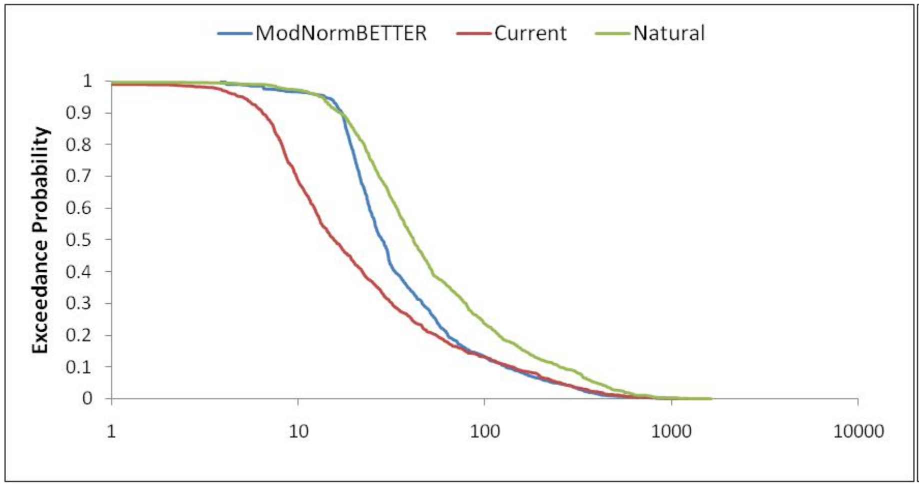
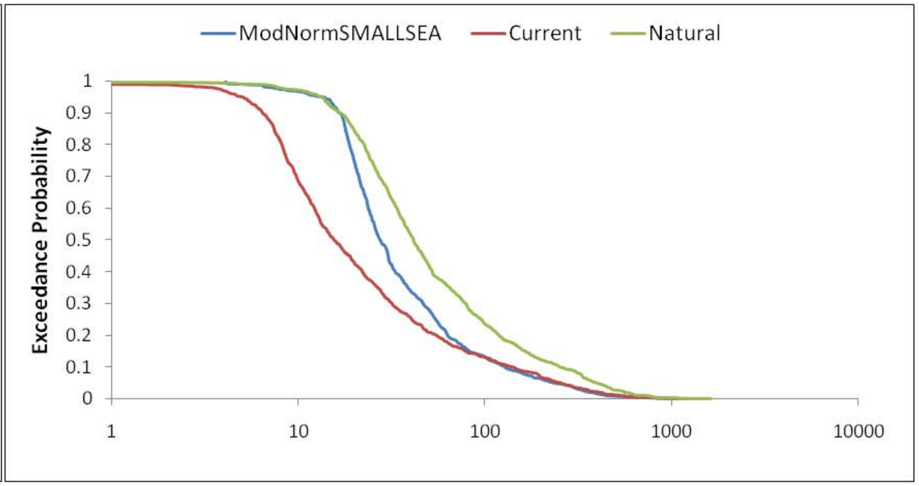


ModNormSMALLSEA

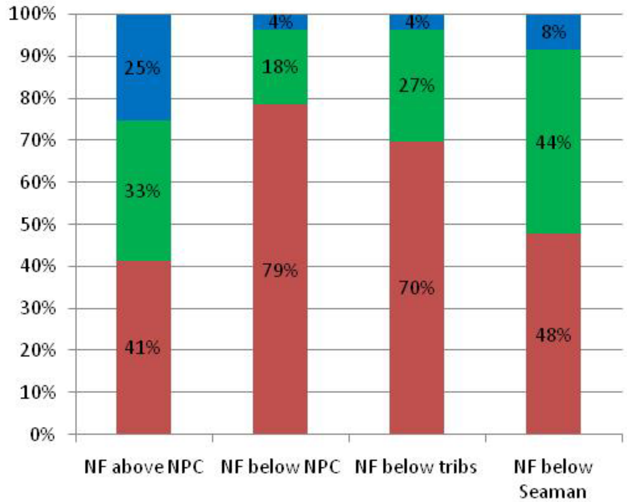


Streamflow metrics

Frequency that monthly flows fall below, within or above streamflow targets
This is based on the original streamflow targets published by The Nature Conversancy

= Above =Within =Below

Default APA



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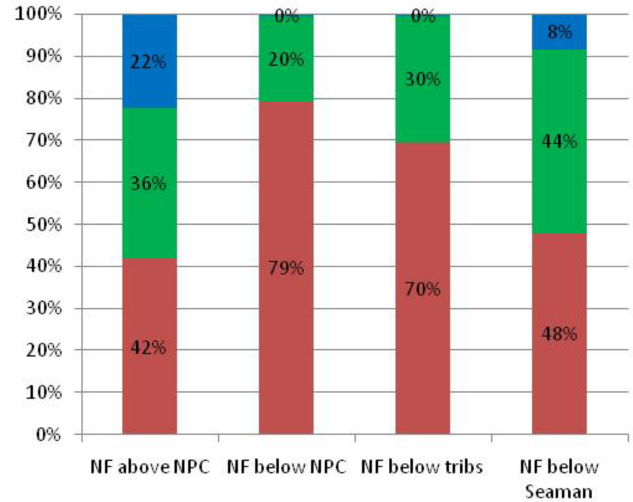

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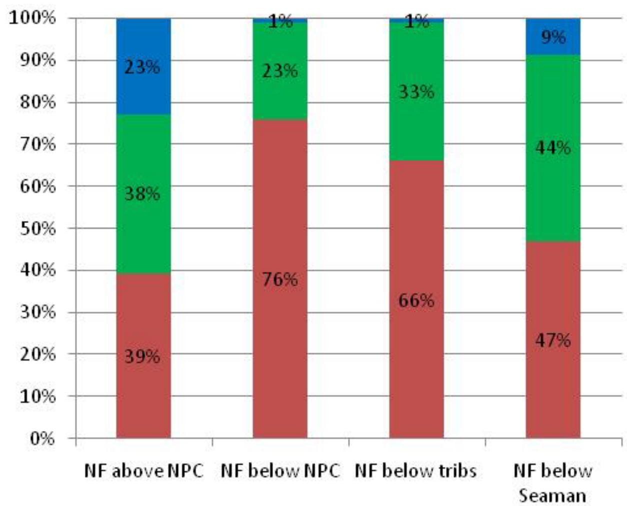
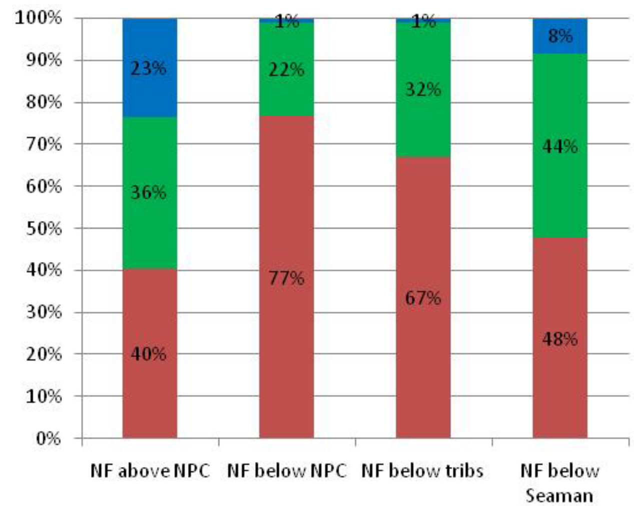


ModNormSMALLSEA



Flow Percentiles

Percentiles by month, Phantom Canyon, current and natural conditions versus alternatives

Current conditions versus four alternatives

	Current				Applicants' Pref. Alt.				ModNormLHF				ModNormBETTER				ModNormSMALLSEA			
	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile
Jan	0.0	0	2	35	3.0	3	5	36	3.0	3	4	33	3.0	3	5	37	3.0	3	5	35
Feb	0.0	0	7	36	2.9	3	9	37	3.0	3	7	35	3.0	3	8	35	3.0	3	7	35
Mar	0.0	0	16	51	3.0	3	13	54	3.0	3	11	51	3.0	3	10	51	3.0	3	10	51
Apr	0.0	11	57	172	4.1	7	61	179	4.1	8	59	176	4.1	8	58	176	4.1	8	58	176
May	73.9	90	199	579	46.9	74	174	553	46.9	74	174	547	46.9	74	174	539	46.9	74	174	538
Jun	31.4	60	198	495	45.9	60	191	446	46.1	60	189	449	47.1	62	189	421	47.1	62	178	421
Jul	4.9	21	122	151	29.1	43	105	145	31.7	51	109	149	30.7	51	109	153	30.7	47	109	153
Aug	2.5	20	84	141	16.4	22	95	135	16.5	30	101	139	16.5	28	103	143	16.5	28	103	143
Sep	3.2	7	36	106	9.9	14	56	94	7.0	15	59	96	3.8	15	61	99	4.1	14	62	100
Oct	1.5	1	17	95	6.3	10	19	83	3.4	4	18	80	3.3	4	18	81	3.3	4	17	81
Nov	0.0	0	1	3	0.0	3	3	6	3.0	3	4	21	3.0	3	5	21	3.0	3	6	21
Dec	0.0	0	2	13	3.0	3	3	14	3.0	3	4	13	3.0	3	5	16	3.0	3	5	16
	32 months with zero flow				*1 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*			

Color codes

At least 50% less than Current or Natural
At least 10% less than Current or Natural
Within +/- 10% of Current or Natural
At least 10% more than Current or Natural
At least 50% more than Current or Natural

Natural conditions versus four alternatives

	Natural				Applicants' Pref. Alt.				ModNormLHF				ModNormBETTER				ModNormSMALLSEA			
	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile
Jan	0.6	5	17	37	3.0	3	5	36	3.0	3	4	33	3.0	3	5	37	3.0	3	5	35
Feb	4.9	9	18	36	2.9	3	9	37	3.0	3	7	35	3.0	3	8	35	3.0	3	7	35
Mar	5.5	10	26	53	3.0	3	13	54	3.0	3	11	51	3.0	3	10	51	3.0	3	10	51
Apr	10.8	20	60	176	4.1	7	61	179	4.1	8	59	176	4.1	8	58	176	4.1	8	58	176
May	31.7	85	209	595	46.9	74	174	553	46.9	74	174	547	46.9	74	174	539	46.9	74	174	538
Jun	17.4	55	224	511	45.9	60	191	446	46.1	60	189	449	47.1	62	189	421	47.1	62	178	421
Jul	2.2	13	73	119	29.1	43	105	145	31.7	51	109	149	30.7	51	109	153	30.7	47	109	153
Aug	0.0	10	36	91	16.4	22	95	135	16.5	30	101	139	16.5	28	103	143	16.5	28	103	143
Sep	0.2	6	21	64	9.9	14	56	94	7.0	15	59	96	3.8	15	61	99	4.1	14	62	100
Oct	3.5	8	26	59	6.3	10	19	83	3.4	4	18	80	3.3	4	18	81	3.3	4	17	81
Nov	7.5	12	23	49	0.0	3	3	6	3.0	3	4	21	3.0	3	5	21	3.0	3	6	21
Dec	5.9	10	19	42	3.0	3	3	14	3.0	3	4	13	3.0	3	5	16	3.0	3	5	16
	1 months with zero flow				*1 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*			

Flow percentiles by month, Below NPC, current and natural conditions versus alternatives

Current conditions versus four alternatives

	Current				Applicants' Pref. Alt.				ModNormLHF				ModNormBETTER				ModNormSMALLSEA			
	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile
Jan	0.0	0	2	11	3.0	3	5	32	3.0	3	4	29	3.0	3	5	34	3.0	3	5	31
Feb	0.0	0	2	13	2.9	3	9	32	3.0	3	6	30	3.0	3	7	29	3.0	3	7	30
Mar	0.0	0	1	28	3.0	3	11	48	3.0	3	8	46	3.0	3	9	45	3.0	3	9	46
Apr	0.0	0	7	106	3.0	3	32	124	3.0	3	29	121	3.0	3	29	121	3.0	3	29	121
May	0.0	0	86	472	2.4	2	69	466	2.4	2	69	460	2.4	2	69	444	2.4	2	69	439
Jun	0.0	0	73	369	1.2	2	68	322	1.1	2	70	325	1.0	3	66	297	1.0	3	60	298
Jul	0.0	0	0	31	0.0	0	2	40	2.6	3	8	43	2.5	3	12	43	2.5	3	12	45
Aug	0.0	0	1	34	0.0	0	3	37	3.0	3	8	44	3.0	3	10	47	3.0	3	10	47
Sep	0.0	0	0	14	0.0	0	5	17	3.0	3	6	18	3.0	3	10	22	3.0	3	10	19
Oct	0.0	0	6	40	4.1	8	12	44	3.0	3	10	34	3.0	3	10	38	3.0	4	10	43
Nov	0.0	0	1	3	0.0	3	3	6	3.0	3	4	21	3.0	3	5	21	3.0	3	6	21
Dec	0.0	0	2	9	3.0	3	3	13	3.0	3	4	12	3.0	3	5	16	3.0	3	5	16
	288 months with zero flow				*52 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*			

Color codes

At least 50% less than Current or Natural
At least 10% less than Current or Natural
Within +/- 10% of Current or Natural
At least 10% more than Current or Natural
At least 50% more than Current or Natural

Natural conditions versus four alternatives

	Natural				Applicants' Pref. Alt.				ModNormLHF				ModNormBETTER				ModNormSMALLSEA			
	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile
Jan	0.6	5	17	37	3.0	3	5	32	3.0	3	4	29	3.0	3	5	34	3.0	3	5	31
Feb	4.9	9	18	36	2.9	3	9	32	3.0	3	6	30	3.0	3	7	29	3.0	3	7	30
Mar	5.5	10	26	53	3.0	3	11	48	3.0	3	8	46	3.0	3	9	45	3.0	3	9	46
Apr	10.8	20	60	176	3.0	3	32	124	3.0	3	29	121	3.0	3	29	121	3.0	3	29	121
May	31.7	85	209	595	2.4	2	69	466	2.4	2	69	460	2.4	2	69	444	2.4	2	69	439
Jun	17.4	55	224	511	1.2	2	68	322	1.1	2	70	325	1.0	3	66	297	1.0	3	60	298
Jul	2.2	13	73	119	0.0	0	2	40	2.6	3	8	43	2.5	3	12	43	2.5	3	12	45
Aug	0.0	10	36	91	0.0	0	3	37	3.0	3	8	44	3.0	3	10	47	3.0	3	10	47
Sep	0.2	6	21	64	0.0	0	5	17	3.0	3	6	18	3.0	3	10	22	3.0	3	10	19
Oct	3.5	8	26	59	4.1	8	12	44	3.0	3	10	34	3.0	3	10	38	3.0	4	10	43
Nov	7.5	12	23	49	0.0	3	3	6	3.0	3	4	21	3.0	3	5	21	3.0	3	6	21
Dec	5.9	10	19	42	3.0	3	3	13	3.0	3	4	12	3.0	3	5	16	3.0	3	5	16
	1 months with zero flow				*52 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*			

Flow percentiles by month, Below Tributaries/Above Seaman, current and natural conditions versus alternatives

Current conditions versus four alternatives

	Current				Applicants' Pref. Alt.				ModNormLHF				ModNormBETTER				ModNormSMALLSEA			
	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile
Jan	2.6	4	9	19	3.8	7	12	46	4.2	7	11	43	5.2	7	12	47	5.2	7	12	46
Feb	3.5	5	10	21	4.9	8	15	44	5.9	8	13	42	5.9	8	14	41	6.4	8	14	42
Mar	2.9	6	13	46	5.2	9	22	66	6.1	9	19	64	6.1	9	19	63	6.1	9	19	64
Apr	4.2	11	35	187	7.3	14	58	196	8.2	12	55	193	8.2	12	55	193	8.2	12	55	193
May	9.7	27	165	710	14.1	29	147	701	14.1	29	147	690	14.1	29	147	674	14.1	29	147	669
Jun	5.3	22	156	574	8.6	21	159	535	9.3	21	157	530	8.6	21	161	496	8.6	21	145	496
Jul	2.2	6	27	64	2.3	6	28	75	4.8	10	33	75	3.8	10	37	76	3.8	10	37	79
Aug	0.0	4	12	64	0.0	5	13	66	4.0	9	18	69	4.0	9	20	75	4.0	9	20	75
Sep	0.1	4	10	25	4.3	6	13	31	4.3	7	14	30	4.3	7	17	34	4.3	7	18	33
Oct	1.4	4	16	60	9.1	14	23	63	6.4	7	21	55	6.4	8	20	55	6.4	8	20	61
Nov	4.2	6	10	20	6.6	8	12	22	7.6	8	15	33	7.6	9	14	36	7.6	9	16	37
Dec	4.2	5	9	20	7.1	8	11	22	7.2	8	12	23	7.0	8	13	29	7.2	8	13	28
	1 months with zero flow				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*			

Color codes

- At least 50% less than Current or Natural
- At least 10% less than Current or Natural
- Within +/- 10% of Current or Natural
- At least 10% more than Current or Natural
- At least 50% more than Current or Natural

Natural conditions versus four alternatives

	Natural				Applicants' Pref. Alt.				ModNormLHF				ModNormBETTER				ModNormSMALLSEA			
	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile
Jan	0.8	8	23	52	3.8	7	12	46	4.2	7	11	43	5.2	7	12	47	5.2	7	12	46
Feb	6.8	13	26	50	4.9	8	15	44	5.9	8	13	42	5.9	8	14	41	6.4	8	14	42
Mar	7.6	14	36	74	5.2	9	22	66	6.1	9	19	64	6.1	9	19	63	6.1	9	19	64
Apr	15.0	28	83	244	7.3	14	58	196	8.2	12	55	193	8.2	12	55	193	8.2	12	55	193
May	41.4	112	286	825	14.1	29	147	701	14.1	29	147	690	14.1	29	147	674	14.1	29	147	669
Jun	22.7	74	307	716	8.6	21	159	535	9.3	21	157	530	8.6	21	161	496	8.6	21	145	496
Jul	3.0	18	96	164	2.3	6	28	75	4.8	10	33	75	3.8	10	37	76	3.8	10	37	79
Aug	0.0	14	49	117	0.0	5	13	66	4.0	9	18	69	4.0	9	20	75	4.0	9	20	75
Sep	0.3	8	28	84	4.3	6	13	31	4.3	7	14	30	4.3	7	17	34	4.3	7	18	33
Oct	4.9	12	36	81	9.1	14	23	63	6.4	7	21	55	6.4	8	20	55	6.4	8	20	61
Nov	10.4	17	32	68	6.6	8	12	22	7.6	8	15	33	7.6	9	14	36	7.6	9	16	37
Dec	8.2	14	27	59	7.1	8	11	22	7.2	8	12	23	7.0	8	13	29	7.2	8	13	28
	1 months with zero flow				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*			

Flow percentiles by month, Below Seaman, current and natural conditions versus alternatives

Current conditions versus four alternatives

	Current				Applicants' Pref. Alt.				ModNormLHF				ModNormBETTER				ModNormSMALLSEA			
	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile
Jan	0.0	3	9	18	12.0	16	20	55	11.9	16	20	55	11.9	16	20	54	7.6	15	20	54
Feb	0.0	5	10	21	11.9	17	24	54	13.0	17	24	54	14.0	17	24	54	9.2	17	24	54
Mar	0.0	5	13	44	10.9	17	30	74	10.8	17	30	74	13.7	18	30	74	10.8	17	30	74
Apr	4.2	11	35	187	11.5	18	62	182	11.4	18	62	182	11.4	18	62	182	11.4	18	62	182
May	9.7	27	151	710	8.5	25	129	695	8.5	25	135	682	8.5	23	136	659	8.5	22	136	661
Jun	5.3	22	152	514	8.6	20	129	401	8.6	20	114	422	8.6	17	120	389	6.7	14	117	400
Jul	2.2	6	27	64	3.9	4	23	88	3.9	4	25	98	3.9	5	30	94	4.1	5	26	99
Aug	0.0	5	15	75	4.1	4	28	68	4.1	4	29	73	4.1	4	29	77	4.1	5	30	78
Sep	0.1	4	14	54	13.3	14	36	88	13.7	16	35	88	13.7	18	35	88	13.9	16	35	81
Oct	1.4	4	23	76	17.6	20	24	48	16.8	18	24	46	17.5	21	26	57	14.7	17	25	57
Nov	0.1	5	10	19	15.4	17	21	31	15.4	17	21	31	15.4	17	21	31	10.8	17	21	37
Dec	0.5	5	9	20	15.2	16	20	30	15.1	16	20	30	15.1	16	20	30	8.6	16	20	30
	4 months with zero flow				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*			

Color codes

At least 50% less than Current or Natural
At least 10% less than Current or Natural
Within +/- 10% of Current or Natural
At least 10% more than Current or Natural
At least 50% more than Current or Natural

Natural conditions versus four alternatives

	Natural				Applicants' Pref. Alt.				ModNormLHF				ModNormBETTER				ModNormSMALLSEA			
	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile	Min	5th Percentile	Median	95th Percentile
Jan	0.8	8	23	52	12.0	16	20	55	12.0	16	20	55	11.9	16	20	54	7.6	15	20	54
Feb	6.8	13	26	50	11.9	17	24	54	11.9	17	24	54	14.0	17	24	54	9.2	17	24	54
Mar	7.6	14	36	74	10.9	17	30	74	10.9	17	30	74	13.7	18	30	74	10.8	17	30	74
Apr	15.0	28	83	244	11.5	18	62	182	11.5	18	62	182	11.4	18	62	182	11.4	18	62	182
May	41.4	112	286	825	8.5	25	129	695	8.5	25	129	695	8.5	23	136	659	8.5	22	136	661
Jun	22.7	74	307	716	8.6	20	129	401	8.6	20	129	401	8.6	17	120	389	6.7	14	117	400
Jul	3.0	18	96	164	3.9	4	23	88	3.9	4	23	88	3.9	5	30	94	4.1	5	26	99
Aug	0.0	14	49	117	4.1	4	28	68	4.1	4	28	68	4.1	4	29	77	4.1	5	30	78
Sep	0.3	8	28	84	13.3	14	36	88	13.3	14	36	88	13.7	18	35	88	13.9	16	35	81
Oct	4.9	12	36	81	17.6	20	24	48	17.6	20	24	48	17.5	21	26	57	14.7	17	25	57
Nov	10.4	17	32	68	15.4	17	21	31	15.4	17	21	31	15.4	17	21	31	10.8	17	21	37
Dec	8.2	14	27	59	15.2	16	20	30	15.2	16	20	30	15.1	16	20	30	8.6	16	20	30
	1 months with zero flow				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*				*0 months with zero flow*			

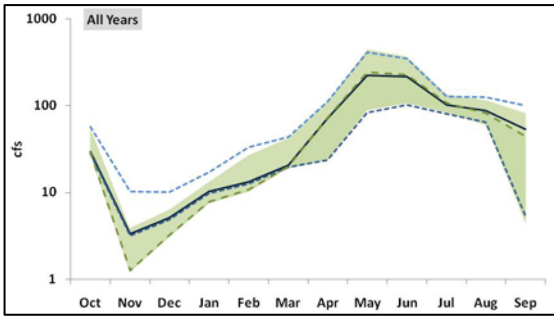
Monthly flow patterns

Average monthly, probably daily maxima and probable daily minima averaged across all years, Phantom Canyon

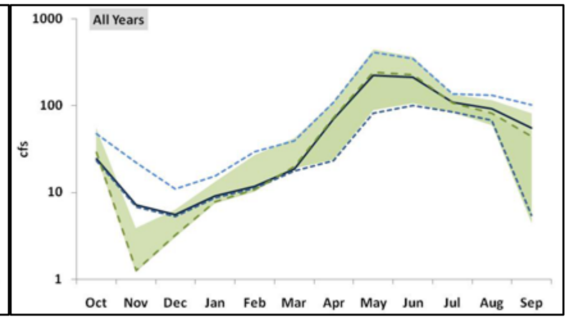
Current/Natural average monthly and daily range | Average and daily range for the displayed alternative

Four alternatives compared to current conditions

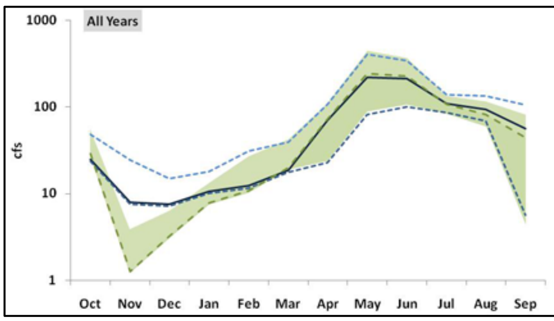
Default APA



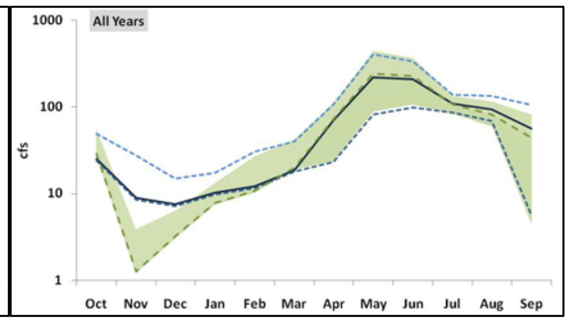
ModNormLHF



ModNormBETTER

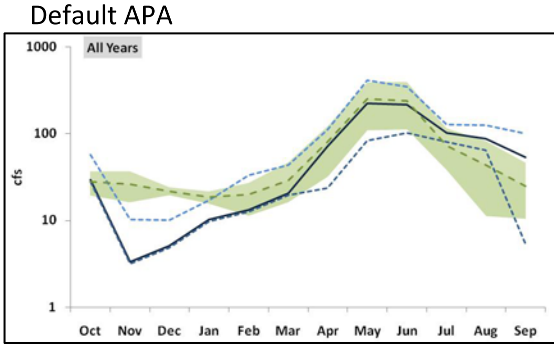


ModNormSMALLSEA



Four alternatives compared to natural conditions

Default APA



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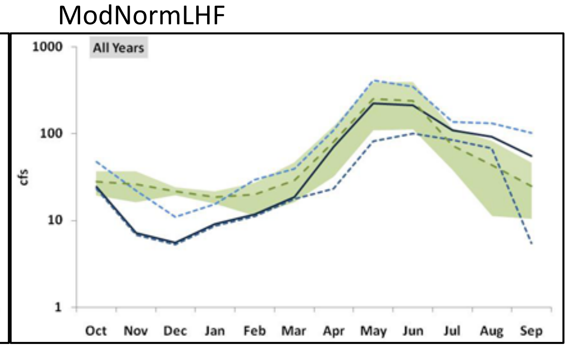
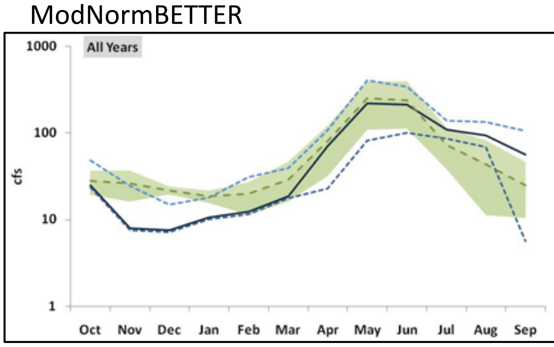
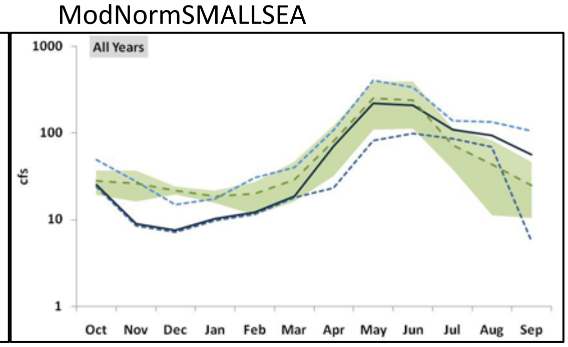


ModNormBETTER



ModNormSMALLSEA



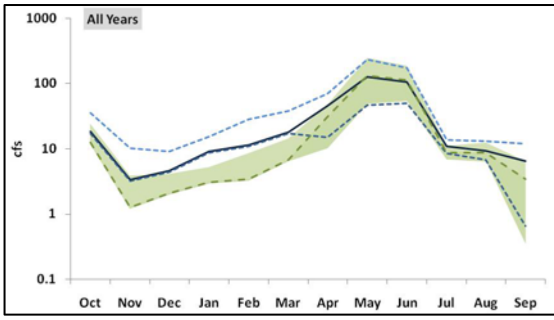
Average monthly, probably daily maxima and probable daily minima averaged across all years, Below North Poudre Canal

Current/Natural average monthly and daily range

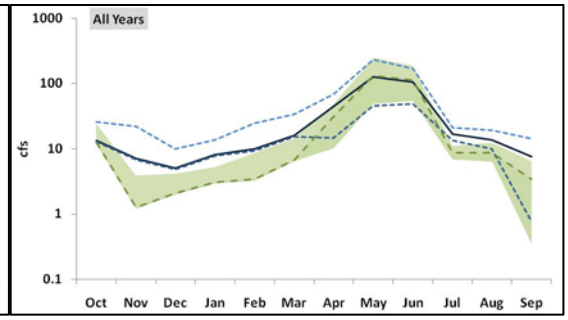
Average and daily range for the displayed alternative

Four alternatives compared to current conditions

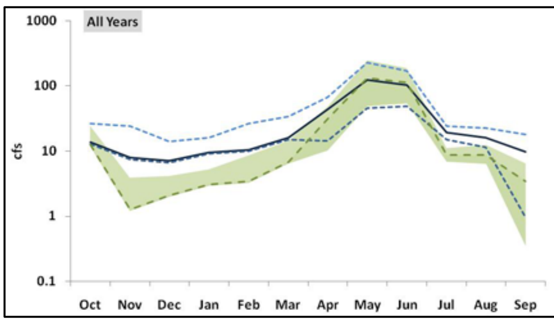
Default APA



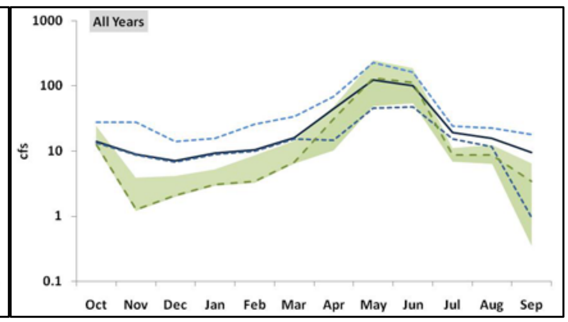
ModNormLHF



ModNormBETTER

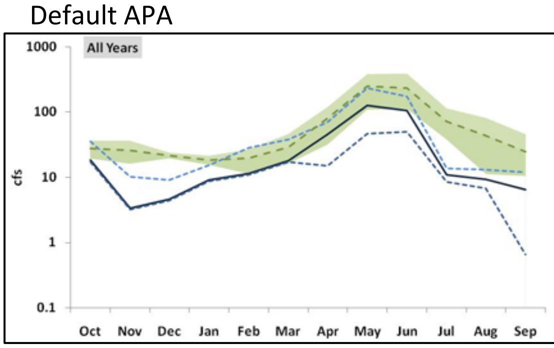


ModNormSMALLSEA

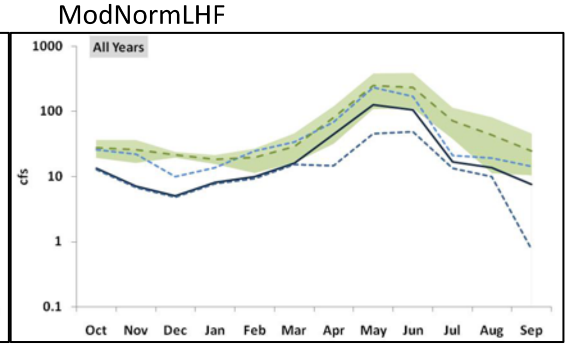


Four alternatives compared to natural conditions

Default APA



ModNormLHF



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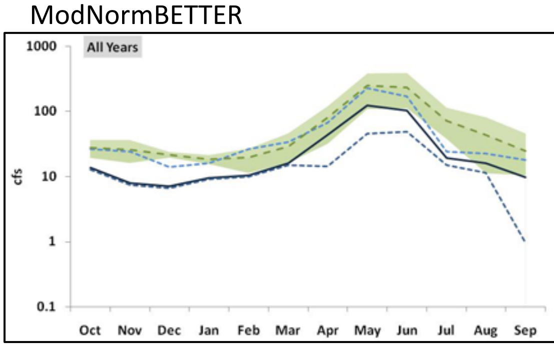

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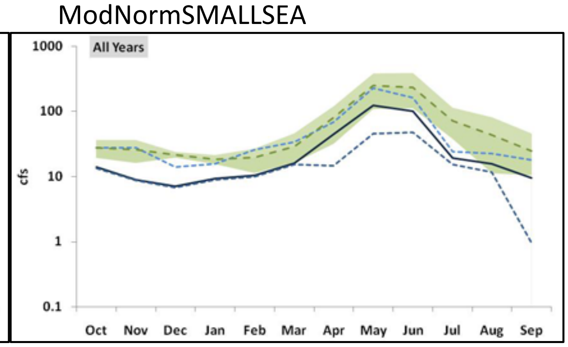
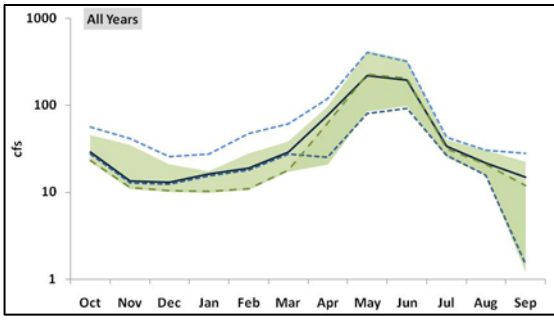


Average monthly, probably daily maxima and probable daily minima averaged across all years, Below Tributaries/Above Seaman

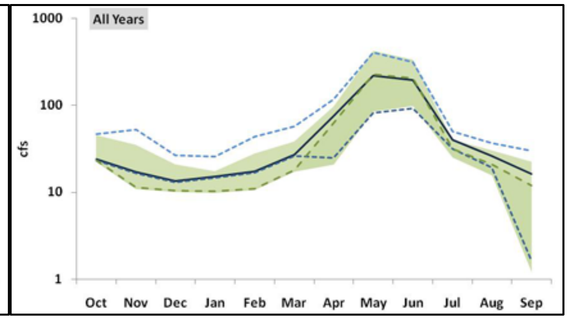
Current/Natural average monthly and daily range — Average and daily range for the displayed alternative

Four alternatives compared to current conditions

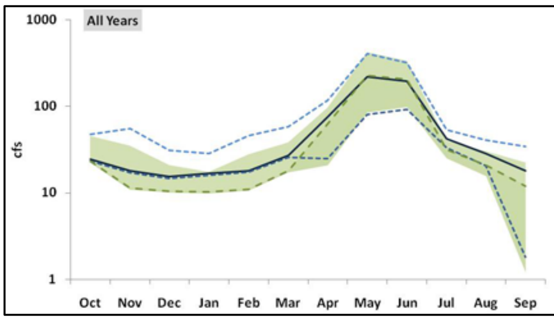
Default APA



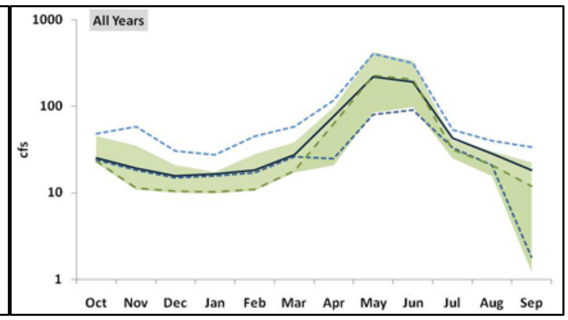
ModNormLHF



ModNormBETTER

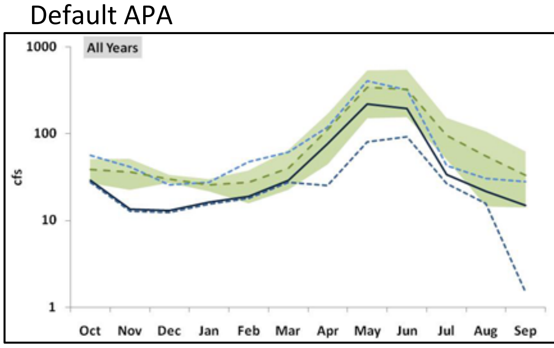


ModNormSMALLSEA



Four alternatives compared to natural conditions

Default APA



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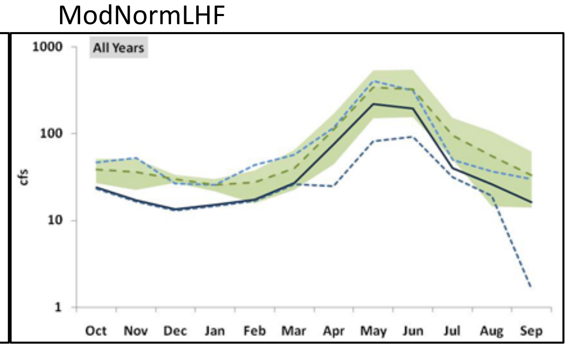

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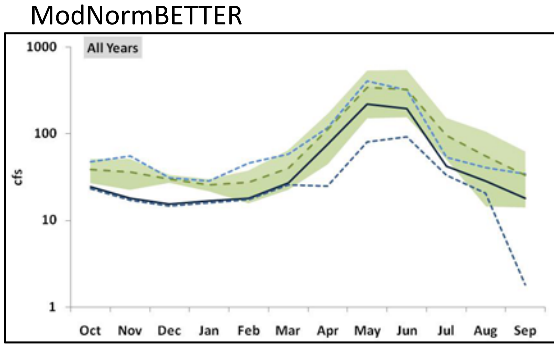
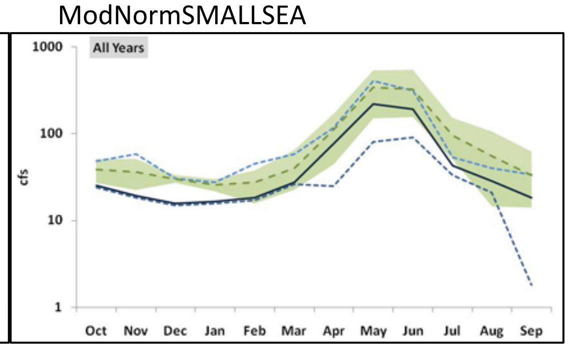


ModNormSMALLSEA



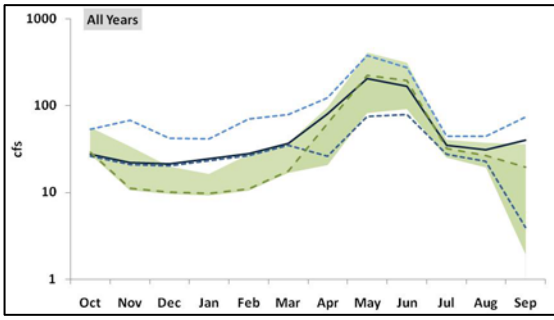
Average monthly, probably daily maxima and probable daily minima averaged across all years, Below Seaman

Current/Natural average monthly and daily range

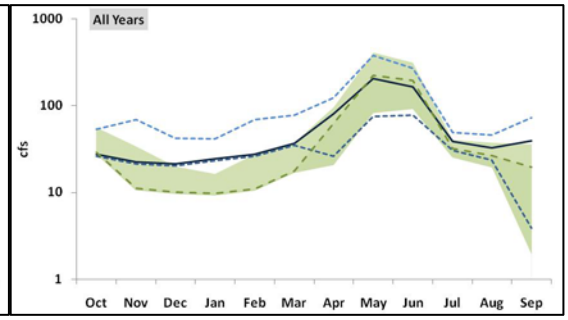
Average and daily range for the displayed alternative

Four alternatives compared to current conditions

Default APA



ModNormLHF



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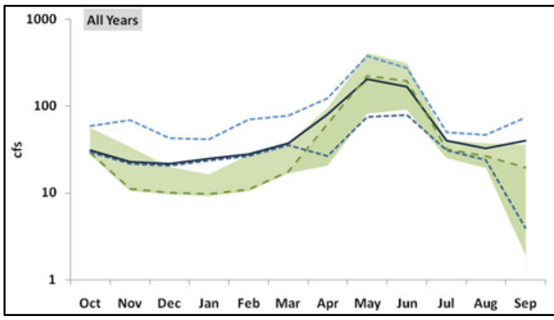
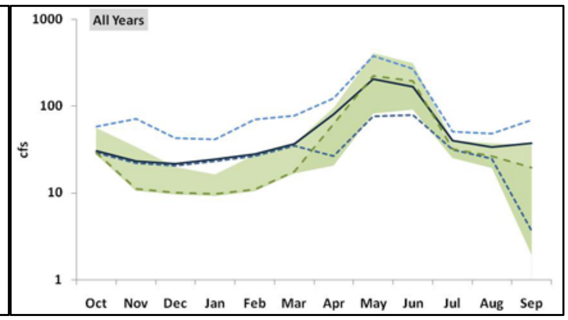
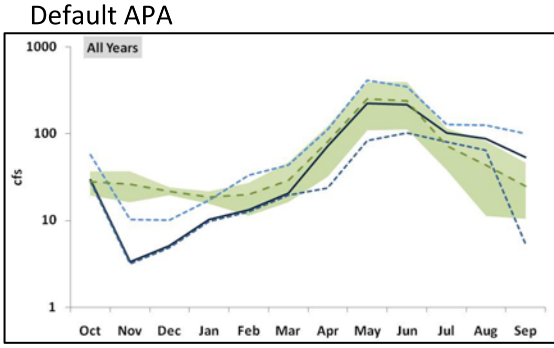


ModNormSMALLSEA

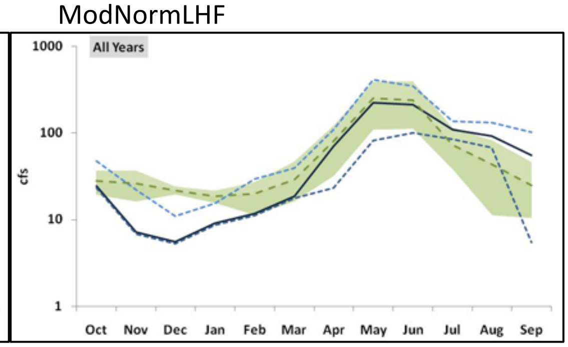


Four alternatives compared to natural conditions

Default APA



ModNormLHF



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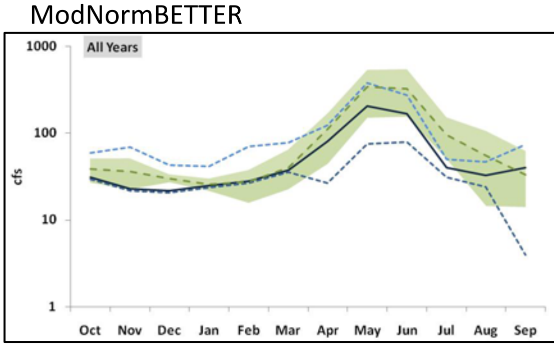
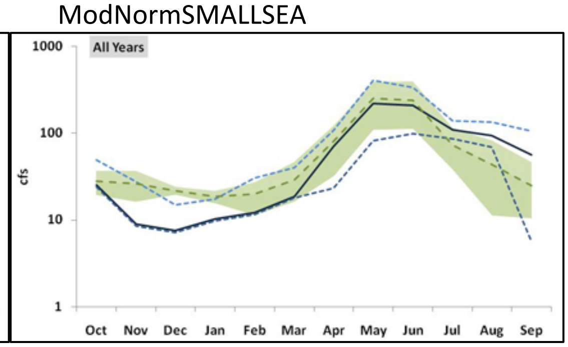


ModNormSMALLSEA

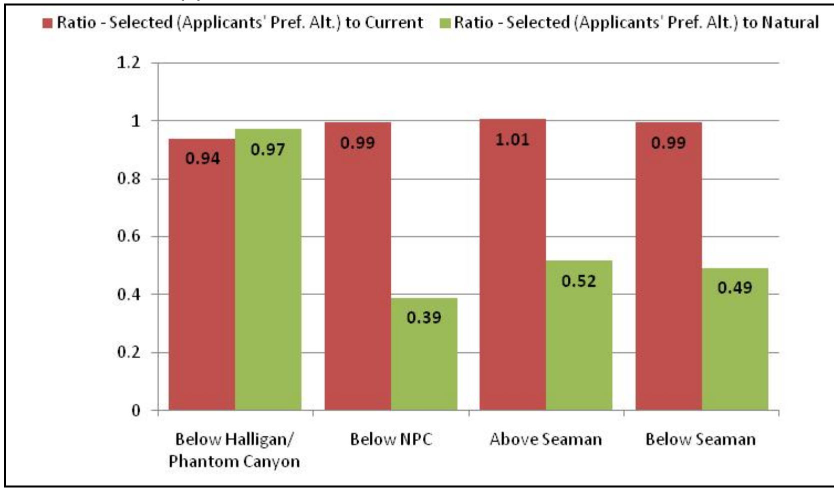


Sediment movement metric

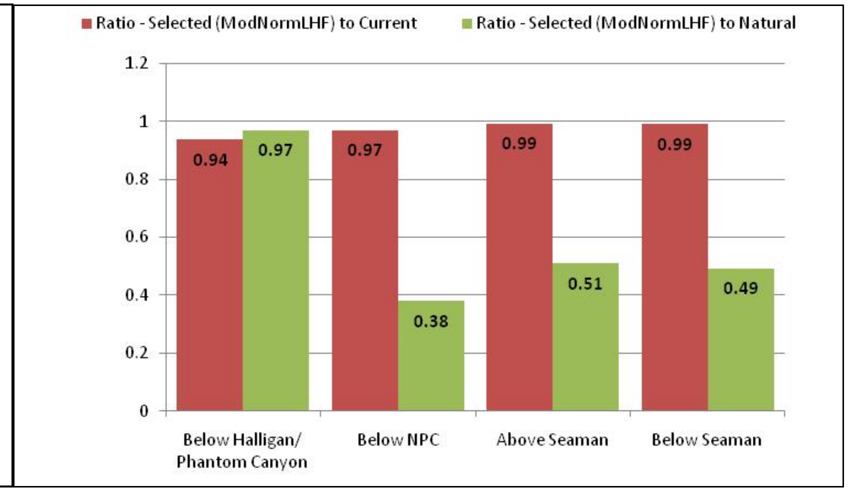
Cumulative bedload transport potential, ratio of alternative to current conditions (RED) and ratio of alternative to natural conditions (GREEN)

Ratio to current conditions   Ratio to natural conditions

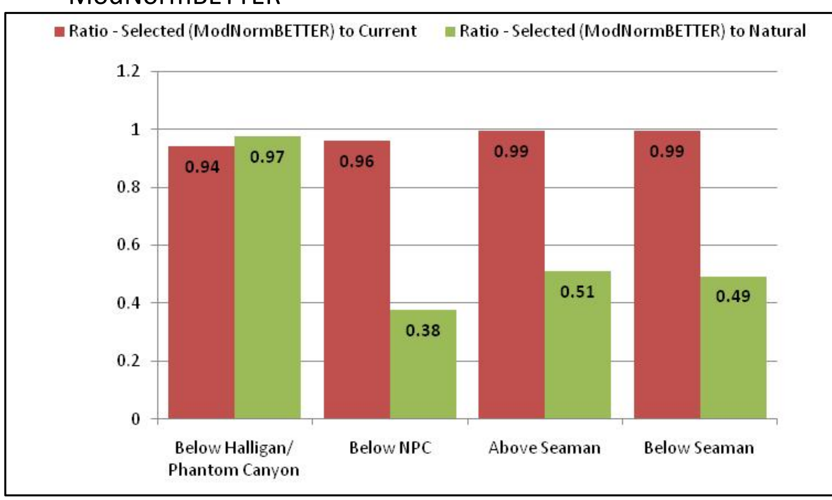
Default Applicants' Preferred Alternative



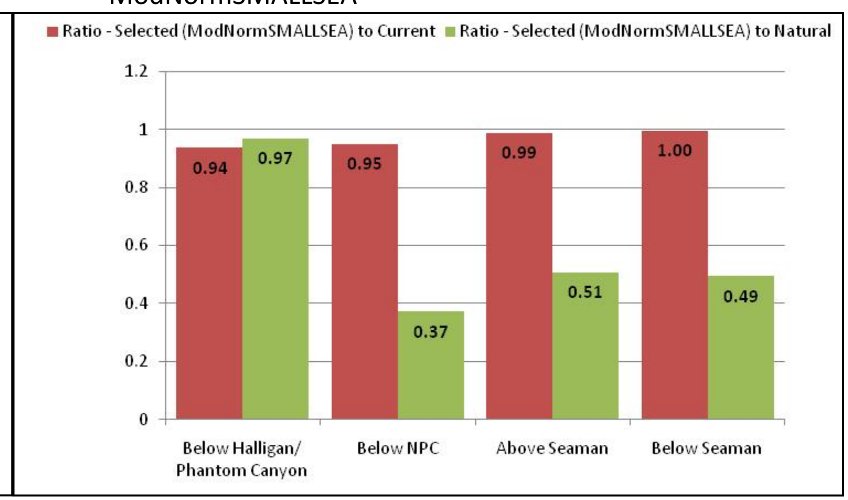
ModNormLHF



ModNormBETTER



ModNormSMALLSEA



Fish habitat availability comparison to current conditions

Average and minima normalized (0-1 scale) habitat availability by species, life stage (for Brown and Rainbow Trout), and river reach; comparison to current conditions

Color Coding Key				
Color Coding Key	Better than Current	>25% better	15% to 25% better	5% to 15% better
	Worse than Current	>25% worse	15% to 25% worse	5% to 15% worse

		AVERAGES								MINIMA							
		Brown Trout			Rainbow Trout			Longnose	Longnose	Brown Trout			Rainbow Trout			Longnose	Longnose
		Fry	Juv.	Adult	Fry	Juv.	Adult	Dace	Sucker	Fry	Juv.	Adult	Fry	Juv.	Adult	Dace	Sucker
Current Conditions	Below Halligan	0.83	0.45	0.34	0.78	0.47	0.24	0.44	0.44	0.71	0.00	0.00	0.61	0.00	0.00	0.00	0.00
	Phantom Canyon	0.53	0.46	0.32	0.55	0.49	0.13	0.47	0.43	0.45	0.00	0.00	0.46	0.00	0.00	0.00	0.00
	Below NPC	0.05	0.18	0.06	0.22	0.18	0.12	0.11	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Below Tributaries	0.92	0.71	0.22	0.88	0.66	0.27	0.59	0.46	0.81	0.00	0.00	0.35	0.00	0.00	0.00	0.00
	Below Seaman	0.87	0.61	0.21	0.89	0.64	0.35	0.53	0.48	0.67	0.00	0.00	0.27	0.00	0.00	0.00	0.00
Default APA	Below Halligan	0.83	0.52	0.38	0.79	0.54	0.27	0.50	0.51	0.71	0.00	0.00	0.70	0.00	0.00	0.00	0.00
	Phantom Canyon	0.53	0.53	0.35	0.52	0.56	0.14	0.53	0.50	0.46	0.00	0.00	0.45	0.00	0.00	0.00	0.00
	Below NPC	0.28	0.34	0.12	0.34	0.34	0.24	0.20	0.22	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Below Tributaries	0.92	0.76	0.27	0.88	0.72	0.30	0.65	0.49	0.85	0.00	0.00	0.37	0.00	0.00	0.00	0.00
	Below Seaman	0.90	0.72	0.38	0.83	0.76	0.45	0.71	0.60	0.69	0.27	0.02	0.48	0.29	0.14	0.18	0.18
ModNormLHF	Below Halligan	0.83	0.53	0.38	0.77	0.55	0.27	0.51	0.51	0.71	0.18	0.05	0.70	0.19	0.08	0.15	0.17
	Phantom Canyon	0.53	0.53	0.34	0.51	0.56	0.15	0.53	0.50	0.46	0.14	0.02	0.45	0.16	0.01	0.15	0.15
	Below NPC	0.28	0.37	0.12	0.65	0.37	0.26	0.22	0.23	0.24	0.12	0.00	0.26	0.12	0.09	0.04	0.05
	Below Tributaries	0.92	0.77	0.28	0.87	0.73	0.31	0.66	0.50	0.86	0.45	0.09	0.66	0.41	0.20	0.34	0.29
	Below Seaman	0.90	0.72	0.39	0.83	0.77	0.45	0.71	0.60	0.69	0.27	0.02	0.48	0.29	0.14	0.18	0.18
ModNorm BETTER	Below Halligan	0.81	0.54	0.39	0.76	0.57	0.28	0.52	0.53	0.71	0.18	0.05	0.70	0.19	0.08	0.15	0.17
	Phantom Canyon	0.53	0.55	0.35	0.51	0.57	0.15	0.55	0.52	0.46	0.14	0.02	0.45	0.16	0.01	0.15	0.15
	Below NPC	0.36	0.41	0.14	0.72	0.41	0.28	0.24	0.26	0.24	0.12	0.00	0.25	0.12	0.09	0.04	0.05
	Below Tributaries	0.89	0.78	0.29	0.86	0.74	0.32	0.66	0.50	0.58	0.44	0.09	0.62	0.39	0.20	0.32	0.28
	Below Seaman	0.89	0.73	0.39	0.85	0.77	0.46	0.72	0.60	0.72	0.27	0.02	0.48	0.29	0.14	0.18	0.18
ModNorm SMALLSEA	Below Halligan	0.82	0.55	0.39	0.76	0.57	0.29	0.53	0.53	0.71	0.18	0.05	0.70	0.19	0.08	0.15	0.17
	Phantom Canyon	0.52	0.55	0.35	0.51	0.58	0.15	0.56	0.52	0.46	0.14	0.02	0.45	0.16	0.01	0.15	0.15
	Below NPC	0.33	0.42	0.14	0.72	0.42	0.29	0.24	0.26	0.24	0.12	0.00	0.25	0.12	0.09	0.04	0.05
	Below Tributaries	0.90	0.78	0.29	0.86	0.74	0.32	0.67	0.51	0.60	0.44	0.09	0.62	0.39	0.20	0.32	0.28
	Below Seaman	0.89	0.73	0.39	0.85	0.77	0.45	0.72	0.60	0.69	0.28	0.03	0.51	0.30	0.15	0.19	0.19

Fish habitat availability comparison to natural conditions

Average and minima normalized habitat availability by species, life stage (for Brown and Rainbow Trout), and river reach; comparison to natural conditions

Color Coding Key				
	Better than Natural	>25% better	15% to 25% better	5% to 15% better
	Worse than Natural	>25% worse	15% to 25% worse	5% to 15% worse

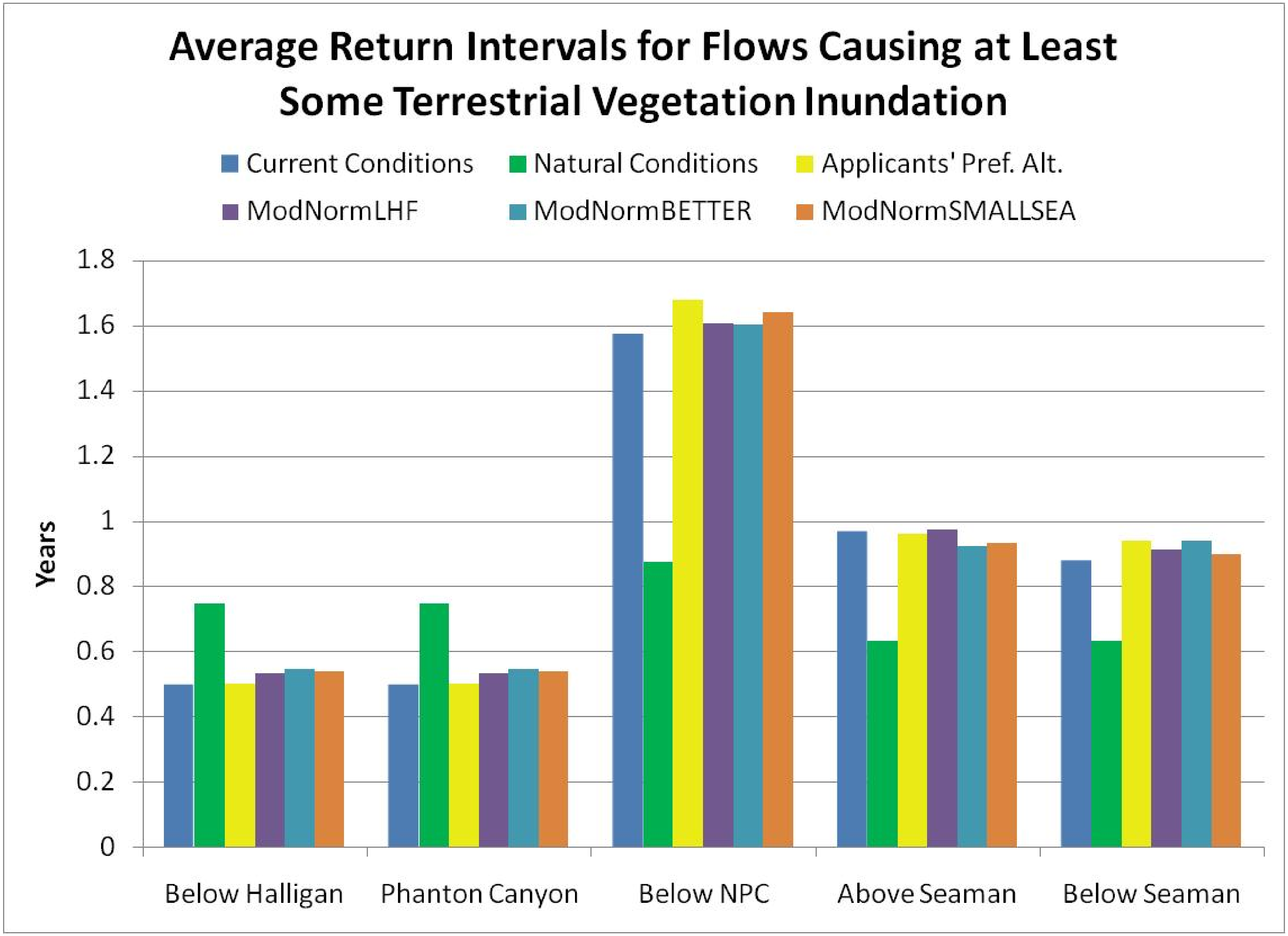
AVERAGES

Scenario	Reach	Brown Trout			Rainbow Trout			Longnose	Longnose
		Fry	Juv.	Adult	Fry	Juv.	Adult	Dace	Sucker
Natural Conditions	Below Halligan	0.87	0.59	0.40	0.87	0.62	0.28	0.57	0.59
	Phantom Canyon	0.57	0.64	0.35	0.60	0.68	0.09	0.65	0.61
	Below NPC	0.76	0.70	0.46	0.78	0.71	0.45	0.58	0.56
	Below Tributaries	0.65	0.86	0.44	0.69	0.84	0.45	0.76	0.56
	Below Seaman	0.85	0.79	0.45	0.87	0.82	0.52	0.77	0.64
Default APA	Below Halligan	0.83	0.52	0.38	0.79	0.54	0.27	0.50	0.51
	Phantom Canyon	0.53	0.53	0.35	0.52	0.56	0.14	0.53	0.50
	Below NPC	0.28	0.34	0.12	0.34	0.34	0.24	0.20	0.22
	Below Tributaries	0.92	0.76	0.27	0.88	0.72	0.30	0.65	0.49
	Below Seaman	0.90	0.72	0.38	0.83	0.76	0.45	0.71	0.60
ModNormLHF	Below Halligan	0.83	0.53	0.38	0.77	0.55	0.27	0.51	0.51
	Phantom Canyon	0.53	0.53	0.34	0.51	0.56	0.15	0.53	0.50
	Below NPC	0.28	0.37	0.12	0.65	0.37	0.26	0.22	0.23
	Below Tributaries	0.92	0.77	0.28	0.87	0.73	0.31	0.66	0.50
	Below Seaman	0.90	0.72	0.39	0.83	0.77	0.45	0.71	0.60
ModNorm BETTER	Below Halligan	0.81	0.54	0.39	0.76	0.57	0.28	0.52	0.53
	Phantom Canyon	0.53	0.55	0.35	0.51	0.57	0.15	0.55	0.52
	Below NPC	0.36	0.41	0.14	0.72	0.41	0.28	0.24	0.26
	Below Tributaries	0.89	0.78	0.29	0.86	0.74	0.32	0.66	0.50
	Below Seaman	0.89	0.73	0.39	0.85	0.77	0.46	0.72	0.60
ModNorm SMALLSEA	Below Halligan	0.82	0.55	0.39	0.76	0.57	0.29	0.53	0.53
	Phantom Canyon	0.52	0.55	0.35	0.51	0.58	0.15	0.56	0.52
	Below NPC	0.33	0.42	0.14	0.72	0.42	0.29	0.24	0.26
	Below Tributaries	0.90	0.78	0.29	0.86	0.74	0.32	0.67	0.51
	Below Seaman	0.89	0.73	0.39	0.85	0.77	0.45	0.72	0.60

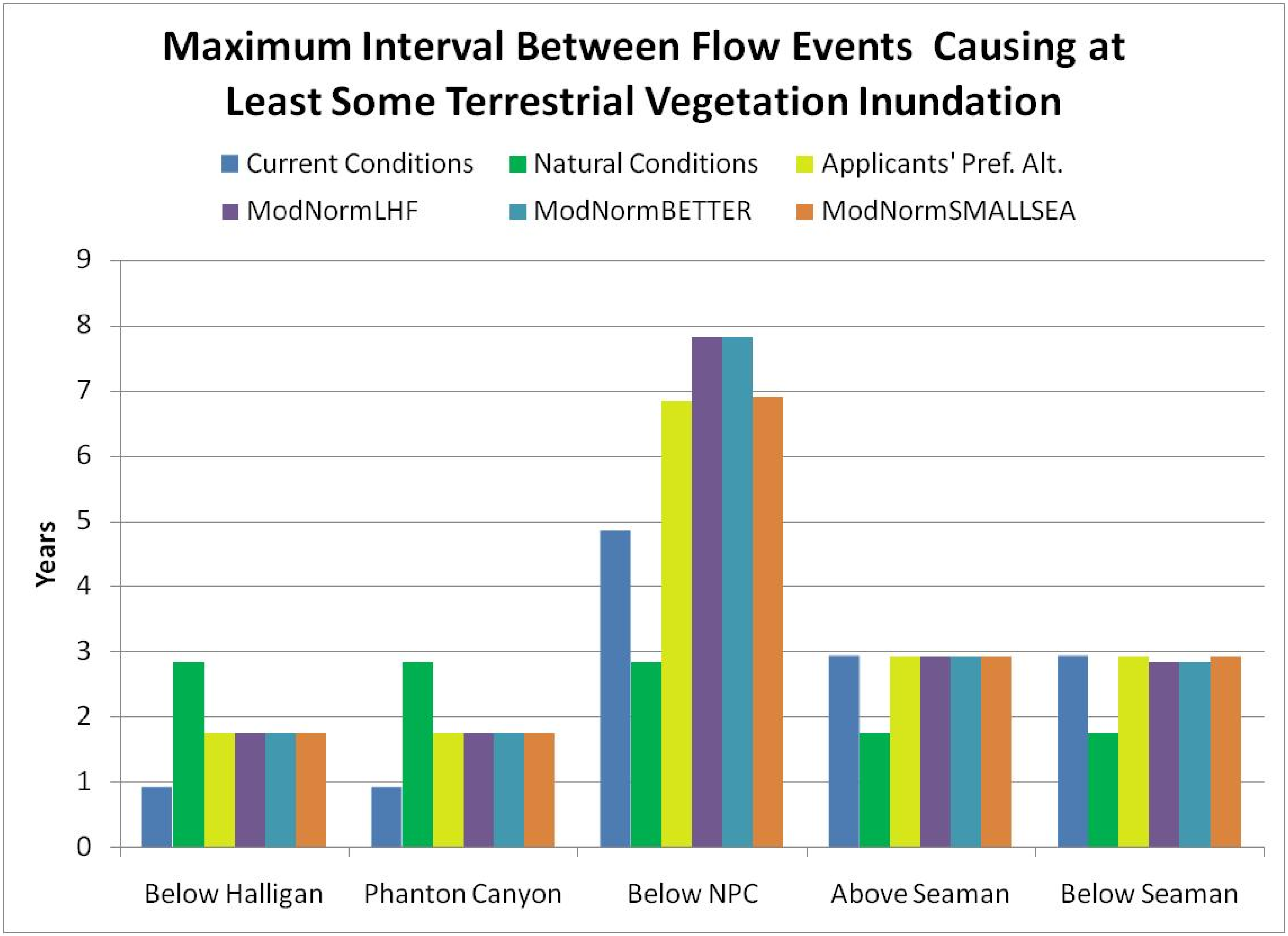
MINIMA

Scenario	Reach	Brown Trout			Rainbow Trout			Longnose	Longnose
		Fry	Juv.	Adult	Fry	Juv.	Adult	Dace	Sucker
Natural Conditions	Below Halligan	0.77	0.00	0.00	0.27	0.00	0.00	0.00	0.00
	Phantom Canyon	0.49	0.00	0.00	0.22	0.00	0.00	0.00	0.00
	Below NPC	0.69	0.00	0.00	0.22	0.00	0.00	0.00	0.00
	Below Tributaries	0.57	0.00	0.00	0.48	0.00	0.00	0.00	0.00
	Below Seaman	0.81	0.00	0.00	0.38	0.00	0.00	0.00	0.00
Default APA	Below Halligan	0.71	0.00	0.00	0.70	0.00	0.00	0.00	0.00
	Phantom Canyon	0.46	0.00	0.00	0.45	0.00	0.00	0.00	0.00
	Below NPC	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Below Tributaries	0.85	0.00	0.00	0.37	0.00	0.00	0.00	0.00
	Below Seaman	0.69	0.27	0.02	0.48	0.29	0.14	0.18	0.18
ModNormLHF	Below Halligan	0.71	0.18	0.05	0.70	0.19	0.08	0.15	0.17
	Phantom Canyon	0.46	0.14	0.02	0.45	0.16	0.01	0.15	0.15
	Below NPC	0.24	0.12	0.00	0.26	0.12	0.09	0.04	0.05
	Below Tributaries	0.86	0.45	0.09	0.66	0.41	0.20	0.34	0.29
	Below Seaman	0.69	0.27	0.02	0.48	0.29	0.14	0.18	0.18
ModNorm BETTER	Below Halligan	0.71	0.18	0.05	0.70	0.19	0.08	0.15	0.17
	Phantom Canyon	0.46	0.14	0.02	0.45	0.16	0.01	0.15	0.15
	Below NPC	0.24	0.12	0.00	0.25	0.12	0.09	0.04	0.05
	Below Tributaries	0.58	0.44	0.09	0.62	0.39	0.20	0.32	0.28
	Below Seaman	0.72	0.27	0.02	0.48	0.29	0.14	0.18	0.18
ModNorm SMALLSEA	Below Halligan	0.71	0.18	0.05	0.70	0.19	0.08	0.15	0.17
	Phantom Canyon	0.46	0.14	0.02	0.45	0.16	0.01	0.15	0.15
	Below NPC	0.24	0.12	0.00	0.25	0.12	0.09	0.04	0.05
	Below Tributaries	0.60	0.44	0.09	0.62	0.39	0.20	0.32	0.28
	Below Seaman	0.69	0.28	0.03	0.51	0.30	0.15	0.19	0.19

Riparian Vegetation Inundation Average Return Intervals

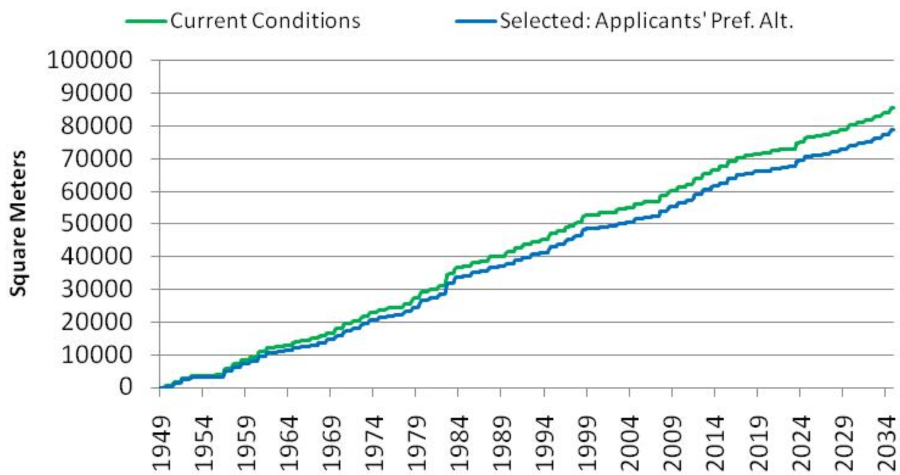


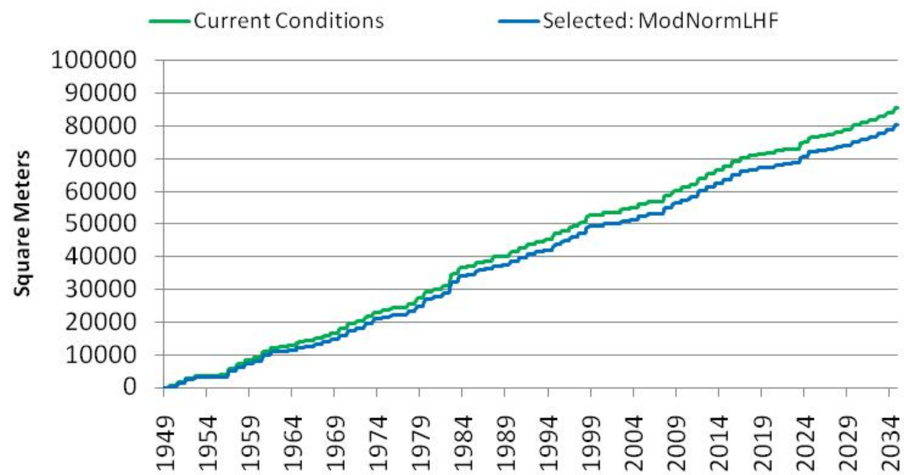
Riparian Vegetation Inundation Maximum Return Intervals

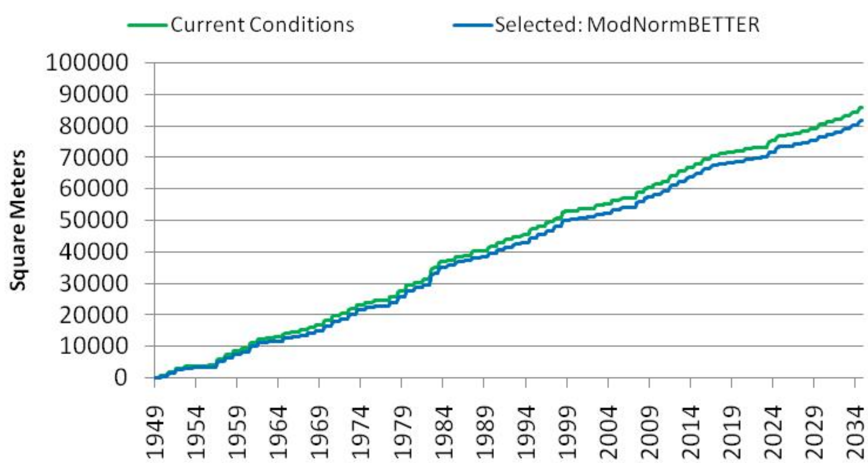


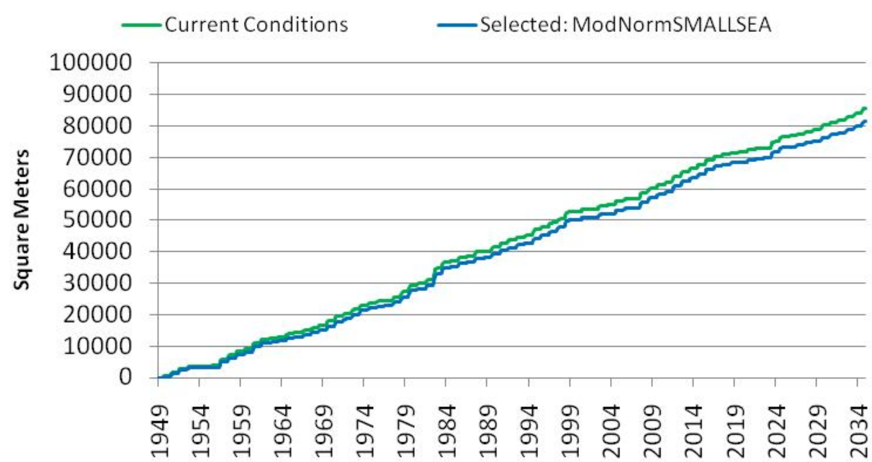
Cumulative Riparian Vegetation Inundation and Comparison to Current Conditions

Cumulative area inundated over entire simulation (square meters), Below Halligan (above the canyon), Current Conditions versus four future alternatives

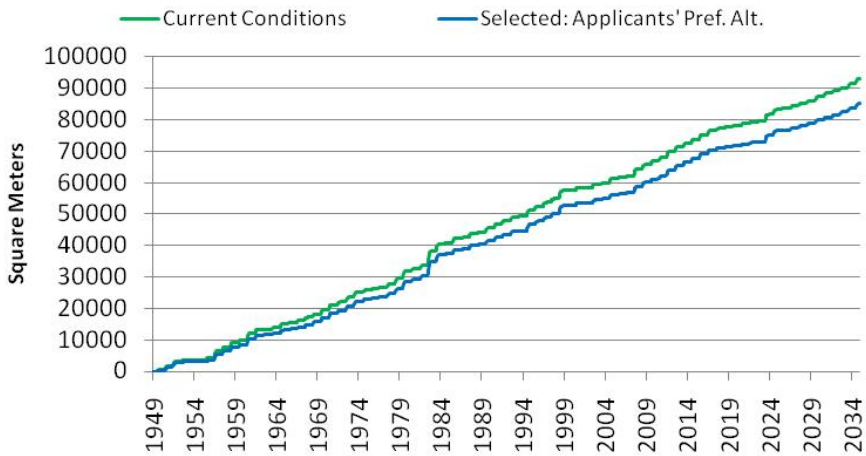


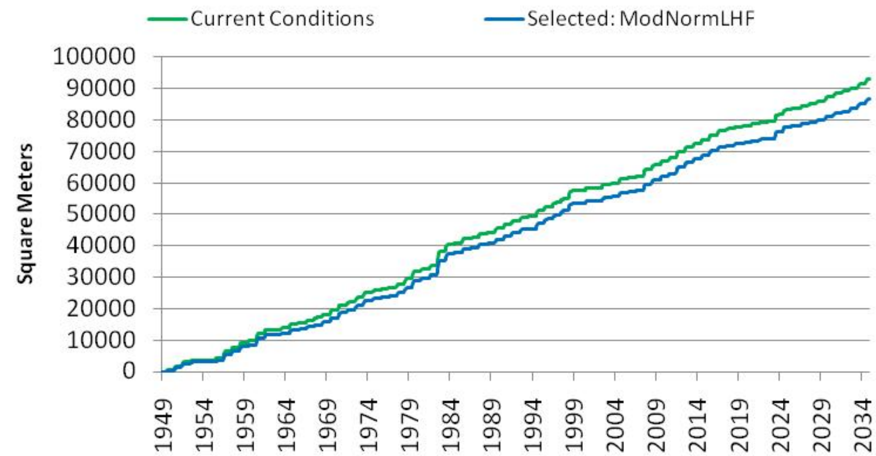


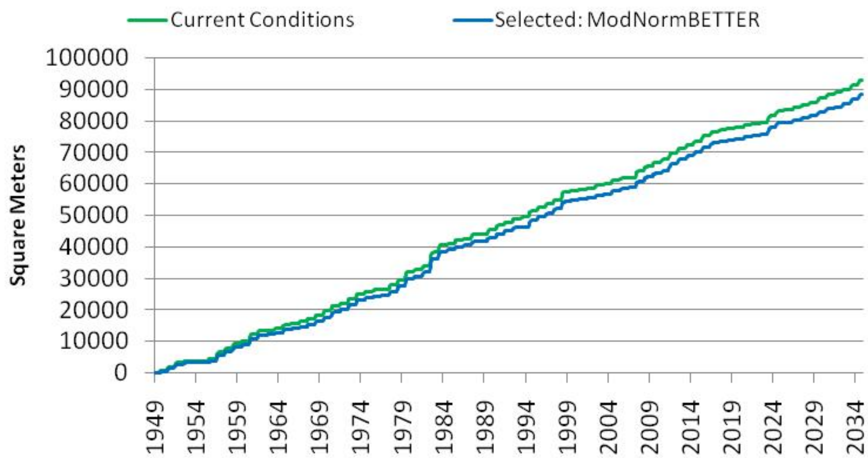


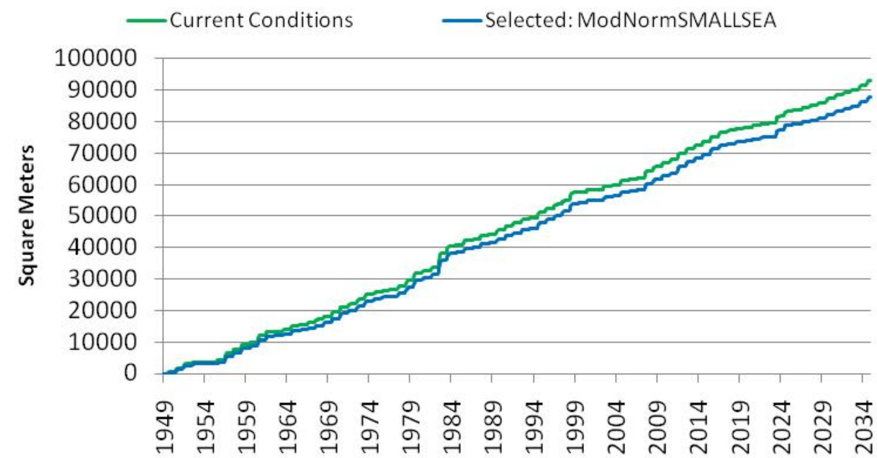


Cumulative area inundated over entire simulation (square meters), Phantom Canyon, Current Conditions versus four future alternatives

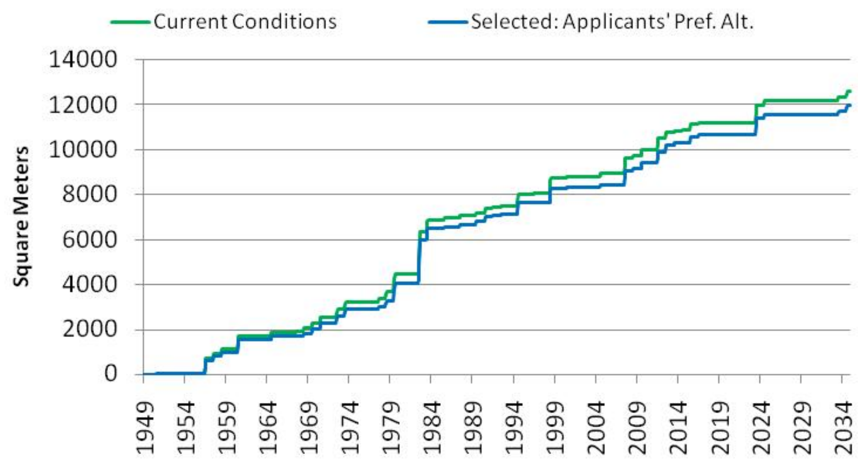


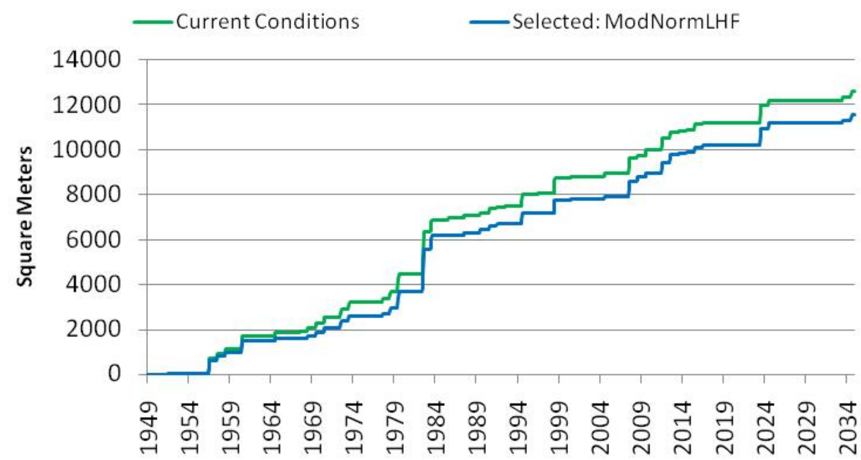


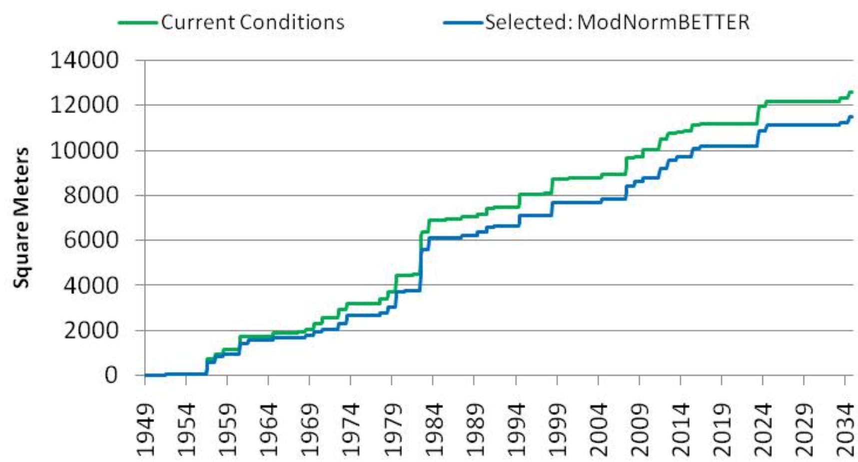


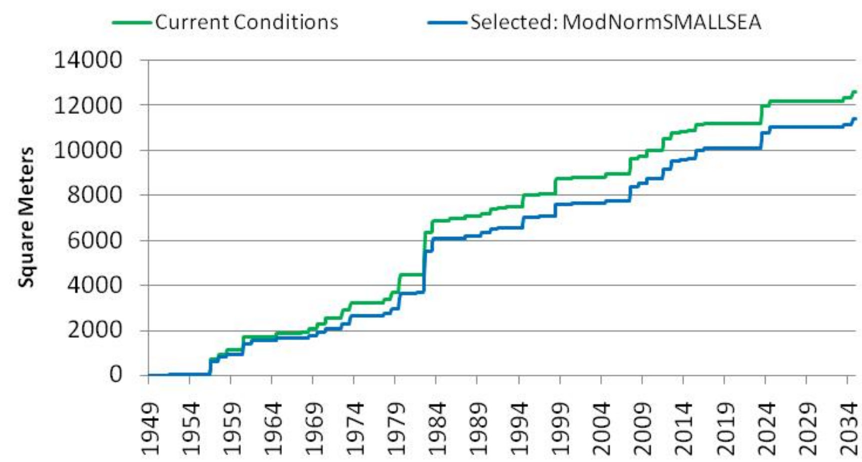


Cumulative area inundated over entire simulation (square meters), Below North Poudre Canal, Current Conditions versus four future alternatives

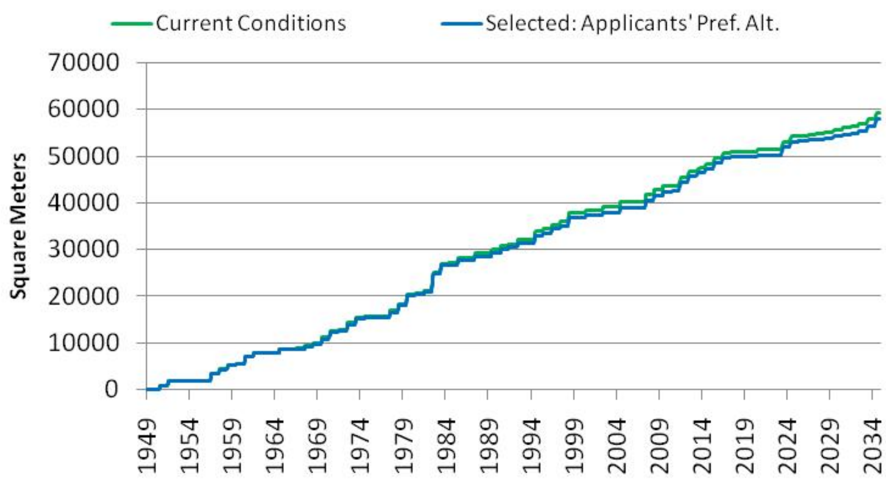


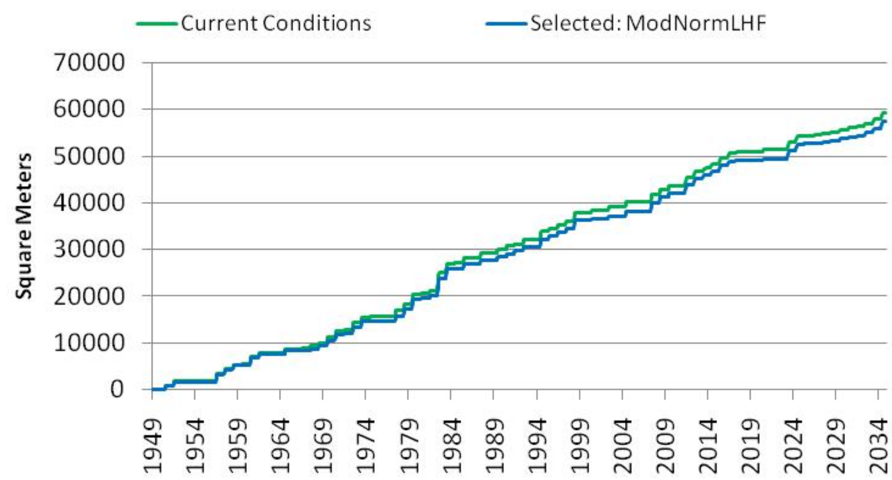


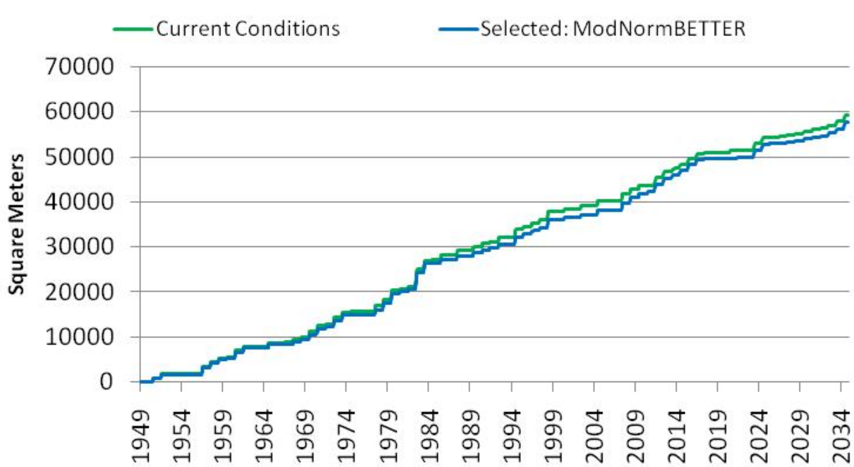


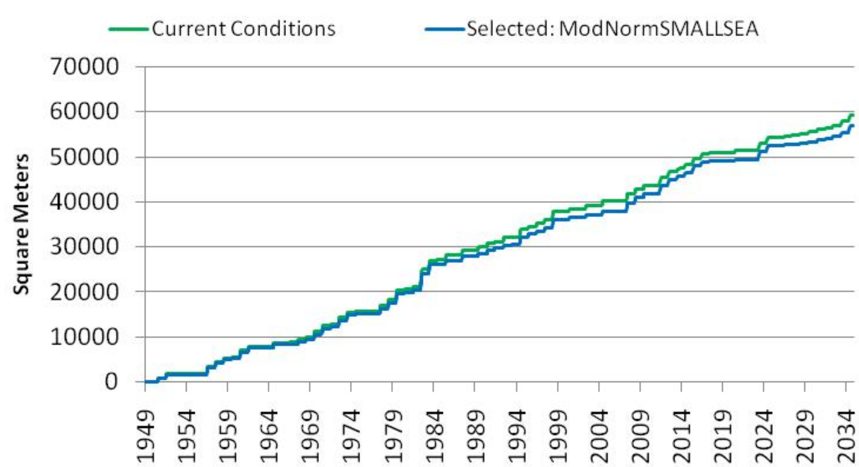


Cumulative area inundated over entire simulation (square meters), Below Tributaries/Above Seaman, Current Conditions versus four future alternatives

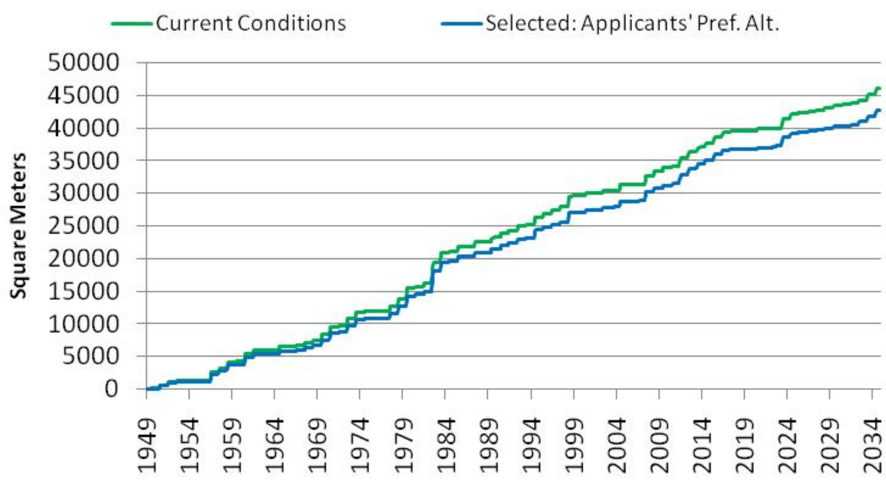


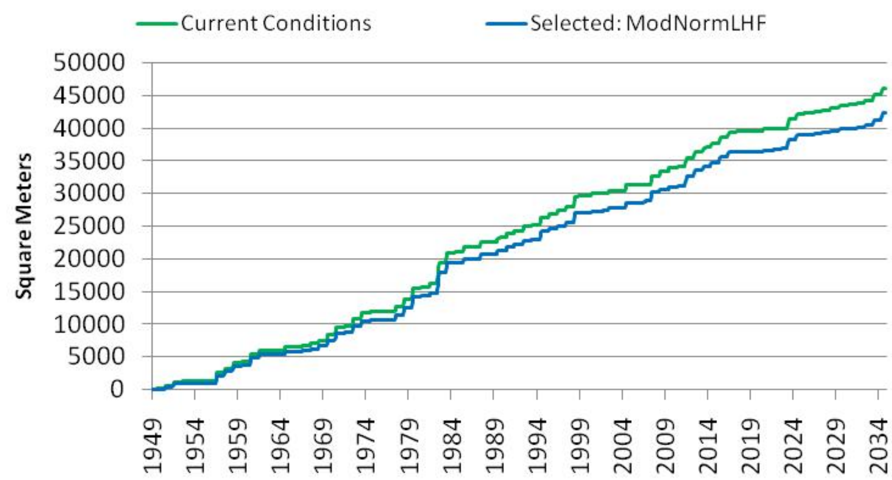


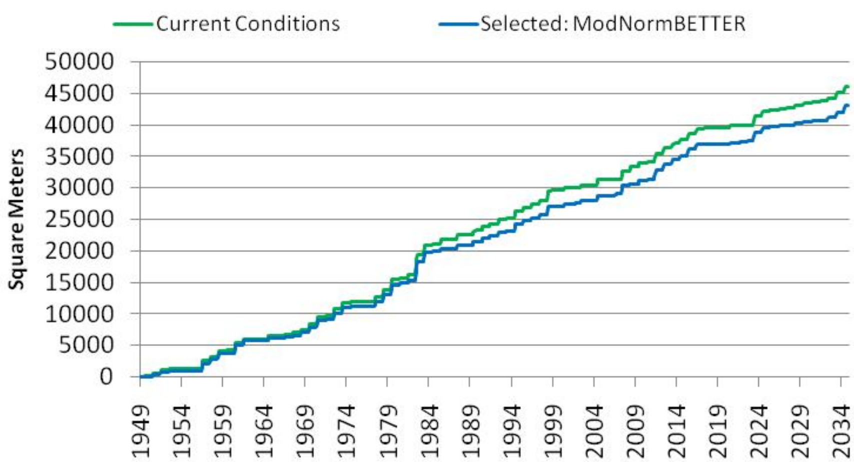


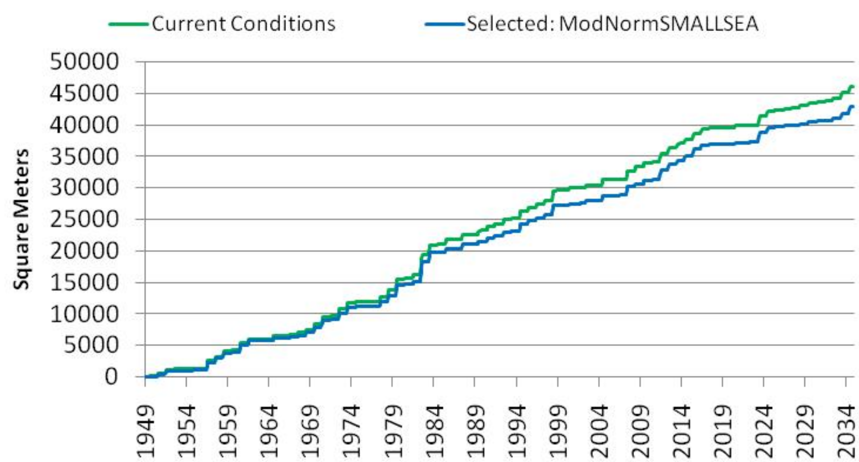


Cumulative area inundated over entire simulation (square meters), Below Seaman, Current Conditions versus four future alternatives



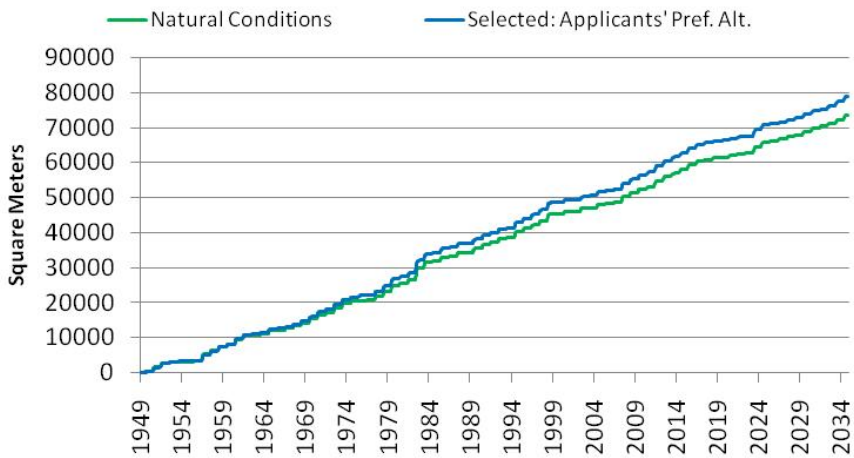


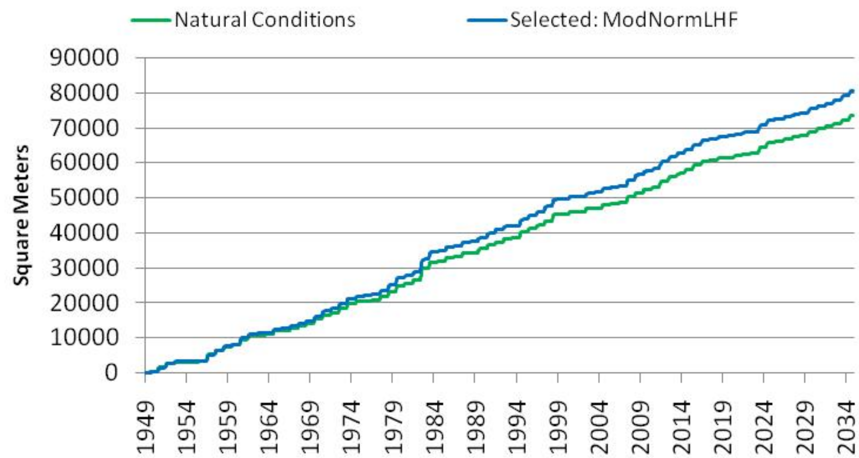


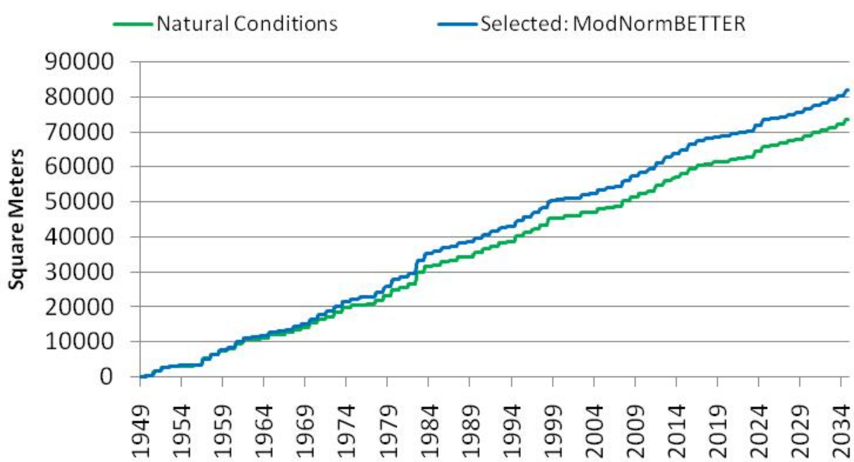


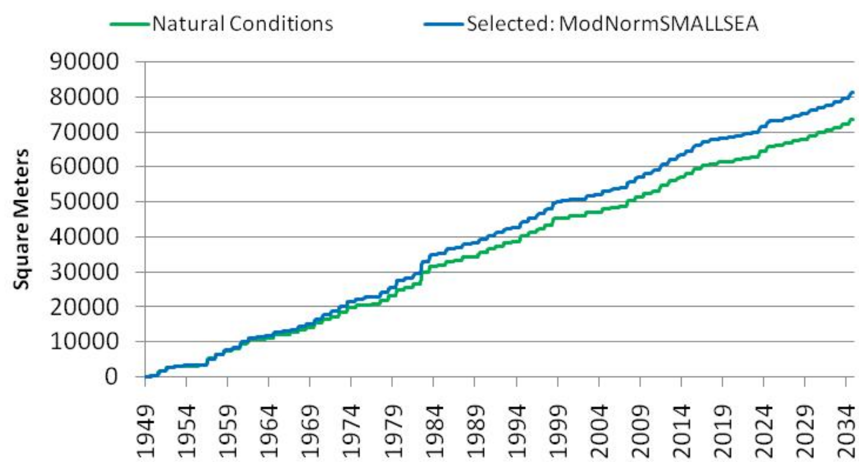
Cumulative Riparian Vegetation Inundation and Comparison to Natural Conditions

Cumulative area inundated over entire simulation (square meters), Below Halligan, Natural Conditions versus four future alternatives

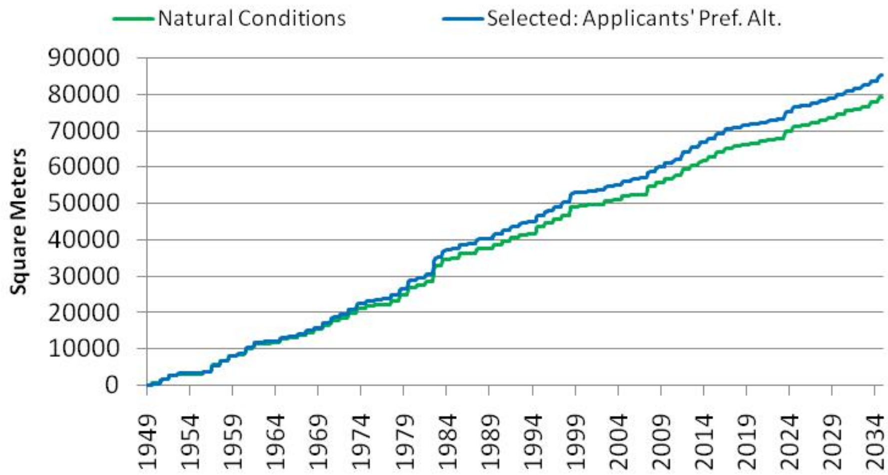


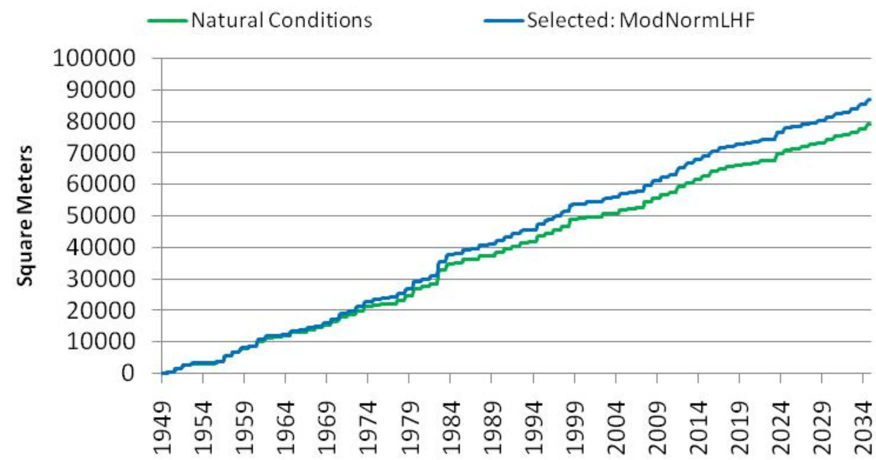


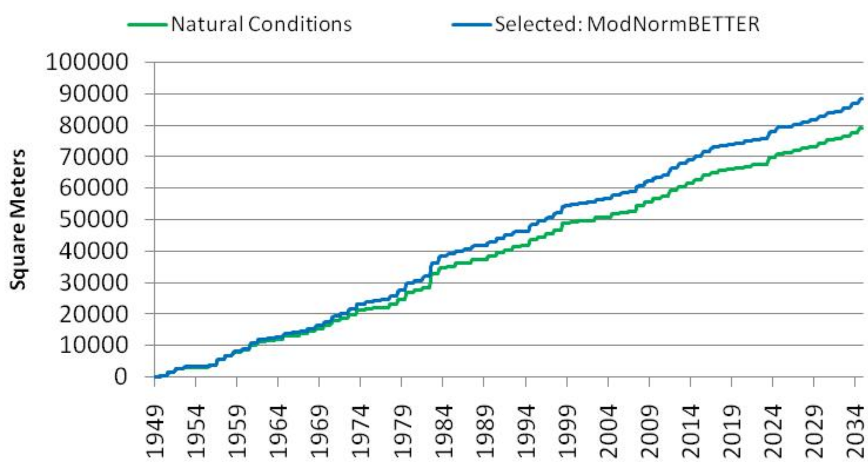


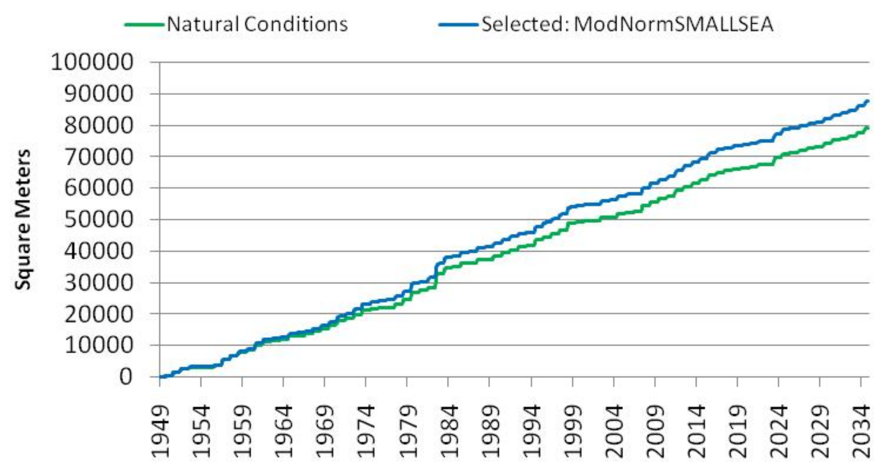


Cumulative area inundated over entire simulation (square meters), Phantom Canyon, Natural Conditions versus four future alternatives

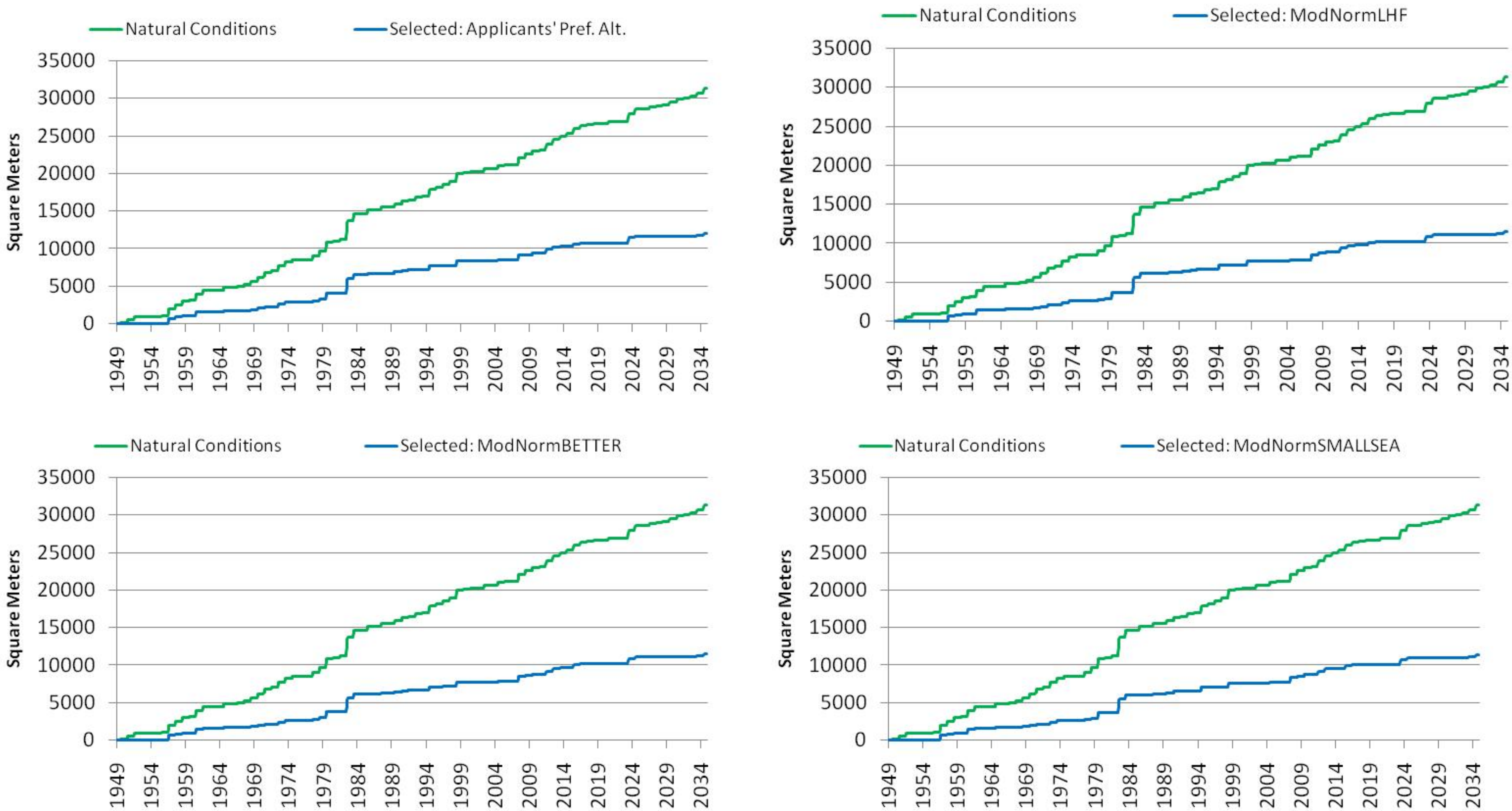




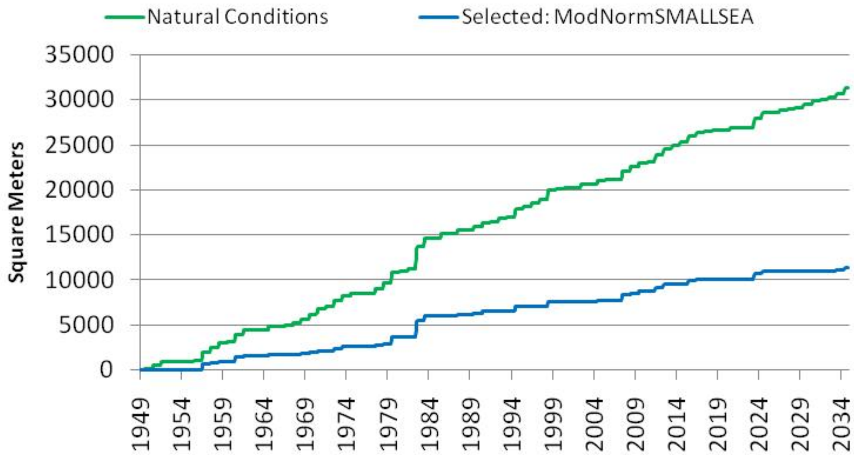


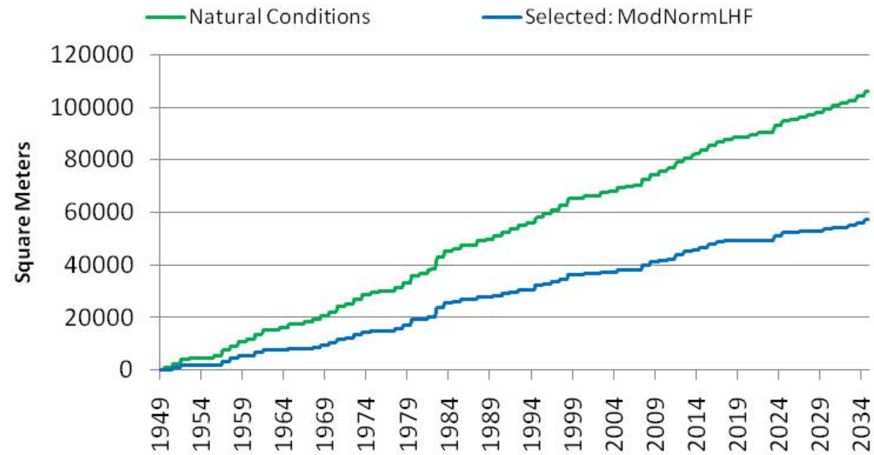


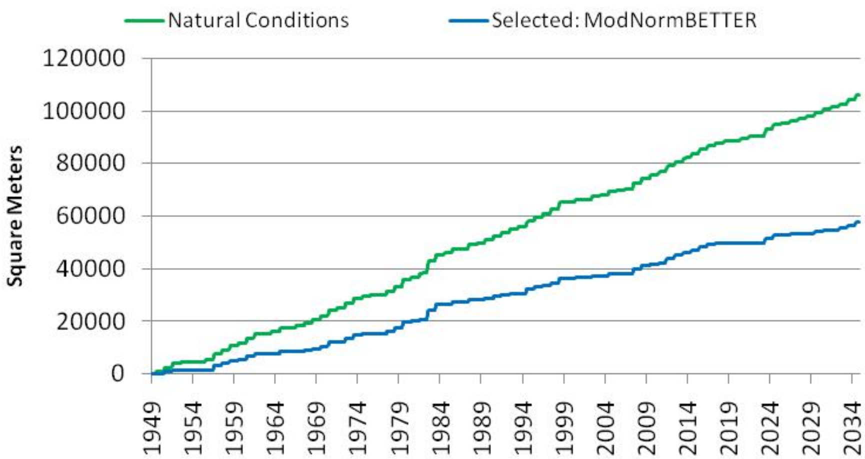
Cumulative area inundated over entire simulation (square meters), Below North Poudre Canal, Natural Conditions versus four future alternatives

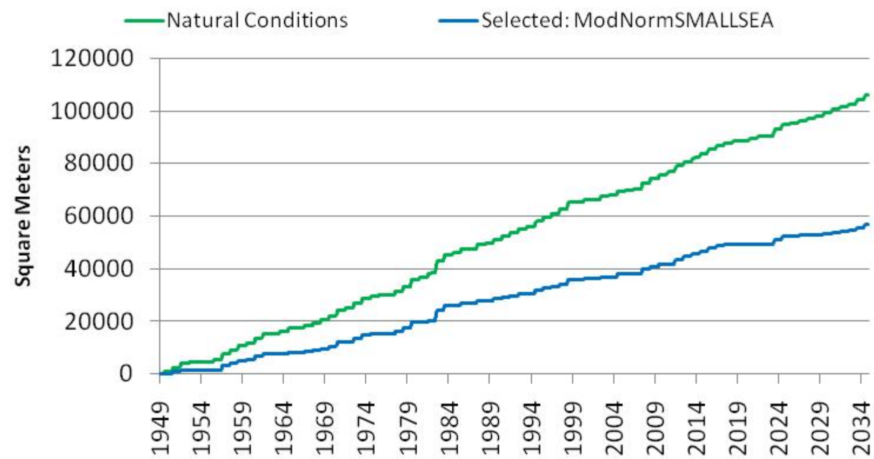


Cumulative area inundated over entire simulation (square meters), Below Tributaries/Above Seaman, Natural Conditions versus four future alternatives

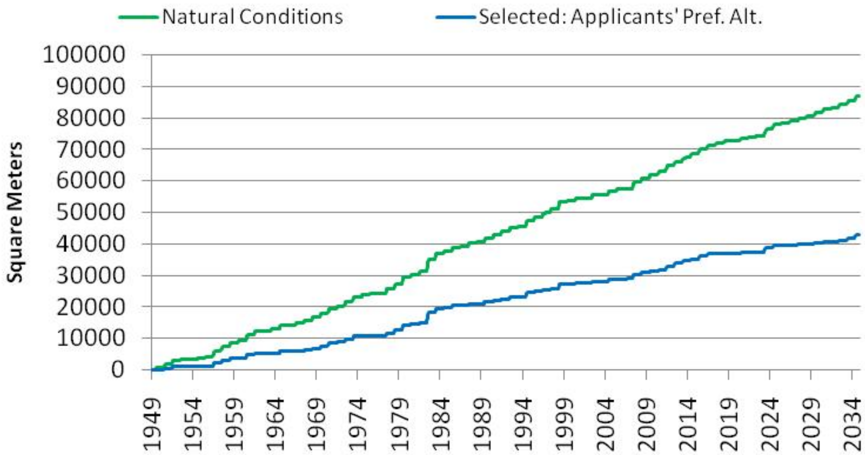


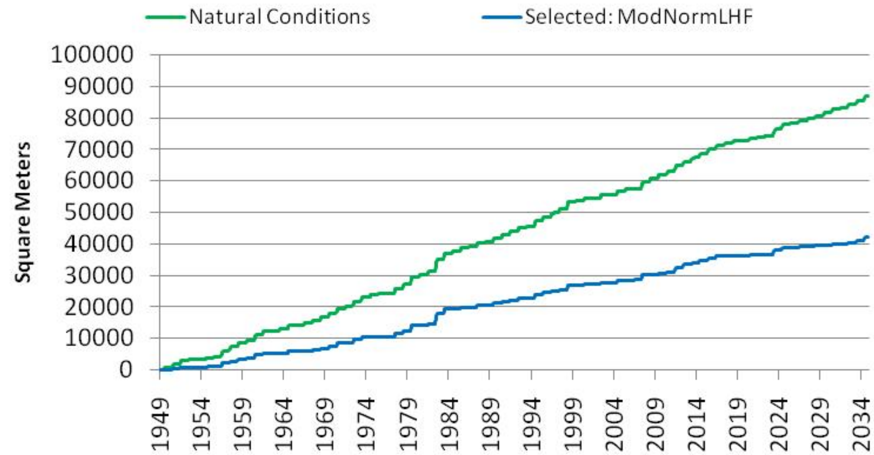


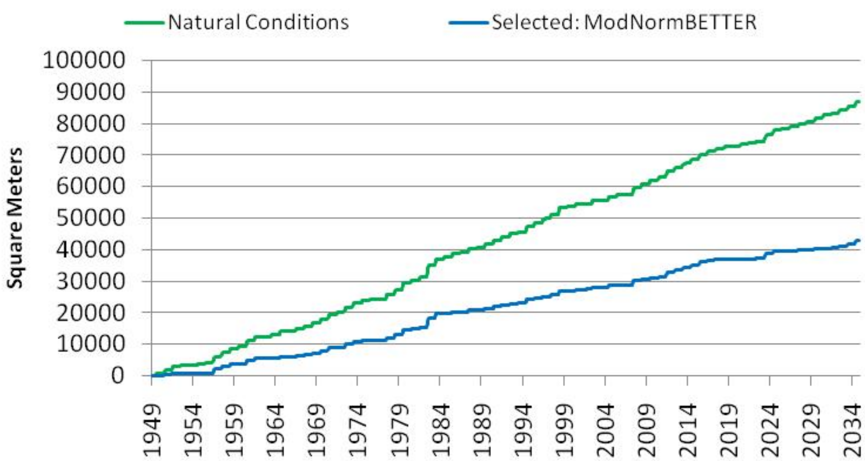


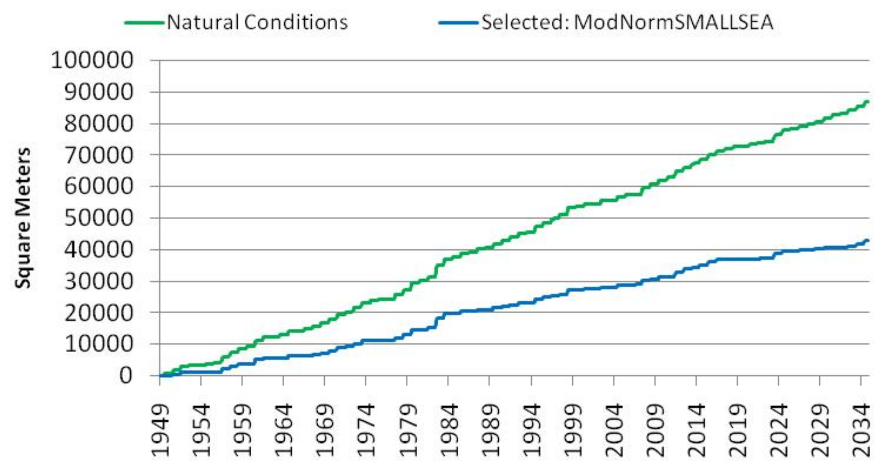


Cumulative area inundated over entire simulation (square meters), Below Seaman, Natural Conditions versus four future alternatives







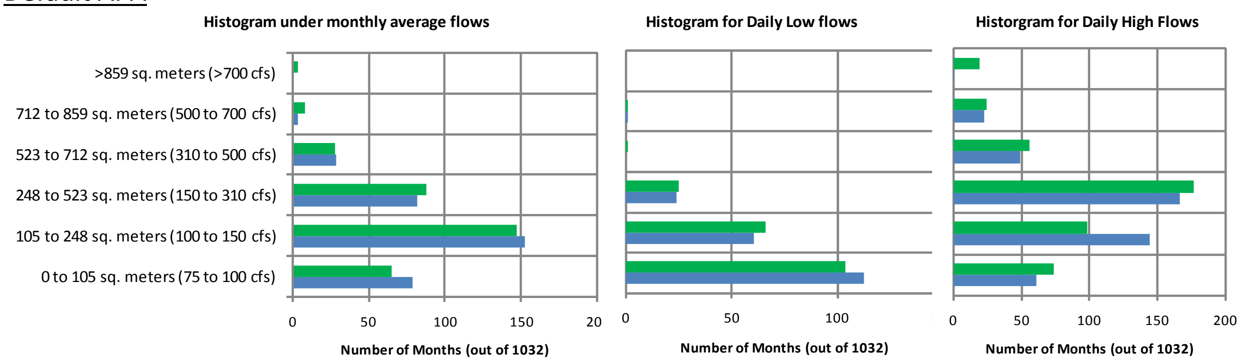


Riparian vegetation inundation frequency histograms, comparison to current conditions

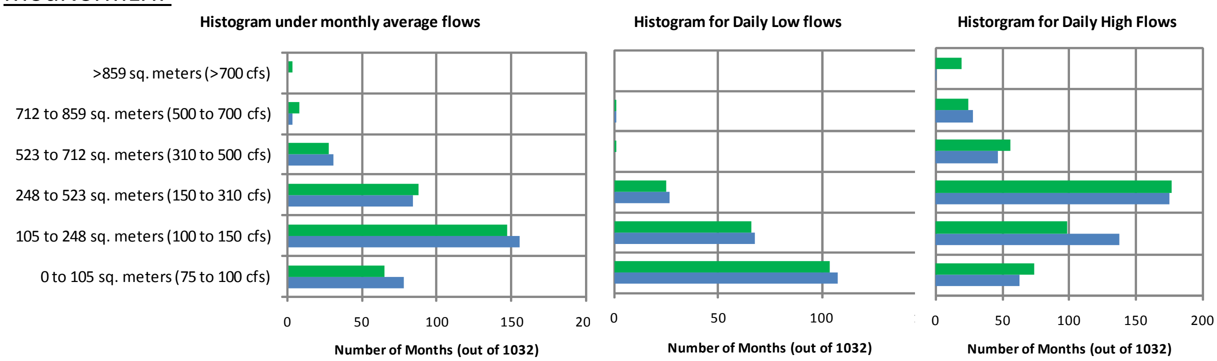
Histograms of inundation quantities under average monthly and probable daily high and low flows for alternatives and current conditions, Below Halligan

Alternative   Current Conditions

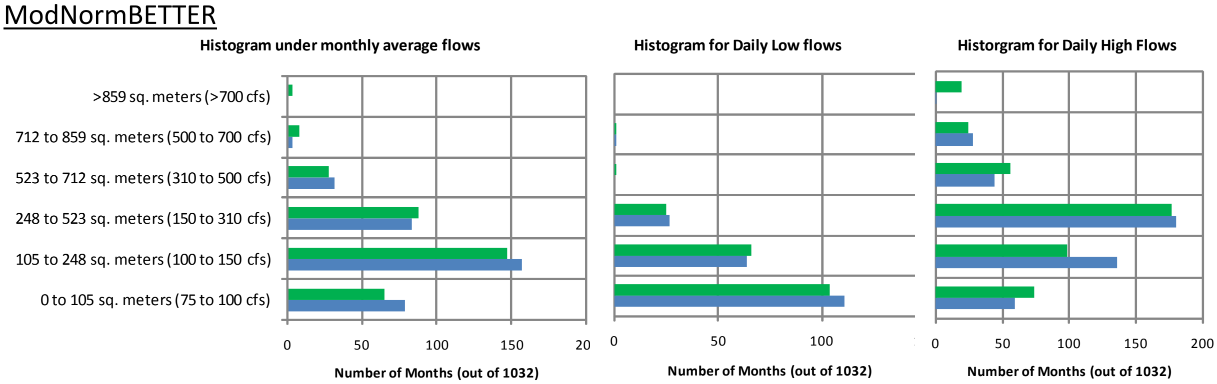
Default APA



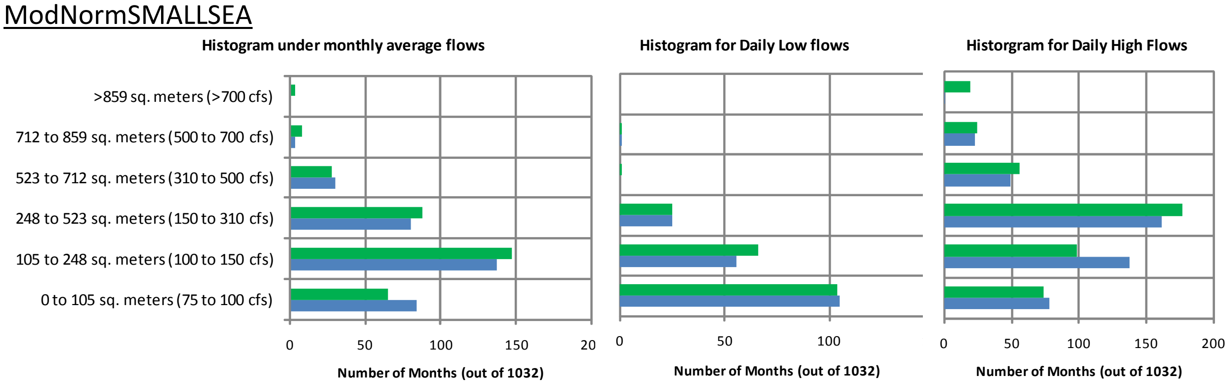
ModNormLHF



ModNormBETTER



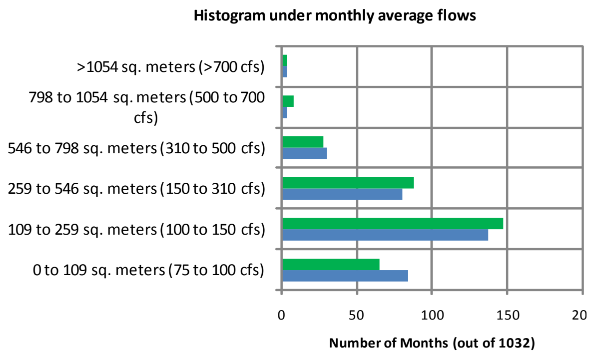
ModNormSMALLSEA

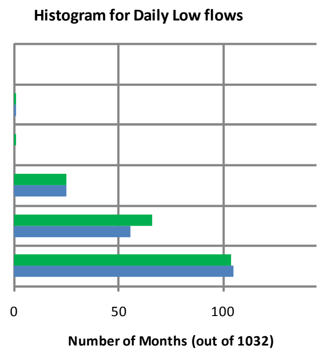


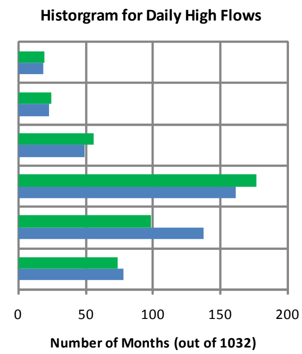
Histograms of inundation quantities under average monthly flows and probable daily highs and lows for alternatives and current conditions, Phantom Canyon

Alternative Current Conditions

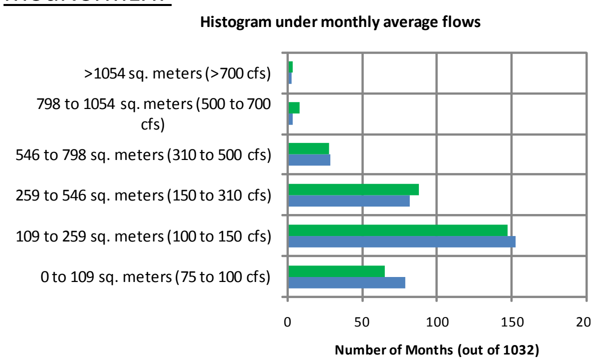
Default APA

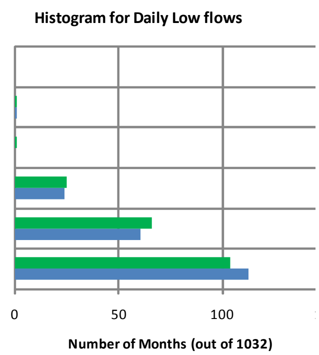


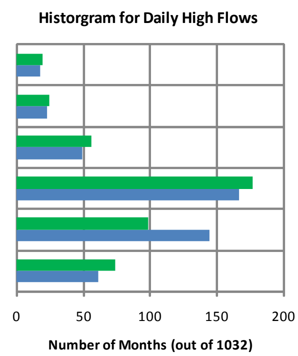




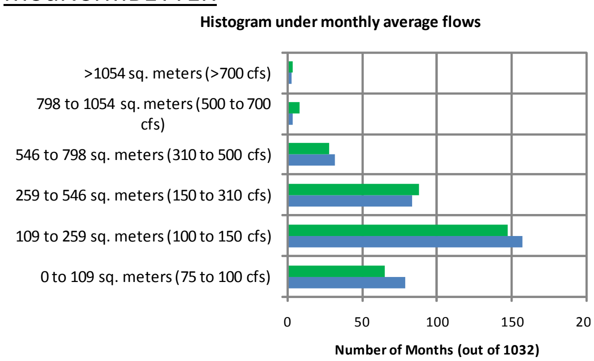
ModNormLHF

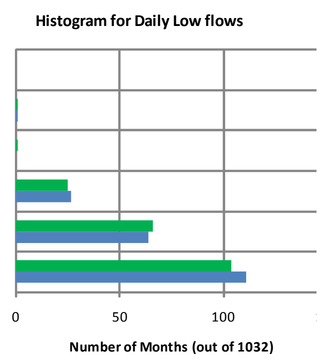


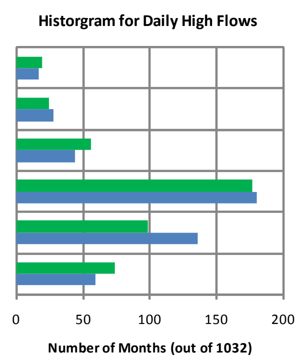




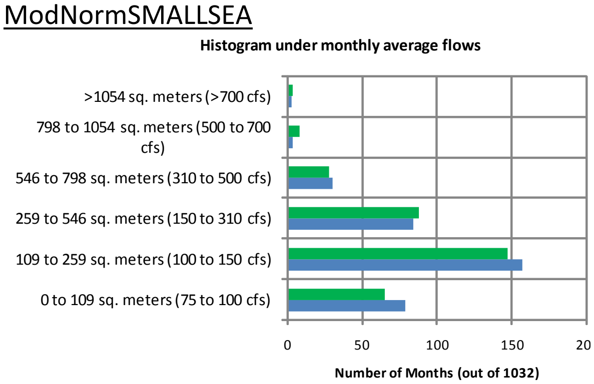
ModNormBETTER

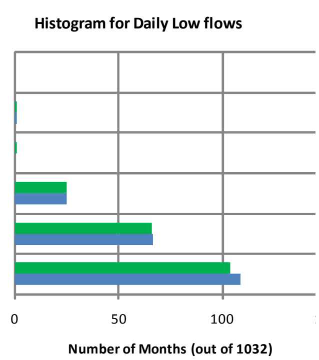


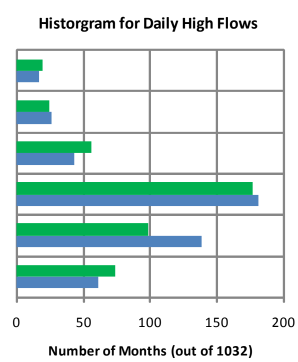




ModNormSMALLSEA

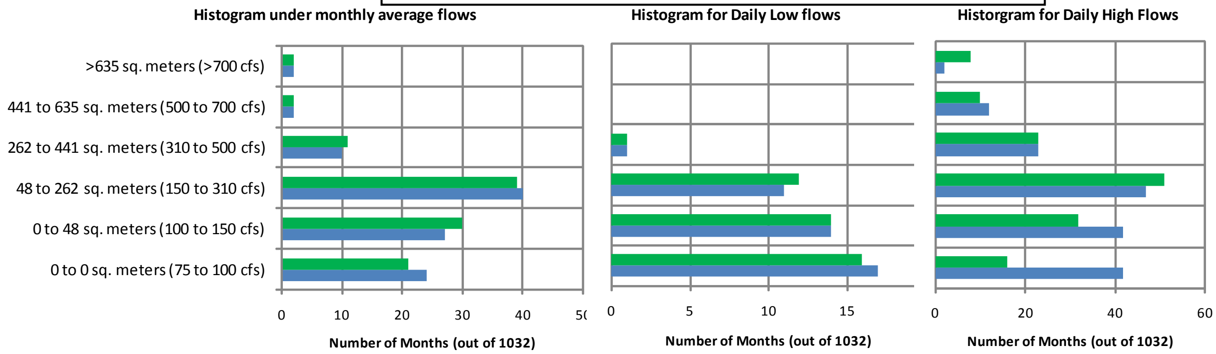




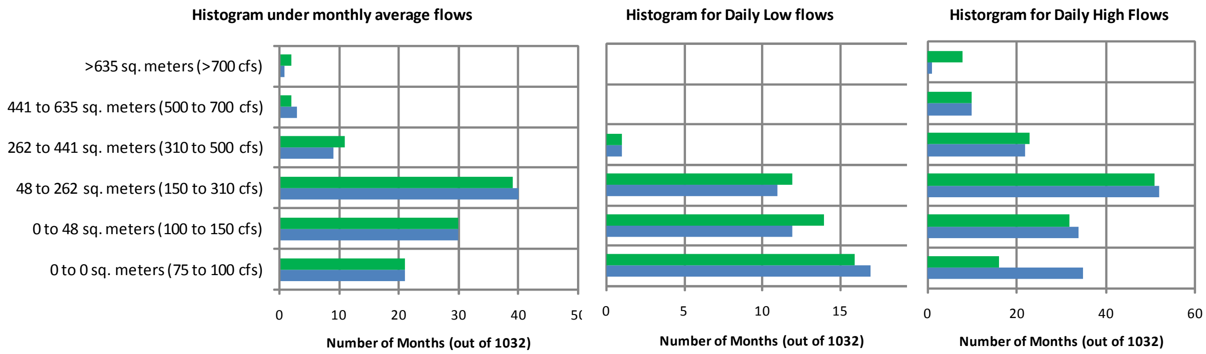


Histograms of inundation quantities under average monthly flow and probable daily highs and lows for alternatives and current conditions, Below North Poudre Canal

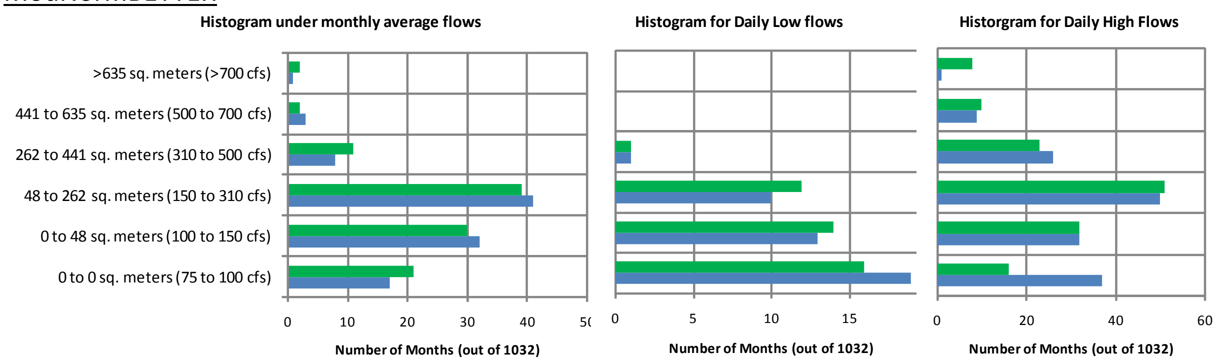
Default APA



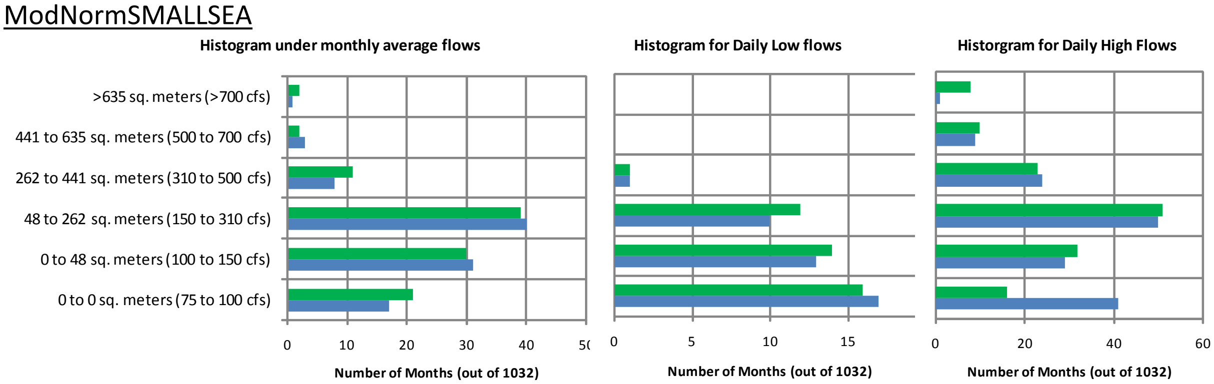
ModNormLHF



ModNormBETTER

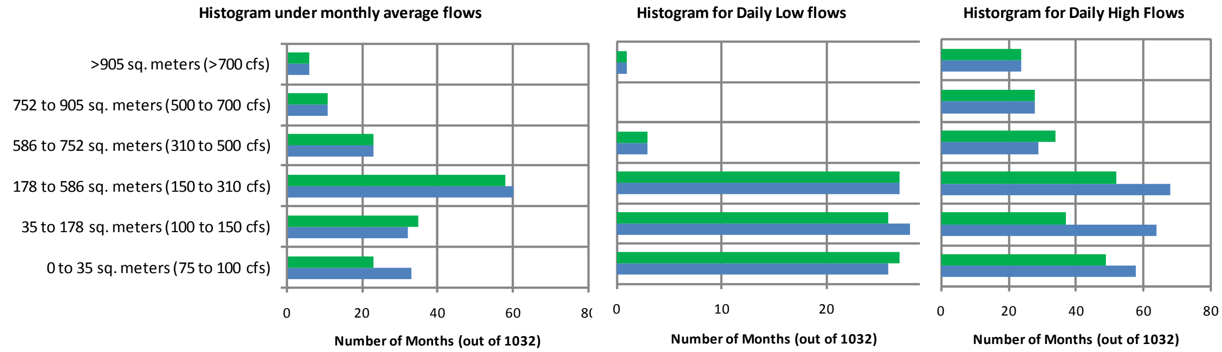


ModNormSMALLSEA

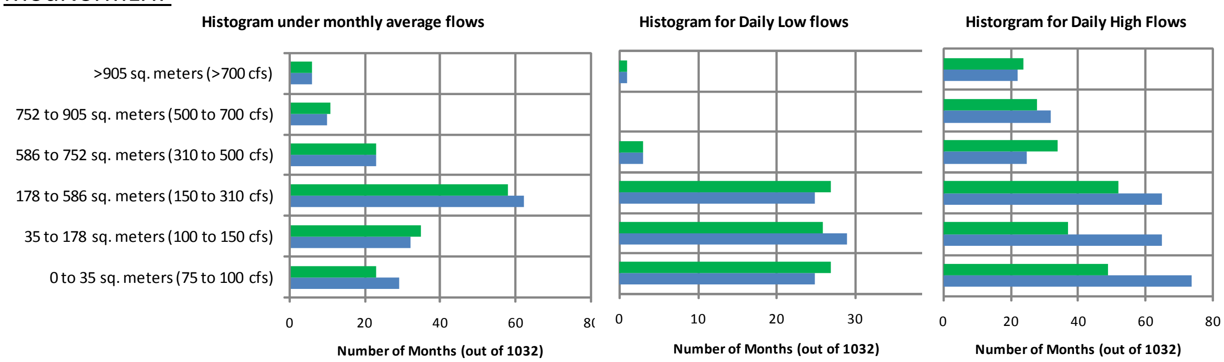


Histograms of inundation quantities under average monthly flows and probable daily highs and lows for alternatives and current conditions, Below Tributaries/Above Seaman

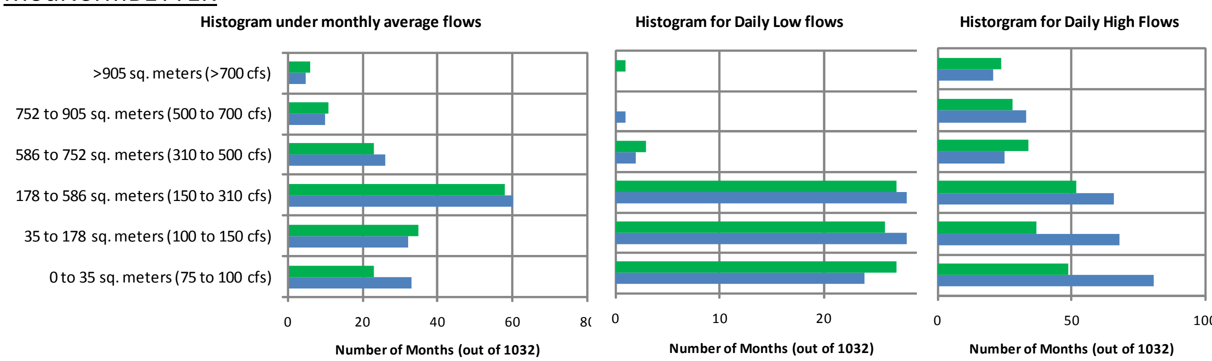
Default APA



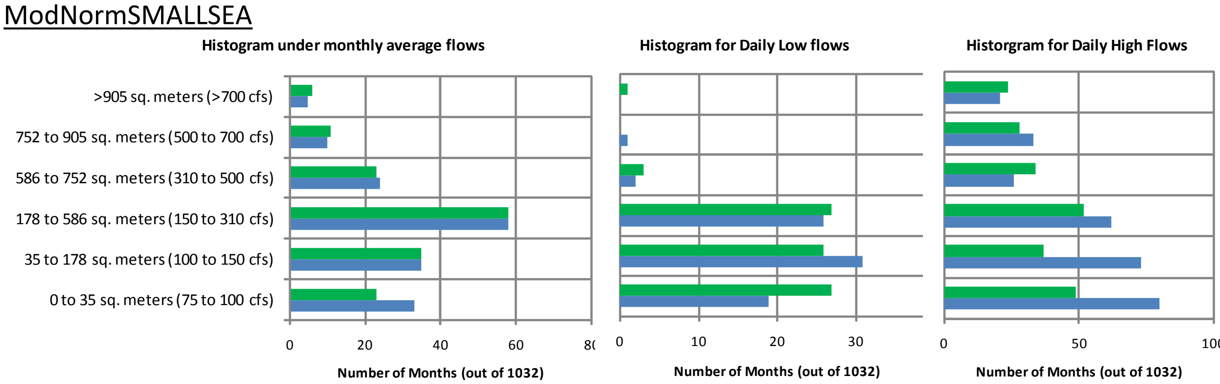
ModNormLHF



ModNormBETTER

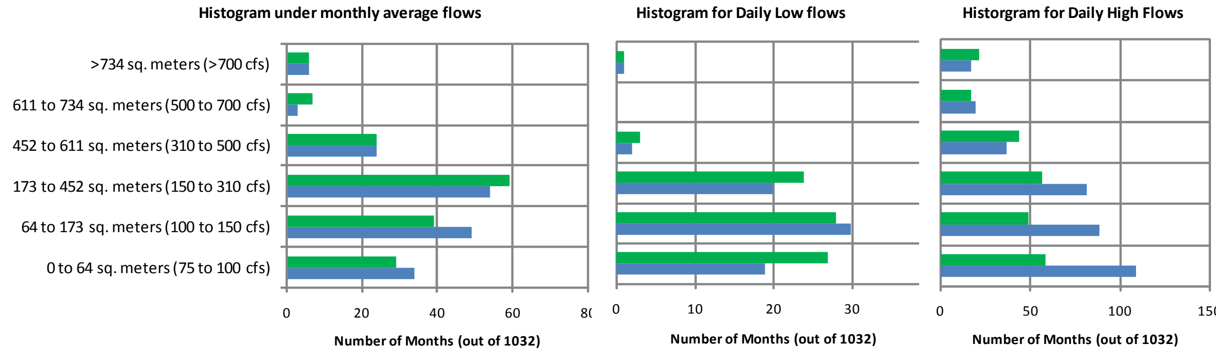


ModNormSMALLSEA

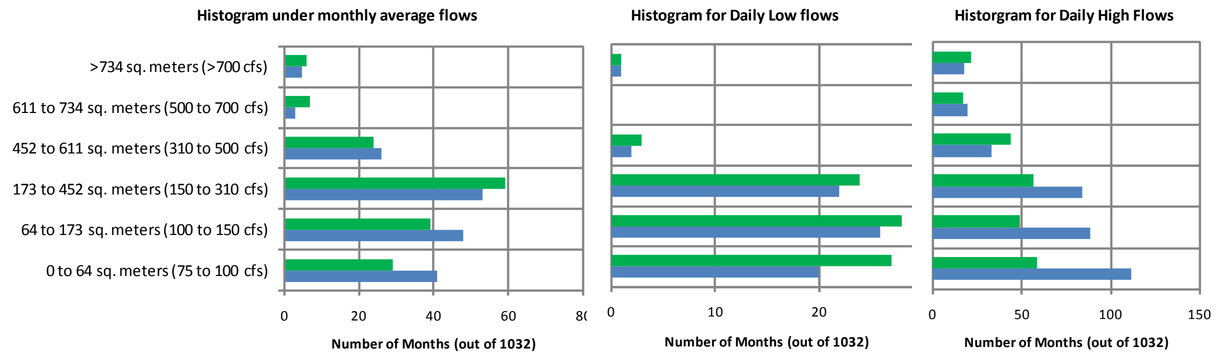


Histograms of inundation quantities under average monthly flows and probable daily highs and lows for alternatives and current conditions, Below Seaman

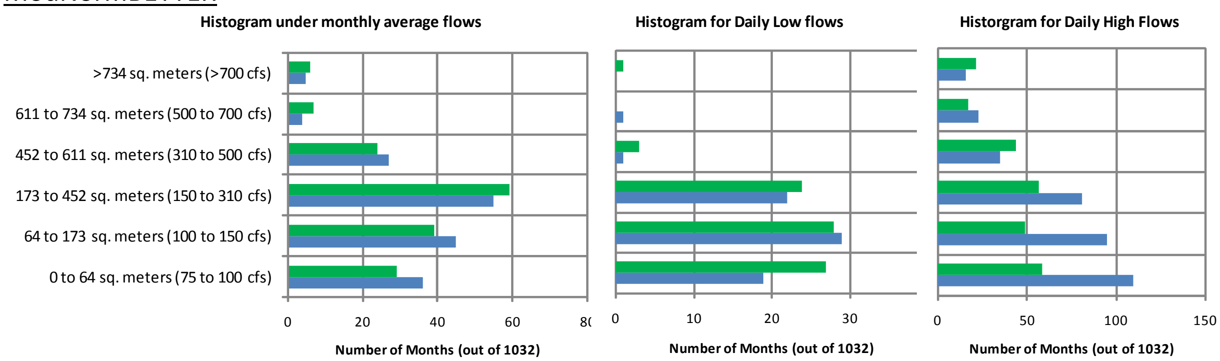
Default APA



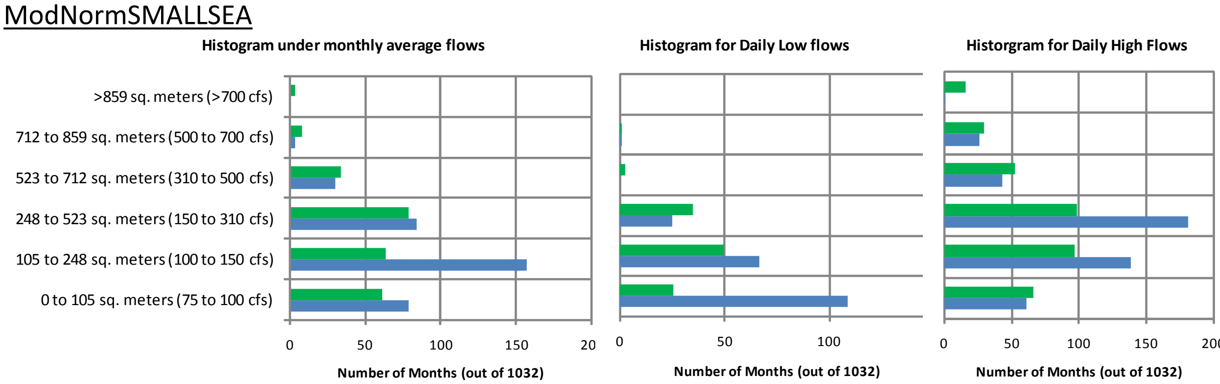
ModNormLHF



ModNormBETTER



ModNormSMALLSEA

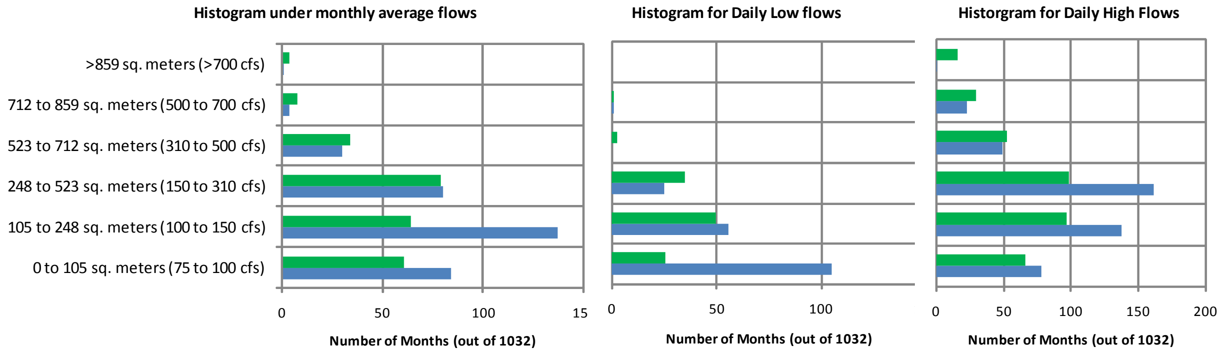


Riparian vegetation inundation frequency histograms and comparison to natural conditions

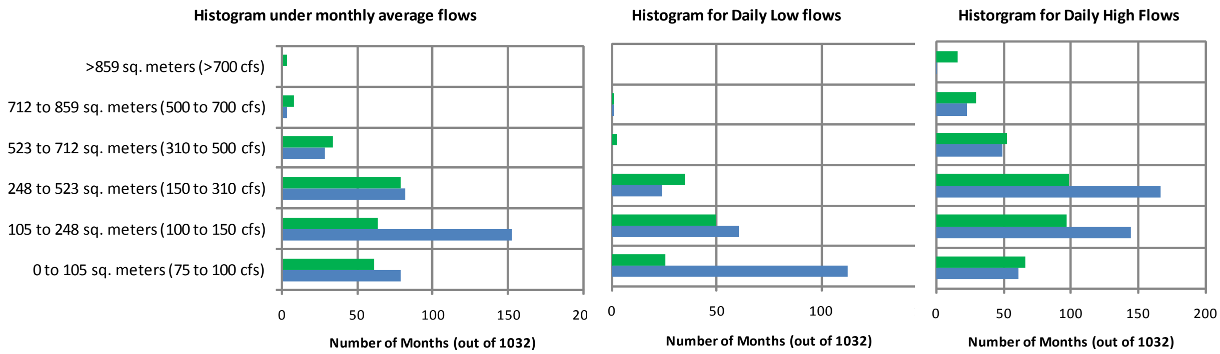
Histograms of inundation quantities under average monthly flows and probable daily highs and lows for alternatives and Natural conditions, Below Halligan

Alternative | Current Conditions

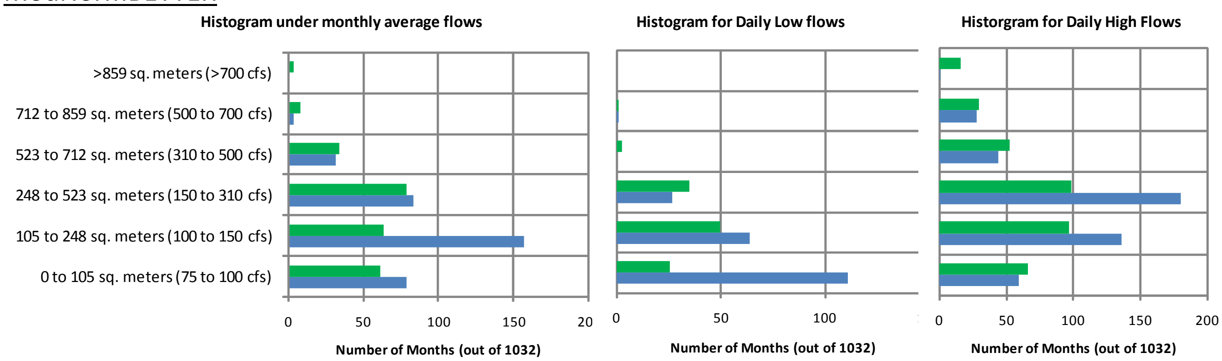
Default APA



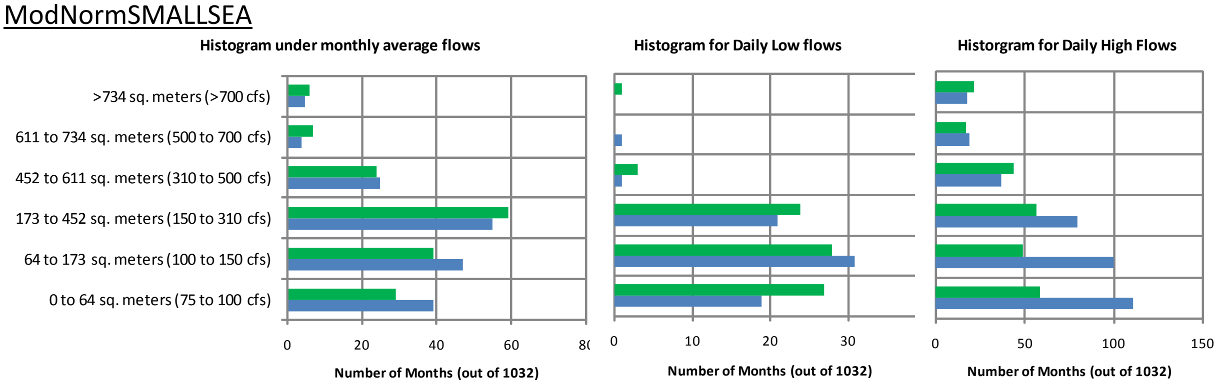
ModNormLHF



ModNormBETTER

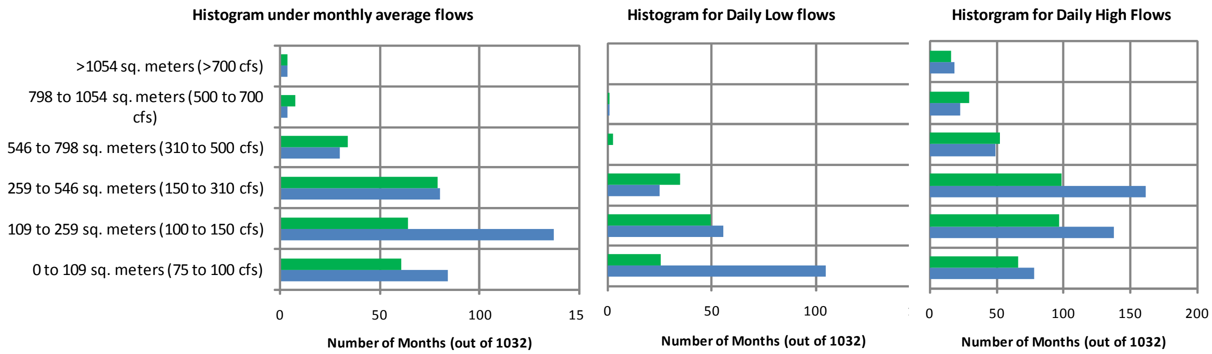


ModNormSMALLSEA

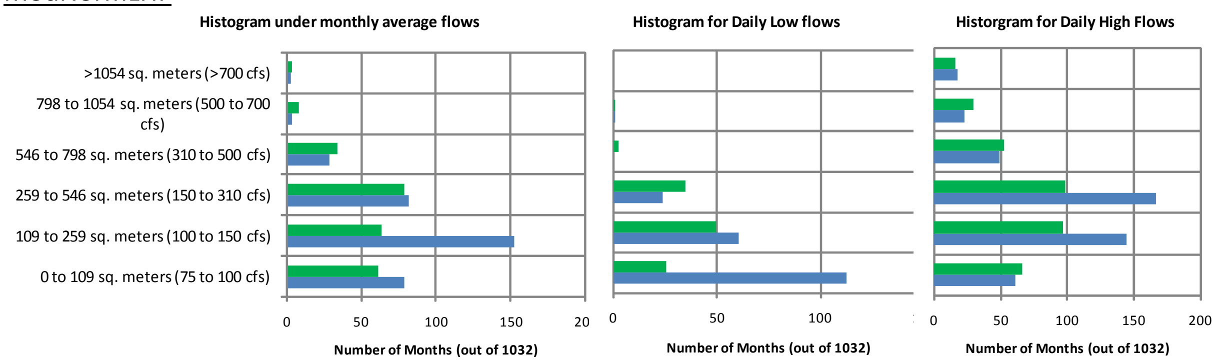


Histograms of inundation quantities under average monthly flows and probable daily highs and lows for alternatives and Natural conditions, Phantom Canyon

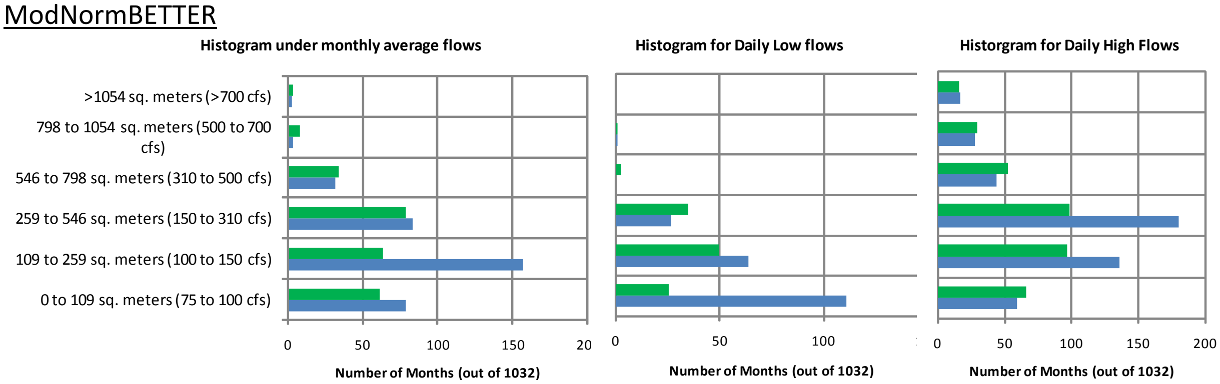
<u>Default APA</u>



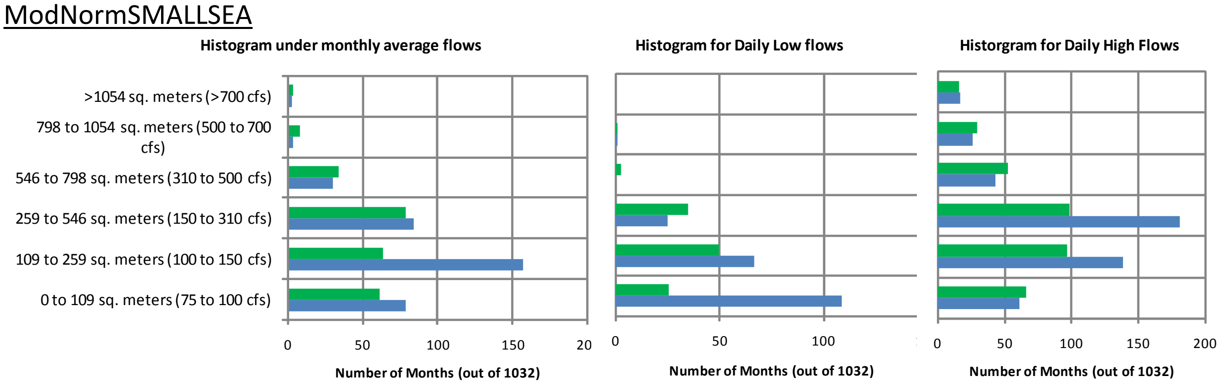
<u>ModNormLHF</u>



<u>ModNormBETTER</u>



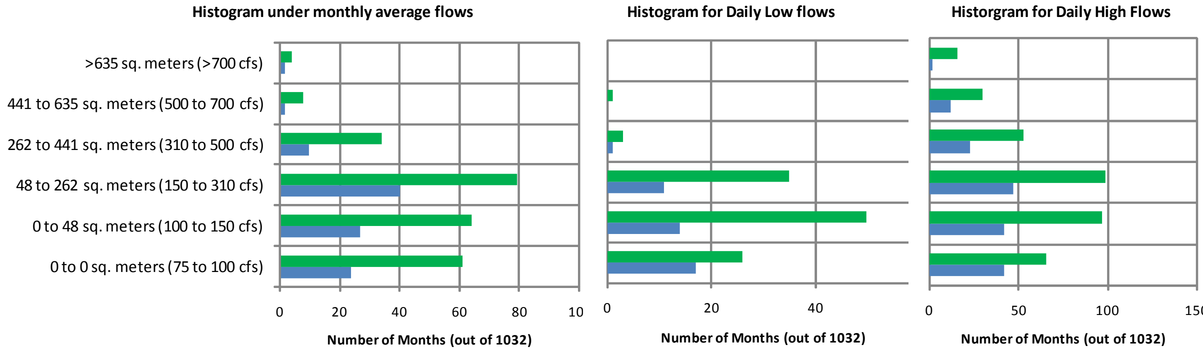
<u>ModNormSMALLSEA</u>



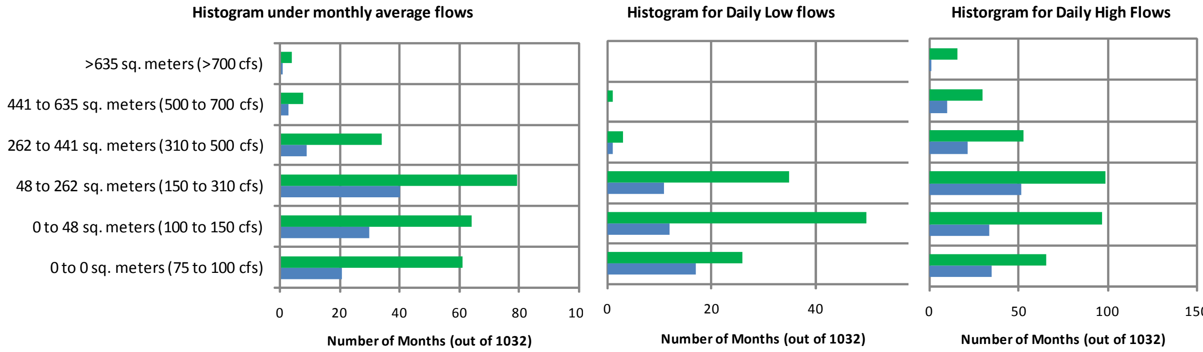
Histograms of inundation quantities under average monthly flows and probable daily highs and lows for alternatives and Natural conditions, Below NPC

Alternative   Natural Conditions

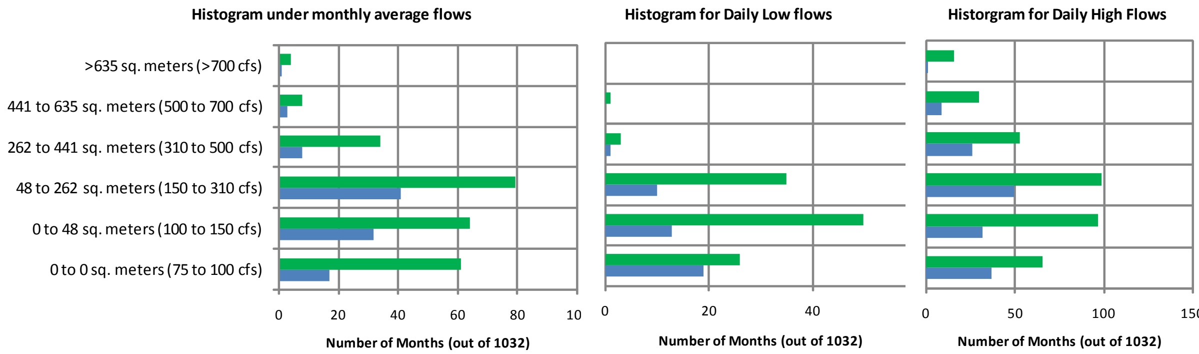
Default APA



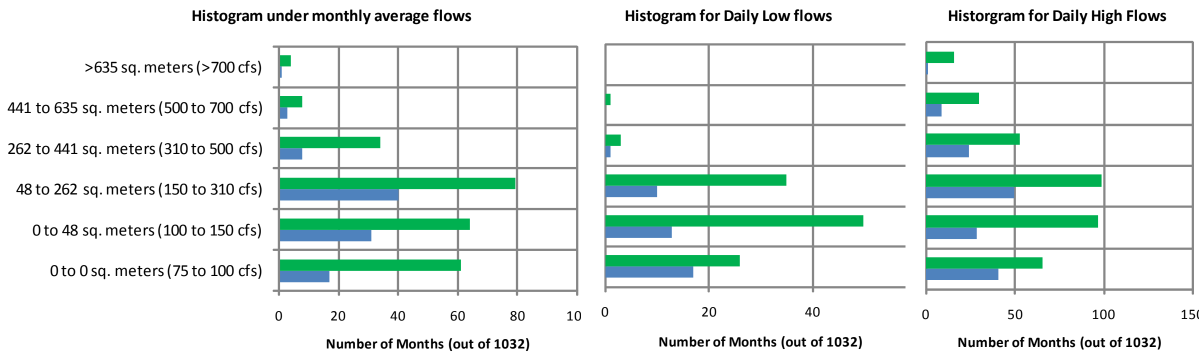
ModNormLHF



ModNormBETTER



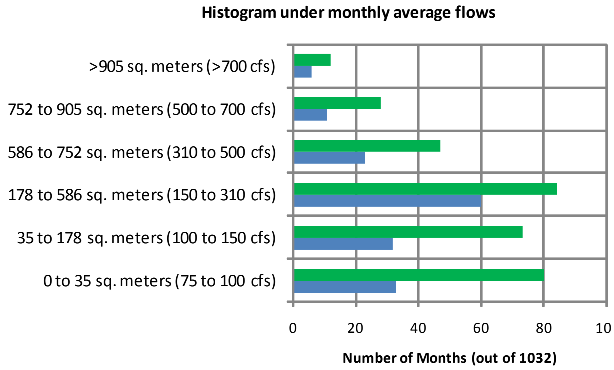
ModNormSMALLSEA

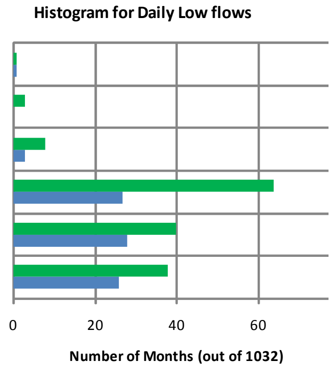


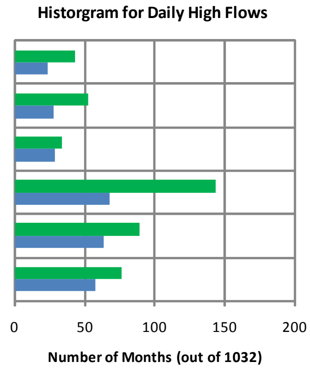
Histograms of inundation quantities under average monthly flows and probable daily highs and lows for alternatives and Natural conditions, Below Tributaries/Above Seaman

Alternative   Natural Conditions

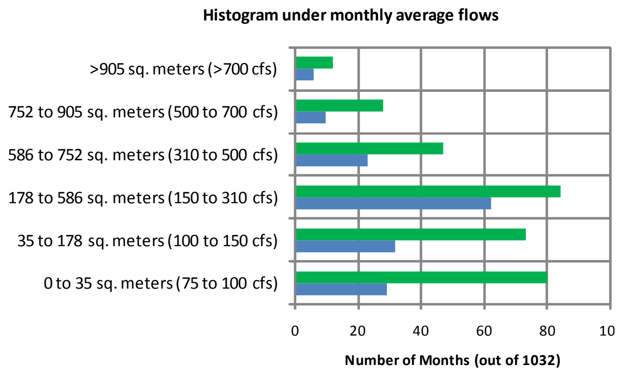
Default APA

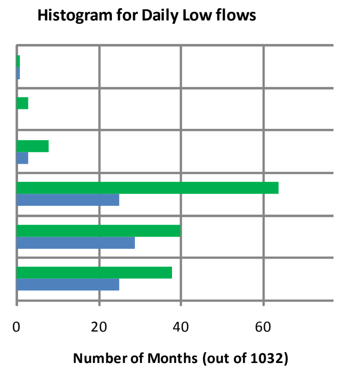


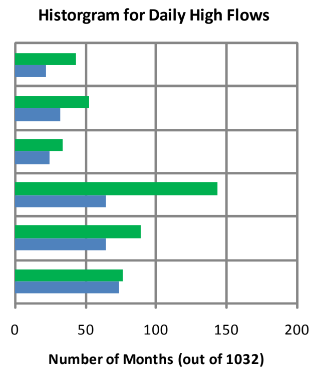




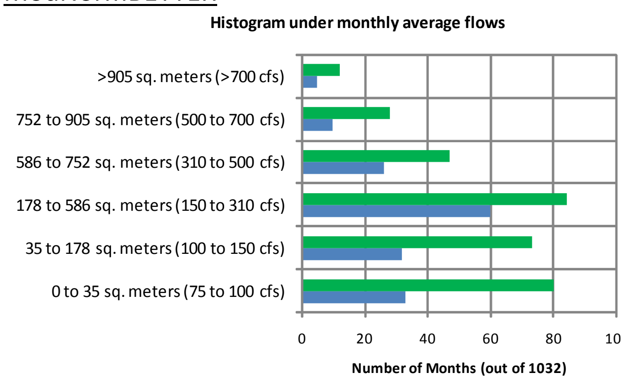
ModNormLHF

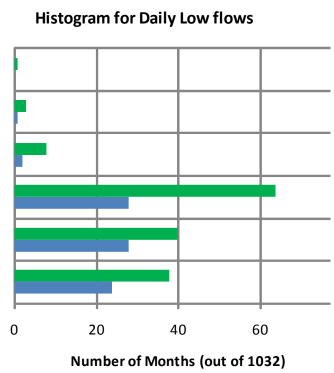


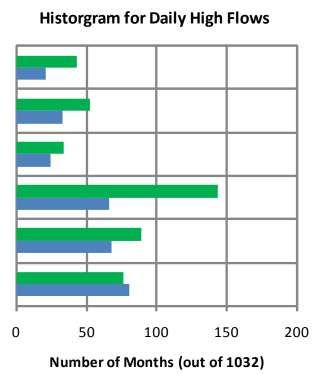




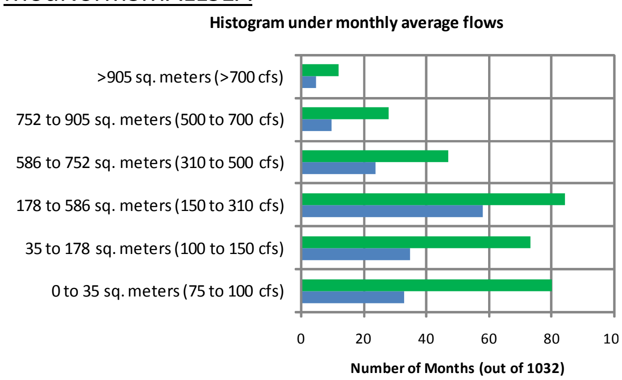
ModNormBETTER

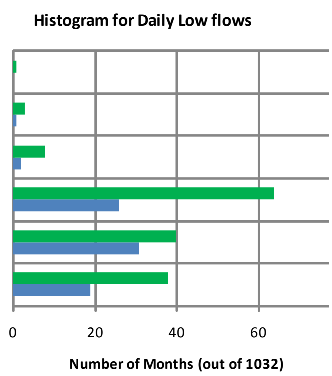


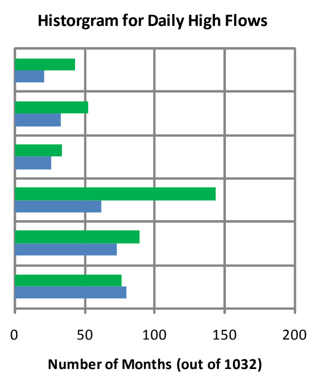




ModNormSMALLSEA



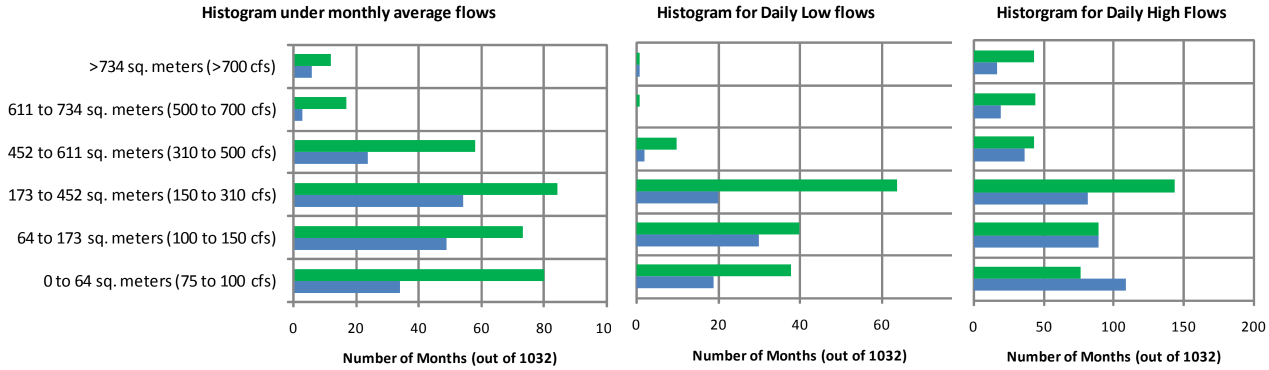




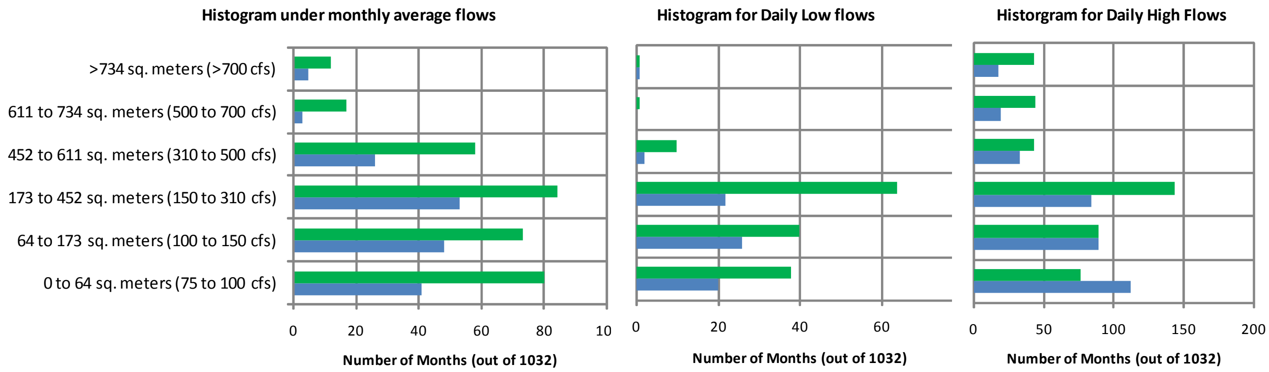
Histograms of inundation quantities under average monthly flows and probable daily highs and lows for alternatives and Natural conditions, Below Seaman

Alternative　　Natural Conditions

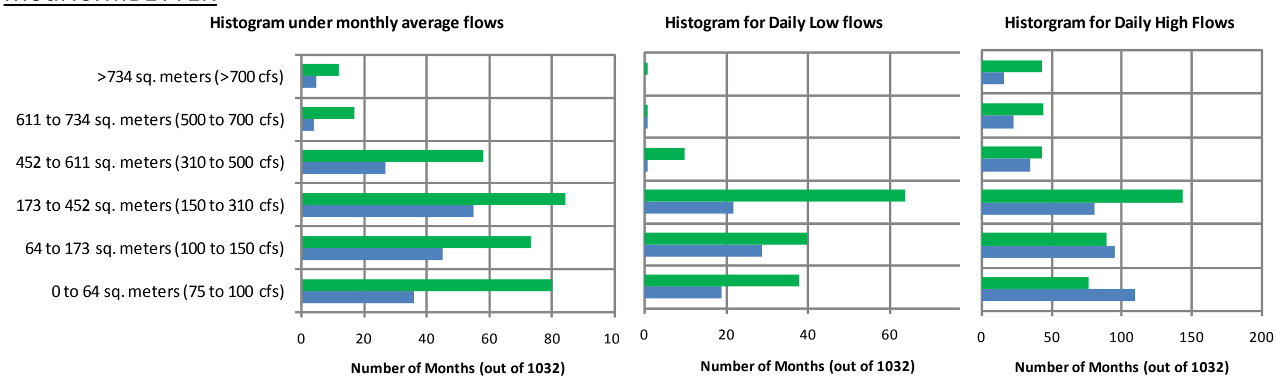
Default APA



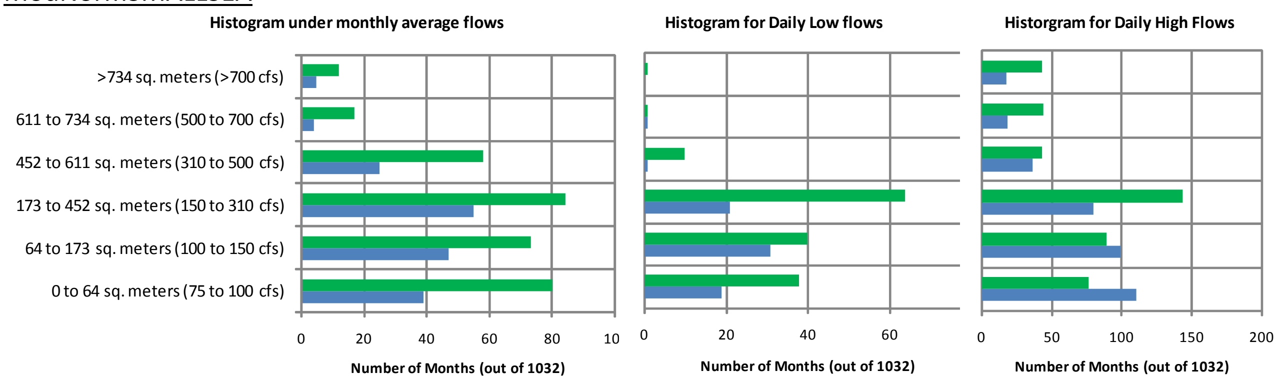
ModNormLHF



ModNormBETTER



ModNormSMALLSEA

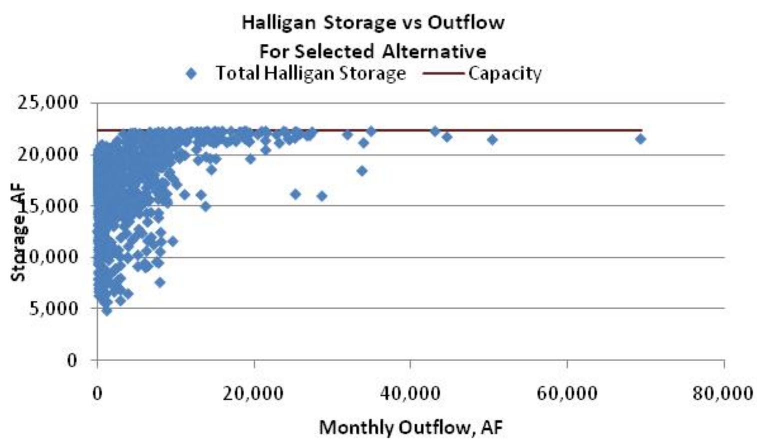


Large flood events

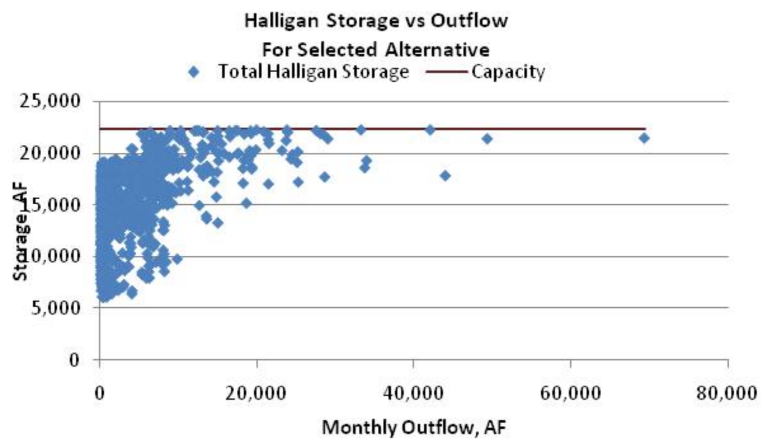
Very large flood events (~7500 cfs) occur over a matter of minutes and hours, not months. Analysis of similar events from other front range stream gage records suggests that such an event on the North Fork will require about 10,000 af of spillway outflow in a month. The reservoir and dam may attenuate the flow so some kind of collapsible spillway may also be required. These displays show how often such events might occur

Metric	Default APA	ModNormLHF	ModNormBETTER	ModNormSMALLSEA
Number of Spill Events	10	4	2	2
Largest Spill Event (af/month)	43,153	42,136	30,941	32,010
Smallest Spill Event (af/month)	14,083	19,969	23,826	23,863

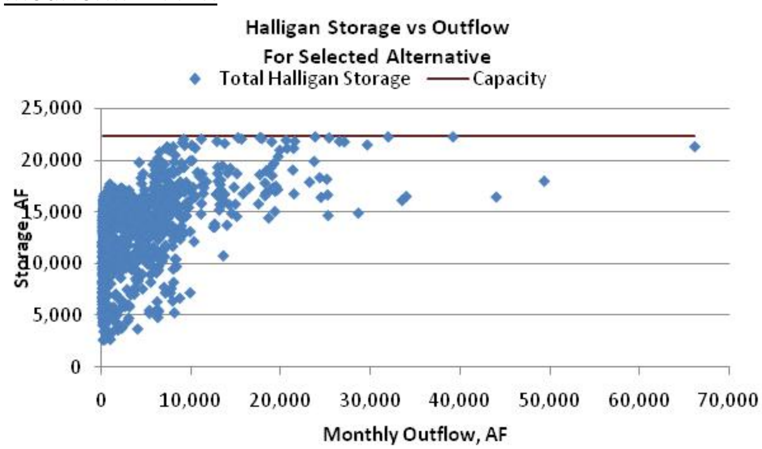
DefaultAPA



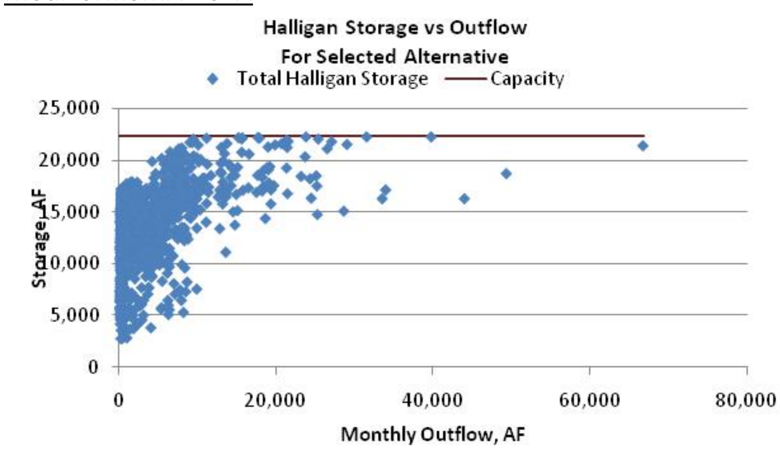
ModNormLHF



ModNormBETTER



ModNormSMALLSEA



Terrestrial Habitat Inundation

Halligan-Seaman

Acres of Habitat Lost and Relative Impact on Connectivity

L/E = Local/Edge

L = Low

M = Moderate

H = High

100% = Complete disconnection

Note: All activity maps dated 08202009 except Preble's Meadow Jumping Mouse, which had not date.

Habitat	**Halligan - 22.3K**		**Halligan - 23.4K**		**Seaman / Existing Site - 42K**		**Seaman / Existing Site - 53K**		**Seaman / New Site - 42K**		**Seaman / New Site - 53K**	
	acres	**conn.**	**acres**	**conn.**	**acres**	**conn.**	**acres**	**conn.**	**acres**	**conn.**	**acres**	**conn.**
Bighorn Migration Corridors	0		0		0		0		0		0	
Bighorn Migration Patterns	0		0		0		0		0		0	
Bighorn Mineral Lick	0		0		0		0		0		0	
Bighorn Overall Range	193	L	211	L	223	L	256	L	269	L	307	L
Bighorn Production Area	0		0		0		0		0		0	
Bighorn Severe Winter Range	0		0		0		0		0		0	
Bighorn Summer Concentration Area	0		0		0		0		0		0	
Bighorn Summer Range	193	L	211	L	0		0		0		0	
Bighorn Wate rSource	0		0		0		0		0		0	
Bighorn Winter Concentration Area	0		0		0		0		0		0	
Bighorn Winter Range	0		0		0		0		0		0	
BlackBear Fall Concentration	0		0		0		0		0		0	
Black Bear Human Conflic tArea	0		0		0		0		0		0	
Black Bear Overall Range	203	L/E	222	L/E	415	L/E	528	L/E	397	L/E	486	L/E
Black Bear Summer Concentration	203	L/E	222	L/E	0		0		0		0	
Elk Highway Crossings	0		0		0		0		0		0	
Elk Limited Use Area	0		0		0		0		0		0	
Elk Migration Corridors	0		0		0		0		0		0	
Elk Migration Patterns	0		0		0	100%	0	100%	0	100%	0	100%
Elk Overall Range	203	L/E	222	L/E	415	L/E	528	L/E	397	L/E	486	L/E
Elk Production Area	0		0		0		0		0		0	
Elk Resident Population Area	0		0		415	H	515	H	397	H	486	H
Elk Severe Winter Range	0		0		212	H	265	H	135	H	189	H
Elk Summer Concentration Area	0		0		0		0		0		0	
Elk Summer Range	0		0		0		0		0		0	
Elk Winter Concentration Area	0		0		415	H	528	H	397	H	486	H
Elk Winter Range	0		0		415	L/E	528	L/E	397	L/E	486	L/E
Mtn Lion Human Conflict Area	0		0		415	L	528	L	397	L	486	L
Mtn Lion Overall Range	203	L/E	222	L/E	415	L/E	528	L/E	397	L/E	486	L/E
Mtn Lion Peripheral Range	0		0		0		0		0		0	

Terrestrial Habitat Inundation (continued)

Habitat	Halligan - 22.3K		Halligan - 23.4K		Seaman / Existing Site - 42K		Seaman / Existing Site - 53K		Seaman / New Site - 42K		Seaman / New Site - 53K	
	acres	conn.	acres	conn.	acres	conn.	acres	conn.	acres	conn.	acres	conn.
Mule Deer Concentration Area	0		0		0		0		0		0	
Mule Deer Critical Winter Range	202	L	221	L	415	H	528	H	397	H	486	H
Mule Deer Highway Crossing	0		0		0		0		0		0	
Mule Deer Limited Use Area	0		0		0		0		0		0	
Mule Deer Migration Corridors	0		0		0		0		0		0	
Mule Deer Migration Patterns	0		0		0		0		0		0	
Mule Deer Overall Range	203	L/E	222	L/E	415	L/E	528	L/E	397	L/E	486	L/E
Mule Deer Resident Population Area	0		0		0		0		0		0	
Mule Deer Severe Winter Range	203	L/E	222	L/E	415	L/E	528	L/E	397	L/E	486	L/E
Mule Deer Summer Range	203	L/E	222	L/E	415	L/E	528	L/E	397	L/E	486	L/E
Mule Deer Winter Concentration Area	202	M	221	M	415	M	528	H	397	M	486	H
Mule Deer Winter Range	203	L/E	222	L/E	415	L/E	528	L/E	397	L/E	486	L/E
pjm occupied range	193	H	209	H	0		0		0		0	
pjm overall range	203	L/E	222	L/E	415	L/E	528	L/E	397	L/E	486	L/E
Pronghorn Concentration Area	18	L/E	20	L/E	0		0		0		0	
Pronghorn Limited Use Area	0		0		0		0		0		0	
Pronghorn Migration Corridors	0		0		0		0		0		0	
Pronghorn Migration Patterns	0		0		0		0		0		0	
Pronghorn Overall Range	203	L/E	222	L/E	0		0		0		0	
Pronghorn Perennial Water	0		0		0		0		0		0	
Pronghorn Resident Population Area	0		0		0		0		0		0	
Pronghorn Severe Winter Range	0		0		0		0		0		0	
Pronghorn Winter Concentration	18	L/E	20	L/E	0		0		0		0	
Pronghorn Winter Range	203	L/E	222	L/E	0		0		0		0	
River Otter Concentration Area	0		0		0		0		0		0	
River Otter Nata lDen	0		0		0		0		0		0	
River Otter Overall Range	0		0		325	L/E	369	L/E	348	L/E	405	L/E
River Otter Winter Range	0		0		325	L/E	369	L/E	348	L/E	405	L/E
Turkey Overall Range	0		0		415	M	528	M	397	M	486	M
Turkey Production Area	0		0		402	H	472	H	371	H	450	H
Turkey Roost Sites	0		0		0		0		0		0	
Turkey Winter Concentration Area	0		0		0		0		0		0	
Turkey Winter Range	0		0		0		0		0		0	

Joint Operating Plan (JOP)

Preferred Alternative

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Frequncy > 12 cfs	100%	2%	0%	0%	1%	1%	0%
Frequncy > 10 cfs	100%	100%	100%	100%	100%	100%	1%
Frequncy < 10 cfs (JOP Target)	0%	0%	0%	0%	0%	0%	99%
Minimum Total Release by Month	*29.91*	*10.02*	*10.00*	*10.00*	*10.01*	*10.00*	*0.00*

Selected Alternative = ModNormLHF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Frequncy > 12 cfs	100%	3%	0%	1%	2%	2%	0%
Frequncy > 10 cfs	100%	100%	100%	100%	100%	100%	2%
Frequncy < 10 cfs (JOP Target)	0%	0%	0%	0%	0%	0%	98%
Minimum Total Release by Month	*31.17*	*10.02*	*10.00*	*10.00*	*10.01*	*10.00*	*0.00*

=better than Pref. Alt. =worse than Pref. Alt.

Selected Alternative = ModNormBETTER

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Frequncy > 12 cfs	100%	2%	0%	2%	3%	6%	0%
Frequncy > 10 cfs	100%	100%	100%	100%	100%	100%	1%
Frequncy < 10 cfs (JOP Target)	0%	0%	0%	0%	0%	0%	99%
Minimum Total Release by Month	*29.91*	*10.02*	*10.00*	*10.00*	*10.01*	*10.00*	*0.00*

=better than Pref. Alt. =worse than Pref. Alt.

Selected Alternative = ModNormSMALLSEA

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Frequncy > 12 cfs	100%	3%	1%	1%	2%	3%	0%
Frequncy > 10 cfs	100%	100%	100%	100%	100%	100%	1%
Frequncy < 10 cfs (JOP Target)	0%	0%	0%	0%	0%	0%	99%
Minimum Total Release by Month	*26.99*	*10.02*	*10.00*	*10.00*	*10.01*	*10.00*	*0.00*

=better than Pref. Alt. =worse than Pref. Alt.

Appendix 2

Water Rights Implications of the Unconstrained Scenario in the Halligan-Seaman Shared Vision Model

June 4, 2010

Prepared by

Lee Rozaklis
Principal
AMEC Earth & Environmental

Fort Collins and Greeley have applied for permits to enlarge Halligan and Seaman Reservoirs (the North Fork Reservoirs) as the principal components of the Halligan Seaman Water Management Project (the Project), a water supply project proposed by the Cities in partnership with the North Poudre Irrigation Company, (collectively the Participants). The Project would utilize the enlarged North Fork Reservoirs to regulate and deliver water from the Participants' water rights to meet portions of the Participants' water demands. The Participants have engaged other stakeholders in a Shared Vision process in order to refine the Project to better meet environmental stream flow goals while continuing to meet the Project's original water supply purposes.

As part of the Shared Vision process, a Shared Vision Model (SVM) was developed to allow stakeholders to explore alternative ways to configure and operate the North Fork Reservoirs. The SVM allows the user to specify North Fork Reservoir enlargement sizes and environmental flow targets and to adjust the North Fork Reservoirs' operating rules in order to increase the Project's "environmental score" while also meeting the Project's water supply purposes. The SVM includes representations of the Participants' individual water rights that would be used to store water in the North Fork Reservoirs or to divert water at the North Poudre Canal. The Cities' water rights represented in the SVM include irrigation rights that have been changed (or are being changed) to municipal uses and the Cities' interests in conditional storage rights that have been changed (or are being changed) from their originally decreed locations of storage to allow for storage in the North Fork Reservoirs.

The SVM includes both a constrained and an unconstrained scenario. The constrained scenario allows for exploration of alternative North Fork Reservoir sizing and Project operations, but individual water rights must be used in strict accordance with their initially intended uses. Each water right can only be used according to its ownership, location of storage, location of use, and type of demand. For example, Fort Collins' changed irrigation rights can only be stored in Fort Collin's portion of Halligan Reservoir and can only be released to meet Fort Collins' raw water demands.

The operational and accounting constraints associated with water rights in the constrained scenario are relatively complex, which makes it difficult to effectively examine alternatives for refining the Project to meet environmental flows. The purpose of the unconstrained scenario is to allow for exploration of the

Project's environmental flow potential without having to deal with the complexity of the spatial, type of use and ownership aspects of water rights constraints, although the fundamental constraint of staying within the individual water rights' divertible flow amounts (as discussed below) is still respected. (Also note that, in the unconstrained scenario, only the Cities' water rights are unconstrained. NPIC's water rights are used in a fully constrained manner.) For example, in the unconstrained scenario, Greeley's changed irrigation rights could be initially stored in enlarged Halligan Reservoir, released to help meet environmental flow targets on the North Fork between Halligan and Seaman, re-stored in Seaman, and ultimately released to meet Greeley's demands.

It was determined that partial relaxation of the water rights constraints in the unconstrained scenario would still provide a reasonable depiction of the Project's potential operations because of the way in which water rights are initially quantified for inclusion in the SVM.

The SVM includes several sets of monthly time series input data that represent, at each reservoir or ditch location, the portion of total stream flows that can be legally diverted at that location by one or more of the Participants' water rights (divertible supplies). Each set of divertible supply data represents individual water rights (or groups of similar water rights) that are specified by ownership (Fort Collins, Greeley or NPIC), type of water right (originally decreed water rights, changed water irrigation rights, changed conditional storage rights, wholly consumable vs. single use), type of use (irrigation, municipal or multi-purpose) and location of diversion (Halligan, Seaman or North Poudre Canal).

The divertible supplies were quantified using three other models: the Poudre Basin Network model (PBN), Fort Collins' water supply system model, and Greeley's water supply system model. The PBN simulates the allocation of natural Poudre Basin stream flows, in-basin return flows and trans-basin imports to individual water rights; and simulates the resulting stream flows in individual stream segments that reflect the effects of water rights operations. In the PBN, individual water rights are represented in terms of their relative priorities, decreed amounts, diversion seasons, demands and return flows. Fort Collins' and Greeley's water supply system models simulate the operation of each City's raw water supply system, utilizing each City's divertible supplies from in-basin water rights, CBT and Windy Gap supplies to operate each City's reservoirs and meet each City's raw water demands.

The historical yields of the individual water rights included in the SVM's divertible supply data were quantified using the PBN. In the case of Cities' changed irrigation rights, the exchange potential (which represents the ability to divert the yields of those water rights at upstream locations on the North Fork) was determined via an iterative process using the PBN and the Cities' operations models.

Under Colorado water laws, a water right can be changed from its originally decreed use to other uses provided no injury occurs to other rights in existence at the time of the change. A water right is changed based upon its legal historical beneficial use. To avoid injury, a water right must be changed in a manner that avoids expansion of use; maintains historical return flows in time, location and amount; and does not reduce the divertible supplies available to other water rights.

A storage right can be appropriated if there is water available for appropriation and if the applicant "can and will" put the appropriated water to a definite non-speculative beneficial use. A storage right is generally limited to one volumetric fill per year.

The historical uses and net exchangeable amounts associated with the Cities' changed irrigation rights have already been quantified in the PBN, so the issues of potential expansion of use and injury to intervening water rights have already been addressed, irrespective of the manner in which the Cities' changed irrigation rights are represented in the SVM. The historical return flow obligations associated with the Cities' changed irrigation rights are either part of the Cities' demands included in the SVM or are being addressed by the Cities using other means not represented in the SVM, so there are no unresolved return flow obligation concerns. Similarly, the water available for appropriation under the Cities' storage rights has already been quantified in the PBN, including adherence to the one-fill rule, so injury issues associated with the Cites' storage rights have already been addressed irrespective of the manner in which those storage rights are used in the SVM.

So the "unconstrained" aspect of water rights use in the unconstrained scenario of the SVM already meets the tests posed by Colorado water laws of no injury to other water rights and staying within the limits of historical use (for changed irrigation rights) and within the limits of appropriation (for new storage rights).

The specific "unconstrained" aspects of water rights use in the SVM's unconstrained scenario generally fall into five categories as described below. Each of these modes of use correspond to accepted methods of using water rights that are recognized in Colorado decrees for new water rights, changes of water rights, plans for augmentation, and water use agreements between water users.

1. Storing Water Interchangeably in Halligan or Seaman.

In the SVM's unconstrained scenario, Fort Collins' and Greeley's changed irrigation rights and their interests in existing and conditional storage rights are stored interchangeably in Halligan and Seaman Reservoirs.

Storage of a changed irrigation right in multiple reservoirs is a well-established feature in numerous water rights decrees. Under the mechanism of alternate point of diversion, a changed irrigation right can be simultaneously diverted for direct use or storage at several locations, provided that any rate or volumetric limits imposed on diversions by the changed right are adhered to and demonstrated by measurement and accounting[1].

In the case of the Cities' changed irrigation rights represented in the SVM, the issue of those rights staying within their individual volumetric diversion limits has already been addressed when those rights were quantified using the PBN, as previously discussed. Any measurement and accounting requirements that would be a consequence of the Project's operations as simulated in the SVM's unconstrained scenario would be reasonable and well within the Cities' water rights accounting abilities.

In a similar manner, storage of water under a storage right can occur at several locations, provided that the storage right's volumetric limit and the one-fill rule are adhered to. In cases where an absolute or conditional storage right is changed to another storage location, there is an additional constraint that the historical or "contemplated" draft of the storage right as quantified at its original location be adhered to. Most of the storage rights in existence are specifically decreed to fill a single reservoir. This is because storage rights are typically appropriated with a specific reservoir in mind and because, once appropriated, storage rights are relatively infrequently changed to another reservoir. However, there

[1] For example, the City of Lafayette has changed its interests in several South Boulder Creek irrigation rights to allow for storage in several reservoirs including Baseline Reservoir, Gross Reservoir and Waneka Lake. See decrees for Case Nos. W-8346-A-76, W-8346-B(1)-76, W-8347-76, W-8348(1)-76, 80W468, 80CW469, Consolidated Case Nos. W-8346-B(2)-76 and W-8348(2)-76, and Case Nos. 85CW119 and 90CW108.

are examples of storage rights that have been changed to allow for simultaneous storage at multiple reservoirs[2].

In the case of the Cities' storage rights represented in the SVM, the issue of those rights staying within their individual annual volumetric diversion limits and adhering to the one-fill rule has already been addressed when those rights were quantified using the PBN, as previously discussed. Any measurement and accounting requirements that would be a consequence of the Project's operations as simulated in the SVM's unconstrained scenario would be reasonable and well within the Cities' water rights accounting abilities.

To the extent that the Cities' changed irrigation rights or their storage rights have already been decreed without alternate points of storage having been included in the decrees, those rights could be brought back into court for modification of their decrees to allow for such additional points of storage. It is recognized that water right owners are reluctant to bring their decrees back to court for fear of new scrutiny by objectors and additional terms and conditions being imposed by the court. However many water right owners do just that, in order to adapt their decrees to the owners' changed water use objectives or to changed circumstances within their water supply systems. In most of these instances, additional terms and decrees are imposed to accommodate the additional sought-after uses or to respond to the changed circumstances. Rarely are they onerous or unexpected unless the original terms of the decrees were overly generous and not representative of the rights' historical use.

2. <u>Storage and Release from Halligan, Recapture in Seaman, Subsequent Release to Meet City Demands.</u>

In the SVM's unconstrained scenario, water stored under the Cities' water rights in Halligan Reservoir is released to help meet environmental flow targets on the North Fork. It is then recaptured and stored in Seaman Reservoir and is eventually released to meet Fort Collins' or Greeley's demands.

It is a well-accepted principle of Colorado water law that, once a water right has been used to store water in a reservoir according to the terms its decree, there are generally no restrictions on the timing or manner of the subsequent release of that water down a stream, including helping to meet environmental flows along intervening stream reaches between the point of release and the point of delivery. Released water can also be temporarily stored in and released from another reservoir, provided that the released water is eventually delivered and used for decreed purposes.

In order to avoid injury to other water rights, stream transit losses and reservoir evaporation associated with such release and reregulation should be accounted for and that the water temporarily stored in Seaman should be counted against Seaman's one-fill rule. Imposition of stream transit and reservoir evaporation losses and one-fill requirements are within the authority of the Division Engineer and would not require a reopening of the Cities' decrees.

3. <u>Delivering Water from One City's Water Rights to Meet another City's Demands.</u>

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[2] In Case No. 94CW84, the City of Boulder changed its interests in the storage rights of Baseline Reservoir to allow for storage in Barker Meadow Reservoir, Silver Lake Reservoir, and others. In Case No. 85CW119, the City of Lafayette changed the storage rights for Waneka Reservoir and Hecla Reservoir to allow for storage in Gross Reservoir, Baseline Reservoir, and others.

In the SVM's unconstrained scenario, water stored under the Cities' combined water rights is released to meet the Cities' combined demands, irrespective of who owns the water right and whose demands are being supplied. (We haven't examined how often and to what extent this occurs in the unconstrained scenario of the SVM.)

Water supplies can be delivered from one water user to another on a temporary basis under informal arrangements or under State Engineer-approved substitute water supply plans. From a water rights perspective, the potential injury concerns related to such shared use of water rights include no expansion of use; maintenance of return flow requirements in time, place and amount; and storage rights limited to one fill per year.

Arguments could be made claiming that such sharing of water constitutes an undecreed use of changed of irrigation rights (for example, if Fort Collins decree says its changed rights can only be used in Fort Collins), or that such sharing contradicts the "can and will" test for conditional storage rights (i.e. shared uses of conditional storage rights among Cities were not part of what was decreed when conditional storage rights were adjudicated).

The undecreed use argument would probably fail because no injury could be shown so long as each City's return flow obligations are met and changed rights' volumetric limits are adhered to. The Cities could always go back to Court to amend their decrees to allow for such sharing, but this is probably not necessary, unless other water users filed a complaint with the Division Engineer or the Water Court.

The "can and will" argument is probably not applicable to Cities' shares of the Grey Mountain storage right because that right was originally decreed for regional use that included both Cities' service areas.

4. Delivering Single Use Water to Meet Fully Consumable Demands and Vice Versa.

In the SVM's unconstrained scenario, water supplies attributable to both Cities' wholly consumable rights and single use rights are used interchangeably to meet either City's wholly consumable or single use demands.

Wholly consumable water is distinguished from single use water in that it can be used to extinction through successive use, reuse or exchange and can be used to offset stream depletions in a plan for augmentation. Single use water can only be used for a single use and the return flows from that use belong to the stream. The SVM has separate municipal demand schedules for wholly consumable and single use water. A city like Greeley, which has both wholly consumable and single use supplies, may prefer to take delivery of its wholly consumable supplies during the winter months when municipal consumptive use is relatively low, in order to maximize its reusable return flows.

Separate accounting of wholly consumable vs. single use supplies stored in the North Fork Reservoirs is necessary in order to demonstrate that only wholly consumable water is delivered from the reservoirs to wholly consumable demands in a timely manner. However, such accounting need not be done on a reservoir-specific basis, because deliveries of wholly consumable water occurs downstream of both reservoirs. Such accounting could therefore be done on a combined basis for both North Fork Reservoirs. Ex post accounting could be developed for the unconstrained scenario of the SVM to determine whether there is sufficient wholly consumable water in the reservoirs throughout the modeled study period to meet the SVM's wholly consumable demands. Such a demonstration would provide assurance that this aspect of the unconstrained scenario could be implemented in real-world operations.

5. Exchanging High Mountain Reservoir Water to North Fork Storage, Subsequent Release to Meet City Demands.

In the SVM's unconstrained scenario, releases and spills (i.e. excess divertible supplies) from the Cities' high mountain reservoirs located in the headwaters of the mainstem Poudre are used to fill the North Fork Reservoirs by exchange or by direct pumping (Seaman only). This water is then released to help meet environmental flow targets on the North Fork on its way to being delivered to meet the Cities' demands.

The discussion related to Item 2 applies to this mode of unconstrained water rights usage.

There is an additional concern related to diversion by exchange or pumping of high mountain reservoir "spills". By definition, spills would represent water in excess of one complete fill per year for each of the high mountain reservoirs. Diversion of such water, whether in the constrained or the unconstrained scenario of the SVM, would constitute an expansion of use of those storage rights, unless those reservoirs have refill rights.

Appendix 3

Environmental Flows for the North Fork of the Cache la Poudre River

Prepared by The Nature Conservancy of Colorado

01/04/2008

Introduction

The Nature Conservancy (TNC) established the Laramie Foothills community-based conservation project in 1987 with the purchase of 1,120 acres, including 4 miles of the North Fork of the Cache la Poudre River, just below Halligan Dam and Reservoir. Conservation of the aquatic and riparian ecosystems situated along the North Fork Cache la Poudre River (North Fork) is an important objective of the Laramie Foothills project. It is now widely recognized that to conserve aquatic and riparian ecosystems, flow must retain elements of natural variability of flow events such as floods and droughts, including magnitude, frequency, timing, duration, and rate of change of (see, for example, Poff et al. 1997, Postel and Richter 2003, Arthington et al. 2006).

Stream flow through the Phantom Canyon Preserve (PCP) is affected by upstream water importation, irrigation diversions, and regulation by reservoirs, especially Halligan Reservoir, located immediately upstream from the preserve. The cities of Fort Collins and Greeley and their partners plan to develop additional storage through coordinated enlargements of Halligan Reservoir and Seaman Reservoir (the latter located approximately 16 river miles below Halligan Reservoir; together called the Halligan – Seaman Water Management Project or HSWMP). The proposed enlargements could further erode flow conditions through PCP, yet they may also provide a unique opportunity to improve flow through joint municipal water management that explicitly recognizes the need for environmental flows on the North Fork.

This paper describes environmental flow recommendations for the North Fork Cache la Poudre River, in anticipation of the proposed expansion of the two reservoirs. We anticipate that these recommendations will be considered during the emerging Shared Vision Planning process. The SVP process will explore the ability of the HSWMP to provide ecologically meaningful flows on the North Fork below Halligan Reservoir and on the mainstem above the North Fork confluence within the HSWMP's operational limitations.

Method

In anticipation of this opportunity, The Nature Conservancy has developed environmental flow guidelines for the North Fork following these specific steps (see Richter et al. 2005):

1. Identify conservation targets and the types of flow events upon which they depend.

2. Summarize the set of flow parameters that describe the flow events needed to sustain all conservation targets ("key flow parameters").

3. Define criteria that delineate environmental flows.

4. Develop hydrographs based on environmental flow criteria.

5. Select measurable ecosystem components to monitor; identify the expected response of those components.

Steps 1 through 3 were based on numerous workshops and studies relating to the hydrology and ecology of the North Fork. Topics that have been investigated and discussed include streamflow (Rozaklis 2002a, 2002b, Merritt 2002), riparian woodlands (Merritt 2002), sediment transport (Wohl and Cenderelli 2000; Rathburn 2001, Rathburn and Wohl 2001, Rathburn and Wohl 2002), fish (Fausch 2002, Miller and others, *unpublished data*), and aquatic macroinvertebrates (Zuellig et al. 2002). Additional analysis of daily natural flows for the stream gage immediately downstream of Halligan Dam (water years 1987-2006; see Rozaklis 2002c for methods of modeling natural flows) was conducted using the Indicators of Hydrologic Alteration software (Richter et al. 1996).

Results and Discussion

The list of conservation targets and their dependence on flow events was compiled from information and data presented at TNC's 2005 Flow Scenarios Workshop (Table 1). Two abiotic factors--sediment and water quality--were included on the list of targets because: (i) they can be useful indicators of habitat conditions for biological targets; (ii) they can be relatively easy to measure; and (iii) they have been studied in relation to the Halligan Dam.

Flow events can be described in terms of measurable flow parameters (e.g., magnitude of daily flows, duration of small floods, frequency of large floods). Freshwater conservation theory suggests that a small set of flow parameters—the "key flow parameters"—describes those aspects of flow that, if addressed through flow management, should lead to sustainable populations and communities of conservation targets. Based on the relationships between flow and conservation targets, four flow events and ten key flow parameters that describe these events were identified for the North Fork (Table 2).

To achieve conservation objectives, specific criteria must be identified for each key flow parameter. These criteria must be based on known or hypothesized flow:ecology relationships (Arthington et al. 2006). Identifying these criteria is challenging because there are generally few empirical data linking specific flow conditions to specific ecological responses, yet the North Fork of the Poudre has had more site-specific work done on it than most rivers, so many of these relationships are relatively well known or can be strongly inferred. Criteria for North Fork key flow parameters (Table 3) were derived to the extent possible from the 2005 flows workshop; however, criteria were also derived from published literature and hypothesized relationships between conservation targets and flow metrics based on frequency and probability of flow events.

To guide flow management, key flow parameter criteria (Table 3) were synthesized into daily hydrographs of environmental flows for the stream reach immediately downstream of Halligan Reservoir (Figures 1, 2, and 3). Environmental flows (those to be achieved through management to sustain conservation targets) are illustrated along with natural flows (i.e., that which would be expected in the absence of storage, diversion, etc., as reconstructed following Rozaklis 2002c) and historical flows (i.e., flows of record). Hydrographs are presented for wet, average, and dry years, where wet years included the third of years with the highest one-day maximum flow events (i.e., the largest flood) under natural conditions; average years included those with the middle third of high flow events; dry years included those with the lowest third of high daily flow events. Based on forecasted water supply, the appropriate hydrograph should be applied to guide the management of environmental flows.

These criteria should be viewed as informed hypotheses on how operational changes might lead to specific improvements in ecological condition. Following operational changes, the hypotheses should be tested through research and monitoring. With more research and more input from subject specialists, we hope that criteria will be linked more explicitly to existing empirical data, and refined and strengthened to ensure the maximum environmental return for any active flow management strategies that are implemented.

Given the 100+ years of flow alteration in the North Fork and associated changes in species composition and other aspects of the ecosystems, there is uncertainty as to what the optimal hydrograph would be needed to achieve conservation objectives. On-going monitoring of both flows (above and below reservoirs) and ecosystem components is essential to understanding if conservation objectives are being achieved. Among the ecosystem components below Halligan Reservoir that we expect to respond to flow management and their expected response are:

- Native and non-native fish biomass—expect increase as higher baseflows are achieved.
- Riparian woody species (alder, birch, and juniper) age-class structure—expect change toward upstream age-class structure.
- Riparian woody species (willow)—expect greater frequency.
- Aquatic algae and vascular plant cover—expect reduced cover after floods.
- Sediment loads—expect suspended and bedload sediment transport during floods.
- Channel structure (proportion of riffle, run, and pool)—expect no change in proportions.
- Channel structure (channel width in riffles)—expect no change in average width.
- Ground water levels—expect regular, flood-induced high water table.
- Water temperature—response dependent on dam design and reservoir levels.

There are a number of issues (discussed below) associated with the North Fork and elsewhere that are not addressed by environmental flows presented.

Sediment – Both sediment capture and sediment release by Halligan Dam can affect ecosystem condition on the North Fork. A natural sediment balance below the dam requires that sediment from upstream of the reservoir be moved through or out of the reservoir into the river below the reservoir. Sediment releases should occur regularly, and should proceed or coincide with moderate to high (i.e., spring) flows, when high sediment movement would naturally occur. Sediment transport is affected by not only high flows but also the rate of increasing and decreasing flows; if regular high flows cannot be achieved, careful attention to rates of flow increase and decrease can achieve some sediment transport objectives.

Below Phantom Canyon Preserve – The context of the North Fork in Phantom Canyon differs from below the canyon. Where stream banks and riparian vegetation are unnaturally degraded below the canyon (e.g. Eagles Nest), flood flows could have unnatural and undesired consequences. Also, man-made structures in the floodplain could be affected by high flows. The stream between Halligan Dam and Seaman Reservoir should be evaluated prior to a managed high flood so that adverse results can be mitigated; at the same time, it should be recognized that this river reach contains few structures and substantial public and agricultural land, thereby presenting unique opportunities.

Greenback cutthroat and non-native species – Prior to hydrologic and ecological alterations of the North Fork, the native top aquatic predator was the greenback cutthroat trout. A fully restored ecosystem would include re-establishment of this species and elimination of the two non-native trout that are present (rainbow and brown). The rainbow trout that are present have hybridized with native greenback cutthroat, and may fill an ecological niche similar to the cutthroat. In contrast, brown trout fill a top-predatory role that did not naturally exist in the North Fork, which may affect the composition and structure of the rest of the aquatic community. Flow management decisions may affect the relative success of spring spawners (rainbow) versus fall spawners (brown), but we encourage ecosystem-based rather than species-based flow management.

Main Stem Cache la Poudre River – Additional storage in Halligan and Seaman Reservoirs would result in changes to the stream flow regime in the main stem of the Cache la Poudre River downstream of the mouth of the North Fork. An enlarged Seaman Reservoir may also provide an opportunity to achieve environmental flow benefits between the Poudre headwaters and the North Fork confluence by allowing for recapture of winter season releases from headwaters reservoirs. Benefits to the North Fork that accrue from enlarged Halligan and Seaman Reservoirs must be viewed in the context of flow changes on the main stem. A full analysis of these changes on the main stem have not yet been—yet must be—considered in this development of flow guidelines for the North Fork.

Conclusion

We expect that managing for environmental flows in the North Fork Cache la Poudre River between Halligan Reservoir and Seaman Reservoir will help restore and maintain the river's environmental values while allowing for municipal water supply. Hydrographs illustrate expected environmental flow needs for wet years (Figure 1), average years (Figure 2), and dry years (Figure 3). These hydrographs also illustrate current flow surplus or deficit with respect to environmental flows: surpluses exist when historic flows exceed environmental flows and deficits exist when historic flows are less than environmental flows. Managing for environmental flows would entail applying the appropriate environmental flow hydrograph, depending on the type of year forecasted by predictive models of available water supply.

We believe environmental flows could be attained through coordinated management and operation of the proposed enlarged reservoirs. Options for attaining minimum flows would include combinations of the following: trades of water between participants with interests in Halligan vs. Seaman, storage releases to meet participants' water supply needs, storage releases to meet historical return flow requirements, storage releases that are subsequently recaptured in enlarged Seaman, flexibility in storage diversions under participants' changed irrigation rights, and water exchanges with other parties.

We hope to explore these options and others through the emerging Shared Vision Planning process for flows on the North Fork and mainstem Cache la Poudre. We commend the cities and the COE for engaging The Nature Conservancy and other partners in this important opportunity to restore flows while enhancing clean water supplies for people.

Table 1. Conservation targets and their dependence on flow events.	
Target	**Dependence flow events**
Fish: • Cutthroat Trout (or 'cutbows' as surrogate) • Longnose Dace • Fathead Minnow • Johnny Darter • Iowa Darter	Very large and large floods: • Mobilize bed material to scour bed and remove aquatic vegetation (vascular plants and algae). • Maintain channel width and complexity (e.g., undercut banks, coarse woody debris, off-channel pools), which are linked to habitat and species diversity. High flows and small floods • Mobilize interstitial sediment that clogs spawning beds. Daily flows: • Govern total available habitat and minimum wetted area/habitat. • Provide connectivity during driest periods. • Provide over-wintering habitat. • Affect water quality, with temperature and oxygen being key components Comments: • Greenback cutthroat were naturally found throughout this watershed. • Large floods may reduce current year recruitment for some species.
Aquatic macroinvertebrates	Very large and large floods: • Maintain channel width and complexity (e.g., undercut banks, coarse woody debris, off-channel pools), which are linked to habitat and species diversity. High flows and small floods: • Impact channel and sediment characteristics; clear interstitial sediment and open up habitat. Daily flows: • Govern total available habitat and minimum wetted area/habitat; less total habitat results in lower total abundance and productivity. Comments: • Macroinvertebrates in the North Fork are generally ecologically resilient, widespread, common species, so flow and sediment issues are not a great concern (Zuellig et al. 2002). • Fluctuations of macroinvertebrate diversity and density will be directly related to hydrological and temperature patterns of the river below the new reservoir.

Riparian/Wetland plants and plant associations, including: • Narrowleaf cottonwood / skunkbush • River birch / chokecherry • Alders / forbs • Alders / graminoids • Alders / birches • Blue spruce / cottonwood • Coyote willow Woody species abundances known to vary with flow regulation (Merritt 2002): • *Salix* spp. (willow) • *Alnus incana* (alder) • *Betula fontinalis* (birch) • *Sabina scopulorum* (juniper)	Very large and large floods: • Scour banks, removing vegetation and sediment (during rising limb and peak), but also deposit sediment and propagules (e.g., seeds and live branches) during descending limb. Small floods • Provide surfaces for recruitment of willows and cottonwoods. • Affect distribution of riparian vegetation by creating anoxic conditions and affecting nutrient cycling. Daily flows: • Maintain minimal soil moisture. Comments: • Managed 25-year floods may serve as a target flow for generating canopy gaps, creating regenerative habitat, enhancing biogeochemical processes, and maintaining habitat heterogeneity. • Regional estimates suggest that the magnitudes of 2, 5, 10, 25 year recurrence interval floods have decreased along the North Fork by 70 to 80%; this reduction is most likely due to dam operations. • Riparian vegetation composition below Halligan Dam has shifted in a manner consistent with responses that would be predicted following reduced peak flows, delayed spring peak flow, and stabilized or reduced base flows during the growing season (Merritt and Wohl 2006).
Prebles meadow jumping mouse	Very large and large floods: • Maintain structure and composition of riparian habitat High flows and small floods: • Maintain structure and composition of riparian habitat Comments: • Requires riparian shrub habitat; forages in uplands.
Sediment (indicator target)	Very large and large floods: • Mobilize bed material to scour bed and remove aquatic vegetation (vascular plants and algae). • Mobilize sediment from large, infrequent flows is deposited during gradual descending limb High flows and small floods: • Sediment within bed interstices mobilized during stepped ascending limb Comments: • Channel maintenance needs are minimal.
Water quality (indicator target)	Daily flows: • Affect dissolved oxygen, high temperatures, nutrient enrichment, and other aspects of water quality.

Table 2. Relationships between flow and conservation targets, North Fork Cache la Poudre River.

Flow events and key flow parameters	Relationship(s) to conservation targets
Event: *Daily flows* 1 key parameter: *magnitude.*	Unnaturally low minimums can limit aquatic organisms; unnaturally high maximums can, for example, alter relationships among organisms and their environment. Both minimums and maximums relate to total habitat availability and ecosystem productivity.
Event: *Small floods* 5 key parameters: *timing, magnitude, duration, frequency and rate of change*.	Small flood (~bankfull) conditions transport sediment and maintain saturated soils; some effects of small floods require sustained conditions, e.g., soil anoxia typically takes at least 2 weeks to develop; seed release of riparian species and spawning of some fish species are synchronized with natural floods; rise and fall rates affect patterns of sediment and propagule (seeds and live branches) transport and deposition, the establishment of woody vegetation, and the ability of fish and aquatic macroinvertebrates to survive floods.
Event: *Large floods* 2 key parameters*: magnitude and frequency.*	The 10-year flood is important for re-working channel sediments.
Event: *Very large floods* 2 key parameters: *magnitude and frequency.*	Field evidence suggests that the 25-year flood is sufficient to uproot common riparian shrubs and to saturate floodplain soils. Managed 25-year floods may serve as a target flow for generating canopy gaps, creating regenerative habitat, enhancing biogeochemical processes, and maintaining habitat heterogeneity.

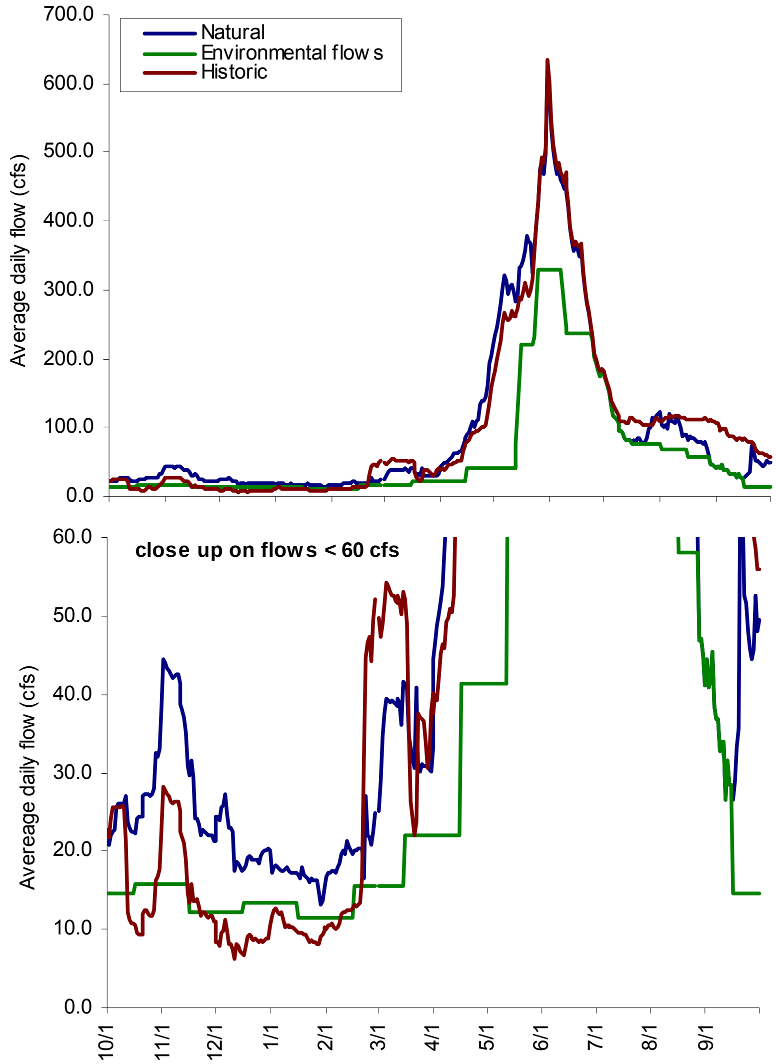
Table 3: Flow Criteria—North Fork Poudre River, below Halligan Reservoir. "Natural flow" criteria describe expected flow conditions in the absence of management; "Environmental flows under managed conditions" describe flow conditions expected to sustain conservation targets.

Conservation Status	Criteria	Justification
Natural flows	Minimum/Maximum flow = inflow +/- 10%.	Several authors (e.g., Arthington and Pussey 2003; Konrad 2007) suggest natural functions begin dropping off with a 10% change from natural conditions.
	Small flood: ≥330 cfs, occurring on average every other year, lasting on average 15 days, peaking around June 1, with rise rate <22.6 cfs per day and fall rate < 13.7 cfs per day.	0.5 probability of a small flood occurring in any given year; natural small flood last on average 15 days, 90% of all floods under natural conditions are at least 2 days long, natural peak was around June 1, 90% of all day-to-day changes during small floods were <22.6 cfs and 13.7 cfs during, respectively, flood rise and fall.
	Large (≥1490 cfs) flood: occurs every 7-22 yrs.	Under natural conditions, the probability of a 1490 cfs or larger flood occurring after 7 yrs is 0.50; after 22 yrs is 0.90.
	Very large (≥7500 cfs) flood: occurs every 17-56 yrs.	Under natural conditions, the probability of a 7500 cfs or larger flood occurring within 17 yrs is 0.50; within 56 yrs is 0.90.
Environmental flows under managed conditions	Minimum/Maximum flows: Daily environmental flows should be maintained between the 25th and 75th percentile of all natural daily flows for each month of a wet, avg, or dry year, unless: In wet and average years: • If the natural median daily flow for that month was between 75-100 cfs and the 25th percentile of natural flows is <75 cfs, in which case the environmental flow = 75 cfs • If the natural median daily flow for that month was >100 cfs and the 25th percentile of natural flows is < 100 cfs, in which case the environmental flow = 100 cfs Under all conditions: • If inflows to the reservoir are outside the 25th-75th percentiles of natural flows, environmental flows = inflows to reservoir.	A general guideline for environmental flows can be established by selecting the range of natural flows between the 25th and 75th percentiles. A more specific range would benefit native fishes, however. All life stages of cutthroat (using 'cutbows' as surrogates) are maintained at flows ranging from 75 cfs to 100 cfs (Rozaklis 2002b); so, during months where the environmental flows would exceed the 25th percentile of natural flows in wet and average years, the environmental flows should be set to optimize trout habitat. Under all conditions, if daily reservoir inflows fall outside the 25th-75th percentiles of natural flows, then environmental flows can be set to inflows.

(Table 3 Continued)

	Small flood: ≥330 cfs, occurring during wettest 1/3rd of years, lasting 13 days, peaking around June 1, with rise rate <22.6 cfs per day and fall rate < 13.7 cfs per day.	~90% chance of small flood recurring within 3 years; 13 days is ~90% of natural mean small flood duration and is approximate minimum time needed to develop anoxic soil conditions, natural peak was around June 1, 90% of all day-to-day changes during small floods were <22.6 cfs and 13.7 cfs during, respectively, flood rise and fall.
	Large flood: ≥1490 cfs, occurs every 22-28 yrs.	Under natural conditions, the probability of a 1490 cfs or larger flood occurring after 22 yrs is 0.90; after 28 yrs is 0.95.
	Very large flood: ≥7500 cfs, occurs every 56-71 yrs.	Under natural conditions, the probability of a 7500 cfs or larger flood occurring after 56 yrs is 0.90; after 71 yrs is 0.95.

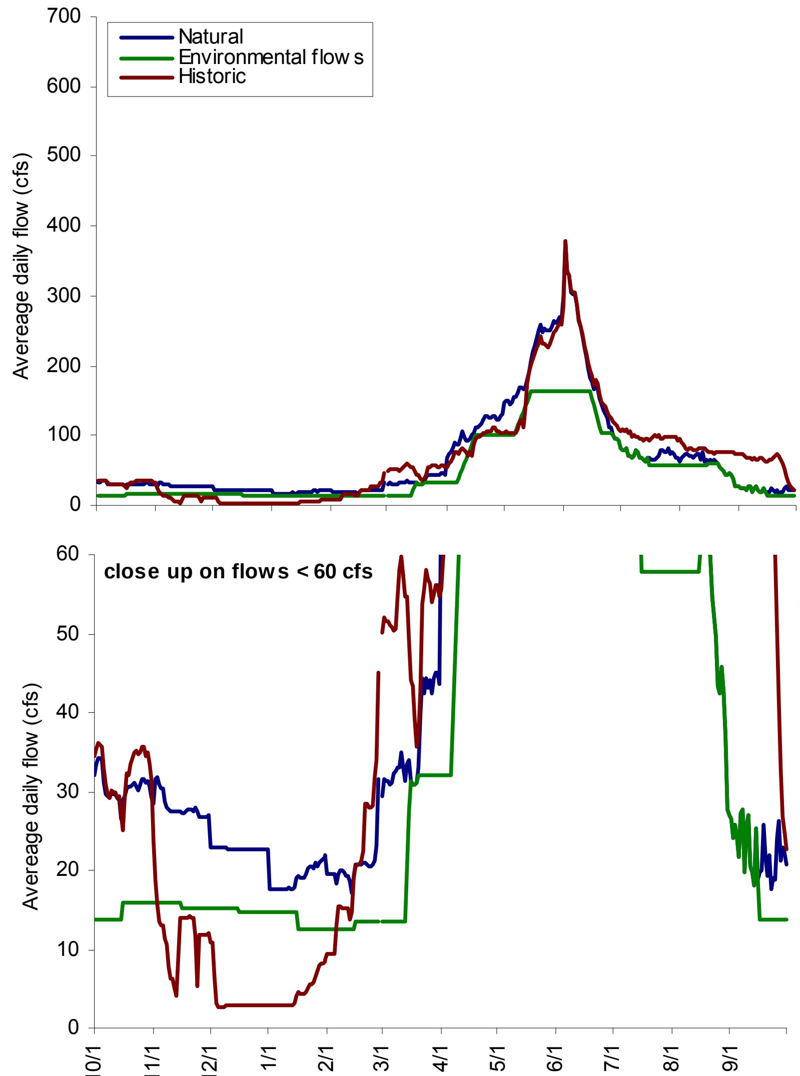
Figure 1. Wet year hydrographs.



Notes:

- Natural and historic lines show average daily flow for the six years during water years 1987-2007 with the highest one-day flow (~ 1/3 of the years), which are defined as wet years. Natural flows were re-constructed following Rozaklis (2002c). Historic flows are actual flows for the same period of record.
- Daily environmental flows are based on natural flows for the six wet years; those flow values were derived on a monthly basis (with monthly flows centered on the 1st of each month, to match timing of annual peak flows) following criteria in Table 3 and according to output from an analysis of natural flows using Indicators of Hydrologic Alteration (IHA).
- Environmental flows are those expected to maintain healthy aquatic and riparian ecosystems as the river is being managed for water supply. The environmental flows illustrated are the bottom of the range and constitute floors; the top end of the range of environmental flows is not illustrated (but is specified in Table 3); at all times matching outflow conditions to reservoir inflow conditions is acceptable to guide deviation from this range.
- Large and very large instantaneous floods are not illustrated for natural, historic, or environmental flows. The large (1490 cfs) managed flood should occur every 22-28 years (less frequently than natural flows), and the very large (7500 cfs) flood should occur every 56-71 years (also less frequently than natural flows). It is expected that these floods will also occur during a wet year, and they will replace the need to manage a small flood for the year in which they occur.

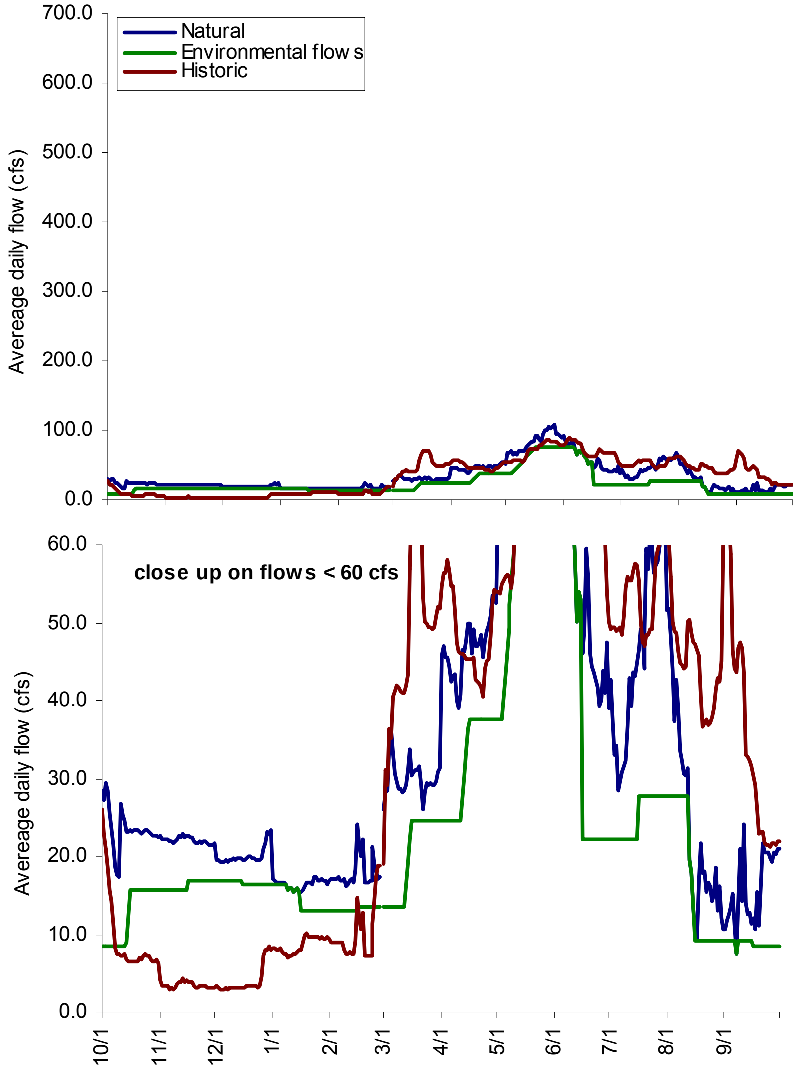
Figure 2. Average year hydrographs.



Notes:

- Natural and historic lines show average daily flow for the eight years with maximum one-day flows in the ~middle third of water years 1987-2006, which are defined as average years. Natural flows were re-constructed following Rozaklis (2002c). Historic flows are actual flows for the same period of record.
- Daily environmental flows are based on natural flows for the eight average years; those flow values were derived on a monthly basis (with monthly flows centered on the 1st of each month, to match timing of annual peak flows) following criteria in Table 3 and according to output from an analysis of natural flows using indicators of hydrologic alteration (IHA). Average rise and fall rates were applied between monthly flows to naturalize flow transitions.
- Environmental Flows are those expected to maintain healthy aquatic and riparian ecosystems as the river is being managed for water supply. The environmental flows illustrated are the bottom of the range and constitute floors; the top end of the range of environmental flows is not illustrated (but is specified in Table 3); at all times matching outflow conditions to reservoir inflow conditions is acceptable to guide deviation from this range.

Figure 3. Dry year hydrographs (mean daily flows for 87, 89, 00, 02, 04, 06)



Notes:

- Natural and historic lines show average daily flow for the six years with maximum one-day flows in the ~bottom third of water years 1987-2006, which are defined as dry years. Natural flows were re-constructed following Rozaklis (2002c). Historic flows are actual flows for the same period of record.
- Daily environmental flows are based on natural flows for the six dry years; those flow values were derived on a monthly basis (with monthly flows centered on the 1st of each month, to match timing of annual peak flows) following criteria in Table 3 and according to output from an analysis of natural flows using indicators of hydrologic alteration (IHA). Average rise and fall rates were applied between monthly flows to naturalize flow transitions.
- Environmental Flows are those expected to maintain healthy aquatic and riparian ecosystems as the river is being managed for water supply. The environmental flows illustrated are the bottom of the range and constitute floors; the top end of the range of environmental flows is not illustrated (but is specified in Table 3); at all times matching outflow conditions to reservoir inflow conditions is acceptable to guide deviation from this range.

References

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

Arthington, A. H. and B. J. Pusey. 2003. Flow restoration and protection in Australian rivers. River Research and applications 19: 377-395.

Fausch, K.D. 2002. Phantom Canyon Preserve and North Fork of the Cache la Poudre River Summary and Recommendations on Fish. Unpublished report to The Nature Conservancy of Colorado. Dept. of Fishery and Wildlife Biology Colorado State University. October 2002.

Konrad, C., A. Brasher, and J. May. 2007. Limits on invertebrate assemblages associated with streamflow patterns in the western United States. Presented at the Lower Columbia River Symposium.

Merritt, D.M. 2002. Maintenance of riparian woodlands along mountain stream channels: roles of historic disturbance and hydrologic variability. Revised version. Unpublished report to The Nature Conservancy. Colorado State University, Fort Collins, CO.

Merritt, D.M. and E.E. Wohl. 2006. Plant dispersal along rivers fragmented by dams. River Research and Applications 22:1-26.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks and J. C. Stromberg. 1997. The natural flow regime. BioScience 47:769-784.

Postel, S. and B. Richter. 2003. Rivers for life: Managing water for people and nature. Island Press, Washington, DC.

Rathburn, S.L., 2001. Modeling pool sediment dynamics in a mountain river. Unpublished Ph.D. dissertation, Dept. of Earth Resources, Colorado State University, Ft. Collins, CO, 205 p.

Rathburn, S.L. and E.E. Wohl, 2001. One-dimensional sediment transport modeling of pool recovery along a mountain channel after a reservoir sediment release. Regulated Rivers: Research and Management 17:251-273.

Rathburn, S.L. and E.E. Wohl. 2002. Phantom Canyon Preserve and North Fork of the Cache la Poudre River Summary and Recommendations on Geomorphology and Sediment Management. Unpublished report to The Nature Conservancy. Colorado State University, Fort Collins, CO.

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

Richter, B.D., A.T. Warner, J.L. Meyer, K. Lutz. 2005. A collaborative and adaptive process for developing environmental flow recommendations. River Research and Applications 22:297-318.

Rozaklis, L. 2002a. Critical review of stream flow data, historical operations and instream flow recommendations for Phantom Canyon. Hydrosphere Resource Consultants.

Rozaklis, L. 2002b. Instream flow strategies for Phantom Canyon. Hydrosphere Resource Consultants.

Rozaklis, L. 2002c. Data and methods used to derive corrected flows at Halligan. Unpublished memorandum to D. Merritt. July 11, 2002. Hydrosphere Resource Consultants.

Wohl, E.E., and D.A. Cenderelli. 2000. Sediment deposition and transport patterns following a reservoir sediment release. Water Resources Research, vol. 36, no. 1, p. 319-333.

Zuellig, R, B.C. Kondratieff, and H.A. Rhodes. 2002. Benthos recovery after an episodic sediment release into a Colorado Rocky Mountain River. Western North American Naturalist: 62: 59-72.

Appendix 4

Implications of a Depressed Thermal Regime on Native Fish Species of the North Fork Cache la Poudre River

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Executive Summary

Population growth along the Front Range in Colorado has created an increase in the demand for municipal water, which has led to a proposal to expand both Halligan and Milton Seaman Reservoirs on the North Fork Cache la Poudre River. Dams alter aquatic ecosystems in three primary ways, affecting: connectivity of critical habitat, the natural flow regime, and the thermal regime. Depressed thermal regimes are often caused by releasing water from the bottom of the reservoir (i.e., hypolimnial releases). Although this effect is not as visible as homogenized flow patterns and connectivity loss, understanding the thermal regime is critical to persistence of native fishes because temperature affects essentially all physiological, biochemical, and life history processes of all fishes.

The river segment between Halligan and Milton Seaman reservoirs is important habitat for fishes along the Front Range of northern Colorado. This area between the plains and mountains (elevation 1400 – 1650 m; 4593 – 5413 ft), known as the transition zone, supports a representative assemblage of fishes that require cool water and coarse, silt-free substrate to sustain populations. Many of these fish are at the fringe of their natural distribution and thus are likely to be ecologically, genetically, and morphologically distinct from the same fish species near the center of their range (e.g., in the Great Lakes region). Urbanization and water storage are two main factors that have caused loss of transition zone habitat, and subsequent declines in native fishes. For example, the segment of the North Fork between the two reservoirs originally supported an assemblage of nine native species (suckers, minnows, and darters), of which two have not been captured since 1959.

The focus of this report is on the potential for reservoir expansion to produce water downstream that is too cold for the persistence of native fishes in the North Fork Cache la Poudre River. Thermal biology of many fishes has been studied extensively, but there are few useful data for assessing the effects of depressed thermal regimes on native transition-zone fishes. Most thermal tolerance studies are conducted in the lab and have focused on game and food fish species, not small-bodied fishes. Moreover, these studies focus on the acute thermal limits of fish, not chronic effects of temperature on populations. We conducted a literature review on cold thermal tolerances of the fishes native to the North Fork, to assess the risk of altering the thermal regime of the river segment. We relied on data from laboratory and field studies with emphasis on survival, growth, spawning, and hatching of early life stages. Although data were lacking for species in several of these categories, we were able to infer basic temperature requirements for the fish assemblage.

The main conclusions from the literature review on cold thermal tolerances of these native fishes are:

1. The native fishes in the North Fork between the reservoirs can **survive** to temperatures as low as 0°C, based on the available data (four of nine species).

2. Few data were available for the lower limits of **growth** of the native species (only three of nine species), and these limits varied substantially, from 1°C to >10°C

3. Eggs, larvae, and juvenile stages of fishes are the most sensitive to temperature, and these life stages are critical for populations to persist. Most native fish in the North Fork require 10°C to initiate **spawning** (data were available for eight of nine species), and this represents an important thermal limit for these native fishes.

4. Stream temperatures need to reach about 15°C for all species to **hatch** successfully. **Moreover, we infer from the limited data on the existing thermal regimes in the North Fork, and those for the main stem Poudre River in Fort Collins (where the same assemblage of fishes is native), that average daily temperatures will need to reach at least 20°C for a month or more to allow sufficient growth of fish larvae to achieve high overwinter survival (i.e., recruitment) for many of these native species.**

5. Overall, data on thermal minima required for survival, growth, and successful recruitment of early life stages of these species are sparse, and often come from other regions. For example, no data were available for bigmouth shiner for any category. More detailed data would be needed to make more accurate predictions specific to this region.

6. Case studies of the effects of depressed or altered thermal regimes on fishes in other rivers were reviewed, and showed:

a. Spawning and migration cues can be disrupted by altered thermal regimes, leading to population declines, such as has occurred for native minnows and suckers in the Colorado River system, and for native burbot (a type of cod) in the Kootenai River in the northern Rockies.

b. Growth and survival can be inhibited in streams with depressed thermal regimes, also leading to population declines, such as for the Colorado River fishes, and native cutthroat trout in high-altitude mountain streams in Colorado.

c. Fish may cope with altered thermal regimes by either compensation or adaptation. A population of darters in an eastern U.S. river compensated for cold temperatures by reducing growth and egg production, and delayed spawning. In contrast, a population of minnows in Texas apparently underwent rapid evolution, as evidenced by altered thermal preferenda in a laboratory test.

The implications of this study extend beyond the Front Range of Colorado. As demand for water increases in the western United States, it is to be expected that reservoirs will be expanded, and may lower temperature regimes that could potentially have adverse effects on native stream fish assemblages. **If a conservation goal for the North Fork Cache la Poudre River is to maintain suitable habitat for the assemblage of native fish species, then their thermal requirements will need to be a primary consideration.** New research likely will be needed to establish these requirements for many species.

Introduction

Population growth in Fort Collins and Greeley, Colorado has created an increase in the demand for municipal water. Increased demand has led to a proposal to expand both Halligan and Milton Seaman reservoirs on the North Fork of the Cache la Poudre River by 2029 (Figure 1; www.halligan-seaman.org). Water storage in Halligan Reservoir would increase nearly four fold, from 6400 acre-feet (ac ft) to 23,000 ac ft, and that in Milton Seaman Reservoir would increase more than 10 fold, from 5000 ac ft to 53,000 ac ft, for a collective 76,000 acre feet more water stored annually after completion. Depending on water storage capacities, the expanded reservoir areas could cause up to a 6 km loss in river habitat. The goal of expanding water storage in the basin is to provide water to the increasing populations in Greeley and Fort Collins, and to provide increased water system reliability in the event of a 1-in-50-year drought. Also, there is a relatively small component of the Halligan Reservoir expansion that is intended to provide additional water to the North Poudre Irrigation Company. Between 2010 and 2040, Greeley is estimated to double to 200,000 people and Fort Collins' population is predicted to grow by 15% up to 165,000 people (www.halligan-seaman.org).

Dams alter aquatic ecosystems in several ways, including creating barriers to fish movement (loss of connectivity), altering the timing and quantity of stream flow (i.e., the natural flow regime), and changing the thermal regime. First, dams sever connections within the river system, which prevents movement of fishes among habitats critical to different life stages (Schlosser 1995; Fausch et al. 2002; Helfman 2007). Second, the natural flow regime is modified because dams often homogenize flow and downstream habitats, often by decreasing peak flows and increasing base flows. This can cause loss of important ecological cues to fishes, such as increased discharge needed to initiate spawning (Poff et al. 1997). Third, thermal regimes are often stabilized, and depressed. This can affect fishes by inhibiting growth, spawning, and movement cues (Fausch 2007; Paragamian 2009).

When dams are constructed, alterations to these three critical factors interact and can lead to declines in native fish populations, including economically and ecologically valuable fishes such as Pacific salmonids, the Colorado River native fishes, and the Kootenai River burbot (*Lota lota*; Poff et al. 1997; Helfman 2007; Paragamian 2009). Depressed thermal regimes are often caused by releasing water from the bottom of the reservoir (i.e. hypolimnial releases). Although this effect is not as visible as homogenized flow patterns and connectivity loss, understanding the thermal regime is critical to persistence of native fishes because temperature affects essentially all physiological, biochemical, and life history processes of all fishes (Beitinger et al. 2000). All three of these effects currently manifest on the North Fork Cache la Poudre River, where the dams and at least one other diversion structure present a complete barrier to upstream movement, average winter flows are in the bottom 10th percentile of natural flows, and stream temperatures are depressed as much as 6 degrees C during bottom releases from Halligan Reservoir (Figures 2 and 3). It is conceivable that these factors have already contributed to the extirpation of several species and reduced populations of others in the North Fork, although there is no clear way to evaluate this possibility.

The river segment between Halligan and Milton Seaman reservoirs is important habitat for fishes along the Front Range of northern Colorado. This area between the plains and mountains (elevation 1400 – 1650 m; 4593 – 5413 ft), known as the transition zone, supports a representative assemblage of fishes that require cool water and coarse silt-free substrate to sustain populations (Fausch and Bestgen 1997). The project proponents in the Shared Vision Planning water management process (promoted by the US Corps of Engineers) have identified the native fish populations of the North Fork as a primary environmental target in project planning. Some of these species, such as the common shiner (*Luxilus cornutus*) and the Iowa darter (*Etheostoma exile*), are glacial relicts. These fish once occurred throughout the Great Plains during cooler and wetter periods after the most recent glaciations, but were extirpated from watersheds on the Great Plains of eastern Colorado as the climate became warmer and drier. Both common shiner and Iowa darter have special conservation status in Colorado, being state threatened and a species of special concern, respectively (Woodling 2006; Hubert and Gordon 2007). Loss of transition zone habitat and subsequent declines in the fish communities have been caused by urbanization and water diversion and storage driven by population growth (Li 1968; Fausch and Bestgen 1997). Continued anthropogenic impacts such as climate change pose thermal challenges and ultimately could lead to the transition zone shrinking farther or shifting to higher elevations (McCullough et al. 2009). Therefore, the river segment between Halligan and Milton Seaman reservoirs is critical habitat for the conservation of these native fishes.

Thermal biology of many fishes has been studied extensively, but many of the criteria are not relevant or are difficult to use for assessing the effects of depressed thermal regimes on native transition zone fishes, for three reasons. First, the majority of studies on thermal relationships in fishes have been conducted in the laboratory using simple endpoints as predictive tools, such as mortality. Two approaches to quantifying temperature tolerance in fishes are universally recognized: the incipient lethal temperature (ILT) technique and the critical thermal method (CTM; Beitinger et al. 2000). The ILT technique, also known as the plunge method, involves placing fish acclimated at a given temperature into several different water temperatures approaching their upper and lower limits, and exposing them for prescribed time intervals (12, 24, 48, or 96 h). The temperature at which 50% mortality occurs over this time period is then estimated. In the CTM, acclimated fish are subjected to a constant linear rate of change until a predefined sublethal effect occurs (loss of equilibrium, muscle spasms; Beitinger et al. 2000). However, both of these methods measure only upper and lower tolerance limits of a species and are not necessarily good indicators of the chronic effects of temperature. Second, the literature related to thermal maxima outnumbers thermal minima data 10 to 1, so data on thermal minima are available for relatively few species (Beitinger, pers. comm.). Third, most of the fish studied have been large-bodied food or sport fishes, not small-bodied fishes such as those found in the North Fork Cache la Poudre River (Wismer and Christie 1987; Beitinger et al. 2000).

We conducted a literature review on thermal tolerances of fishes native to the North Fork Cache la Poudre River to assess the risk of altering the thermal regime of the river segment. Although data are sparse for many of the species native to the North Fork, this problem was addressed by combining different sources of data collected using different methods over various life stages of the target species. We relied on data from laboratory and field studies with emphasis on growth, spawning, and early life stages. We also reviewed studies documenting the effects of tailwater operations on other fish species due to depressed (or altered) thermal regimes to offer insight based on results from other regions.

Methods

Study Area

The North Fork Cache la Poudre River flows through the Rocky Mountain foothills in Larimer County, Colorado, and into the main stem of the Cache la Poudre River near Fort Collins. Halligan Reservoir, completed in 1910, holds water for the North Poudre Irrigation Company and lies upstream of Milton-Seaman Reservoir, finished in 1943, which holds water for the city of Greeley. The river segment of interest lies between these reservoirs and is presently approximately 20 km long (Figure 1). The segment directly downstream of Halligan Reservoir descends through land owned by The Nature Conservancy including the narrow Phantom Canyon. The valley then opens and the river traverses rolling private grasslands, lands owned by Larimer County (Eagle's Nest Open Space), and other private, U.S. Forest Service, and state lands before entering Seaman Reservoir. River habitat in Phantom Canyon includes deep pools formed against the rock faces, whereas in the downstream reaches pools are formed by a combination of boulders and natural fluvial processes in the gravel and cobble bed. During summer baseflow, Halligan Reservoir dam releases water from the bottom of the reservoir (i.e., hypolimnial release) resulting in coldwater habitat downstream.

Target Species

Historical sampling records of the fish fauna in the North Fork Cache la Poudre River show that the river supports an assemblage of native and non-native fishes. Non-native rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), yellow perch (*Perca flavescens*), and brook stickleback (*Culaea inconstans*), species reported from the study area, are not addressed specifically in this report. Yellow perch and brook stickleback were recently found near Milton-Seaman Reservoir and are associated with this still-water habitat more than the river (K. Fausch, Colorado State University, and K. Kehmeier, Colorado Division of Wildlife, unpublished data). Halligan Reservoir is currently operated to discharge hypolimnial water, and creates coldwater habitat downstream that supports thriving populations of nonnative brown trout and rainbow trout. The thermal regimes required by these trout species are well understood and are currently being met. Therefore, the focus of this report will be on thermal regimes required to support native fishes found currently or in the past, which include nine native fishes (Table 1).

The assemblage of native fishes included two suckers (Family Catostomidae), five minnows (Family Cyprinidae; the minnow, dace, chub, and shiners), and two darters (Family Percidae; see Table 1 for scientific names of all species, and Appendix I for their life history). Most require relatively cool to warm water to successfully reproduce and grow, and along the Front Range of Colorado several of these species are found primarily or only in transition zone streams or ponds. Fishes within the North Fork display a wide range of biology and life history within this narrow habitat type. Some of these fish are long-lived and large-bodied, whereas some are small-bodied, short-lived fish. The fish assemblage is comprised of all spring or early summer spawners. However, some will spawn only once each year (e.g., suckers), whereas others will spawn multiple times in a season (e.g., fathead minnow), whenever conditions are adequate. Spawning substrate requirements vary, with six of nine species preferring gravel, two favoring sand, and one spawning in vegetation. Although two species have special conservation status in Colorado, none are federally endangered or threatened, and all have widespread distributions throughout other parts of the Mississippi River basin farther east (e.g, see Becker 1983). However, because the target species are glacial relicts in Colorado, they are likely to be ecologically, genetically, and morphologically distinct from their Great Lakes counterparts (Scheurer et al. 2003). In fact, many have disjunct distributions, with the next closest populations found hundreds of miles to the east. Two of the minnows, bigmouth shiner and common shiner, have not been collected in this river segment since the first collections in 1959, and may now be extirpated from the segment. Nevertheless, other fishes were rediscovered in the transition zone along the Front Range after a long hiatus (Bestgen et al. 1991) or have been collected for the first time only recently (Platania et al. 1986).

Literature review of thermal minima

Three sources of data were relevant to this study on the fishes historically present in the North Fork Cache la Poudre River. First, thermal tolerance data determined in the laboratory using the ILT technique were compiled for native fishes in the North Fork. Second, data reported from the laboratory and field on thermal requirements for growth, spawning, and egg and fry development were assembled for these species. Last, field data on effects of depressed or altered thermal regimes on other fish species downstream of hypolimnial release reservoirs are presented as examples of impacts that could be incurred by the native fishes. These case studies involved species in some of the same genera (*Etheostoma*) and families (Cyprinidae) found in the North Fork, as well as other species.

Many of the data found on thermal minima for fishes were from Canada and the Great Lakes region. However, if data were plentiful and the source was known, we selected those from the most appropriate locations to present (i.e., Colorado data were selected over Great Lakes region data) to account for regional variability that may occur within a species. Data are presented to illustrate both the limits of thermal tolerances and the necessary temperatures for the various fishes throughout their life histories (i.e. egg, larvae, juvenile, adult). Ranges for lower incipient lethal temperatures vary depending on the acclimation temperature tested, so the acclimation temperatures are also presented.

Temperature data

Miller Ecological collected thermal data on the North Fork Cache la Poudre River using temperature loggers in 2003 (unpublished data provided by W. Miller). These data will be used to model the current and future thermal regimes based on different management strategies as part of the Halligan-Seaman expansion project. We used the average daily temperatures from three sites along the North Fork to assess the thermal regime to which the native fish community was exposed. The three sites sampled were above Halligan Reservoir, below Halligan Reservoir, and below Phantom Canyon (Figure 1).

Results

Overall, data were sparse for the thermal biology of most of the native fishes of the North Fork Cache la Poudre River. We were able to find relatively complete data (i.e., on temperature tolerances, and thermal requirements for growth and spawning) for only two of the nine species, white sucker and fathead minnow. For three species (creek chub, longnose dace, and common shiner) data were available for two of the three attributes, and for another three (Iowa darter, johnny darter, and longnose sucker) data for only one attribute were found. One species, bigmouth shiner, had no temperature data available and only general spawning times were found. The most prevalent data were on spawning temperatures (available for eight of nine species), whereas data on growth were available for only three of nine species, and data on tolerances to low temperatures were available for only four of nine species.

Lower incipient lethal thermal tolerances

Data on lower incipient lethal temperatures (LILT) were found for only four species: white sucker, creek chub, common shiner, and fathead minnow (Table 2). Acclimation temperatures are shown in the table to help explain variation in LILT within species. The ranges of LILT were assumed to extend between those tested, because often the data did not include intermediate acclimation temperatures (i.e. acclimation temperatures tested included 20ºC and 25ºC but none between). The four fish tested can survive to temperatures as low as 0-2°C. Data on lower thermal tolerances may be sparse due to the assumption that most temperate fishes can survive at temperatures at or approaching 0°C (Beitinger et al. 2000).

Growth

Data on minimum temperature requirements for growth were limited to three species: white sucker, longnose dace, and fathead minnow (Table 3). Fish were held for long periods at different temperatures, or their growth was measured in the field, so acclimation temperatures are not an issue. White sucker stop growing at temperatures lower than about 12ºC, based on data from Colorado (Wismer and Christie 1969). Fathead minnow can continue to grow at temperatures as low as 7ºC, and longnose dace can sustain some growth to 1ºC. Below these temperatures for each species, fish are expected to stop growing. In contrast, optimum temperatures for growth are usually close to the upper incipient lethal temperature for most fishes. For example, optimum growth for white sucker occurs at 24-27ºC, close to the upper incipient lethal temperature of 29ºC. Minimum temperatures for growth were the least available thermal data type reported by temperatures by Wismer and Christie (1987) possibly due to the difficulty (and cost) of determining temperature requirements for growth during relatively long experiments at cold temperatures, which are difficult to maintain.

Spawning and development

Thermal requirements for spawning and hatching of eggs were found for all species except bigmouth shiner (Table 4). The data available show that most native fish require water temperatures to warm to 10°C or higher to initiate spawning, and require continued warming for successful development, hatching, and growth. Moreover, as temperatures decrease, incubation and hatching times increase (Figure 5). The development of spawning characteristics, including breeding colors and nuptial tubercles in males (projections on the head and fins used in courtship) and ovulation in females, appear to be temperature dependent (Becker 1983). Just as the onset of spawning can be induced by temperature, a significant drop in temperature will delay spawning activity by days in common shiner and fathead minnow (Carlander 1969; Becker 1983). Native fishes spawn during different periods based on water temperature, with darters and suckers tending to be early spring spawners, and minnows tending to spawn during summer (Figure 6).

Current thermal regime

The current thermal regimes show that temperatures reach levels required for all species in the native fish community to spawn in the three reaches for which data were available (above and below Halligan Reservoir, and below Phantom Canyon; Figures 2-4, Table 4). Average daily temperatures in the sampled reaches approached or exceeded 20°C during summer (Figures 2-4). While there are no temperature data available for spring and early summer to assess conditions for early-spawning fish, these fish begin spawning at lower temperatures so we assume that their requirements are being met as well. Temperatures do not reach optima for growth of some species, such as white sucker and fathead minnow, and it is unknown whether thermal units are sufficient to allow larvae of some minnows to grow sufficiently to survive well during the subsequent winter. Additional studies on the thermal requirements for first-year growth and survival of these species would be needed to predict “recruitment” success (see Coleman and Fausch 2007a, 2007b for an example with trout).

Case studies on effects of altered thermal regimes

Reports of the effects of altered thermal regimes in rivers below reservoirs on several species of native fish from throughout North America provide evidence of the importance of these potential effects on fish populations and their persistence. These studies also indicate the role of thermal disruption on multiple life history stages for native fishes. Here, we provide examples of 1) disrupted spawning cues for a burbot population, 2) limited growth and population bottlenecks in trout caused by low temperature regimes, 3) the contribution of depressed thermal regimes to the decline of native minnows and suckers in the mainstem Colorado River, 4) adaptive responses of a minnow to an altered thermal regime, and 5) comparisons of growth and fecundity of a darter species in a warm water segment versus a colder tailwater.

1) Effects of Libby Dam on Kootenai River burbot.- The Kootenai River in Idaho, USA and Kootenay Lake in British Columbia, Canada, both historically supported popular recreational and valuable commercial fisheries for burbot, a freshwater cod (Dunnigan and Sinclair 2008; Paragamian et al. 2008). Libby Dam was completed in 1972 and the fishery collapsed within the decade. By 1992 the burbot fishery was closed, and now even careful sampling reveals only a few burbot each year. The population is estimated at only 25 fish (V. Paragamian, personal communication). Altered temperature has been shown to be a detriment to migration and life history patterns in many fishes, including burbot (Paragamian et al. 2008). Before Libby Dam, temperatures during the winter pre-spawning period (December-February) averaged 0-2°C whereas temperatures after dam closure during the same months have averaged 2.5-8°C. Coupled with increased discharge from the dam, these consistently warmer temperatures are thought to have disrupted spawning cues as well as actual spawning by the burbot population in the Kootenai River and Kootenay Lake (Paragamian 2009). Although in this example, *warmer* temperatures created downstream from a dam are the issue, it is an excellent illustration of how homogenizing temperature regimes can put populations at risk of extinction.

2) Low temperatures create recruitment bottlenecks for trout. – Success of translocations of native cutthroat trout (*O. clarkii*) to start new populations in small high-elevation Colorado mountain streams is highly dependent on thermal conditions. Harig and Fausch (2002) reported that temperatures in July (the warmest month) averaged 10.0ºC in streams where translocations started successfully reproducing populations, but averaged 7.1ºC in those where transplanted fish died out and translocations failed. Further laboratory experiments by Coleman and Fausch (2007b) showed that the mechanism explaining these differences was low cutthroat trout fry survival at cold temperatures (about 75% vs. 30% from fry swim-up to 20 weeks after hatching, in the warm vs. cold regimes described above). Low temperatures delayed egg incubation and reduced growth of fry, which in turn reduced their survival during early winter due to lack of metabolic reserves. Based on additional field surveys of fry survival, Coleman and Fausch (2007a) reported that 900-1000 Growing Season Degree Days (GSDD) are required for successful recruitment of native cutthroat trout. The GSDD are defined as the cumulative average daily temperatures from when temperature exceeds 5ºC in early summer, which initiates spawning, until it drops permanently below 4ºC in the fall, when growth nearly ceases.

Rainbow trout apparently have similar thermal requirements for successful fry recruitment. Prior to 1985, age-0 rainbow trout were absent from the reach below Ruedi Dam on the Fryingpan River, Colorado due to the cold thermal regime caused by the hypolimnial release of water (670 GSDD by 1 October; Fausch 2007). In contrast, after modifications of the outlet structure to release warmer water (900 GSDD by 1 October), fry survival and recruitment increased and age-0 trout became prevalent. These studies show that even coldwater fishes like two species of trout can be inhibited if temperature regimes are too cold.

3) Effects of depressed thermal regimes on Colorado River fishes. – Entire fish communities in the Colorado River and its major tributaries have been largely extirpated by dam construction and the subsequent releases of cold water from the hypolimnion of reservoirs (Clarkson and Childs 2000). For example, after the 1962 closure of Flaming Gorge Dam on the Green River, Utah, spring-summer water temperatures were lowered to 6ºC from the former range of 7-21ºC. Several native species such as speckled dace (*R. osculus*), roundtail chub (*Gila robusta*), and federally endangered native species like Colorado pikeminnow (*Ptychochelius lucius*) and humpback chub (*G. cypha*) disappeared from the 104-km segment downstream of the dam to the confluence with the Yampa River. Reproduction did not occur throughout this entire segment until modifications to the outflow were made. Even then, the 13ºC maximum has allowed only limited spawning, and only in the lower reaches. Glen Canyon Dam on the Colorado River in Arizona had similar effects after it was completed in 1963. Tailwater operations led to a constant 10ºC thermal regime downstream. Colorado pikeminnow, roundtail chub, and bonytail chub (*G. elegans*), among others, were all extirpated. These losses of native fishes can be attributed to the cold water temperatures that lowered fecundity, inhibited spawning, and caused recruitment bottlenecks due to low overwinter survival of young-of-year fish (Clarkson and Childs 2000).

4) Adaptive response of a minnow to a depressed thermal regime. - Calhoun et al. (1982) studied the effect of hypolimnial releases from Morris Sheppard Dam on the Brazos River, Texas on the genetic make-up of red shiner (*Cyprinella lutrensis*). They found that the fish in the regulated tailwater had a much lower thermal preferendum (23.3ºC) when tested in the laboratory, compared with red shiner from a nearby unregulated river (30ºC). Environmental selective pressures due to the lowered thermal regime and the adaptive responses (i.e., rapid evolution; Stockwell et al. 2003) by red shiner are thought to have caused this variation between populations.

5) Compensatory responses by tessellated darters in modified thermal regimes. - Rocky Gorge Dam began operations on the Patuxent River, Maryland in 1954. Tessellated darters (*Etheostoma olmstedi*) have been shown to persist in the river downstream from the dam, despite cold hypolimnial releases. Due to a relatively short life span (commonly to only age 2), the darter was chosen to assess the effects of thermal modifications on fish populations in the river. The data showed that the population abundance and age-class proportions in the affected tailwater were similar to those in a downstream segment of the same river that was warmed by wastewater effluent (age-1 and age-2 fish made up 99.6% of the sample; Tsai 1972). However, fecundity, growth, and abundance of mature fish were lower. Likewise, spawning time was delayed by at least two weeks in the tailwater section compared to the warmer segment. Although the darter was apparently able to compensate for the colder thermal regime, the energetic cost of this compensation may ultimately prove too high, and lead to localized extirpation and a downstream shift of the population to more favorable habitat. The results of this study might be applicable to species in the North Fork in the genus *Etheostoma*, such as native Iowa and johnny darters, especially if temperatures are colder after reservoir expansion.

Conclusions and implications for native fishes in the North Fork

Our review shows that most native suckers, minnows, and darters in the North Fork Cache la Poudre River require water temperatures to warm above 10ºC to spawn successfully, and we surmise that an extended period of warmer temperatures will be needed for the fish larvae and juveniles to grow sufficiently to survive the winter (i.e., for successful recruitment to age 1). Based on data for the current thermal regime for the North Fork, and the main stem Cache la Poudre River, we surmise that growth and recruitment targets could be achieved with mean daily stream temperatures of at least 20°C for at least a month or more. Limited data on the summer thermal regime of the North Fork from one year (2003) indicates that average temperatures reached about 20ºC for about a month, although this may be below the optimum for some native species. Likewise, the thermal regime of the main stem Poudre River in Fort Collins, where all of these fishes were also native, also averages about 20°C for about a month during summer (Dr. Kevin Bestgen, Larval Fish Laboratory, Colorado State University, unpublished data). As a result, if a conservation target is to maintain suitable habitat in the segment for these native fish species, then their thermal requirements should be a primary consideration. New research could establish these requirements for these species.

Overall, data were sparse on the minimum thermal requirements needed to sustain native fishes of the North Fork. Wismer and Christie (1987) and Beitinger et al. (2000) also noted the scarcity of thermal data on non-game and small-bodied fishes, such as suckers, minnows, and darters. Nevertheless, these families include species that are among the most thermally sensitive of fishes (Wismer and Christie 1987).

The data reviewed suggest that cold temperatures directly influence life history patterns seen in these fishes. Data on lower incipient lethal temperatures, and that fact that all these fishes can survive in water with surface ice, support the assumption that fish can survive to temperatures approaching 0ºC. However, these data show only whether an individual of a species can survive a laboratory test, not the chronic effects on a population. Data pertaining to growth were few (three species) and should be investigated further to explore the effects on the fish assemblage, since growth can determine the success of whole year classes. The most striking data found were on spawning and development, where a threshold of 10°C must be met to suit the needs of all but one species in the present community (longnose sucker need colder temperatures for spawning). This trend of increasing sensitivity of biological requirements in fishes follows Shelford's Law of Tolerance (Shelford 1911, in Kendeigh 1961) where survival can occur over the widest range in temperature, growth is positive over a narrower range, and spawning and development of larvae are the most sensitive to environmental extremes and thus occur over the narrowest range of temperatures.

Case studies documenting the responses of fishes to depressed and homogenized thermal regimes below reservoirs provide real-world examples of how altered temperatures can strongly reduce or extirpate fish populations in some locations, and how fish compensate for, or adapt to, altered thermal regimes in other locations. Examples of effects on burbot and two trout species (one trout species is native in Colorado) as well as those on minnows, suckers, and darters (families that are native to the North Fork) all demonstrate that reduced thermal regimes can strongly delay or alter spawning, egg incubation and hatching, and fry growth and survival, leading to recruitment bottlenecks and, in some cases, extirpation of entire populations. Indeed, even small changes in temperature accumulate to result in large changes in fish life history, due to the cumulative nature of changes in development and growth (e.g., Coleman and Fausch 2007a, 2007b). In addition, temperature provides cues for fish to move to spawning habitat, and cues spawning behavior itself, further demonstrating how temperature is a master variable controlling all aspects of the life history of ectotherms (i.e., cold-blooded animals). Nevertheless, if thermal changes are not too extreme, compensation could occur, as in the tessellated darters that persisted, despite lower fecundity, slower growth, and delayed spawning. Likewise, rapid evolution and adaptation are also possible (Stockwell et al. 2003), such as in the red shiner population that evolved a lower thermal preferendum within relatively few generations in response to a depressed thermal regime. While thermal requirements for the native fish community are apparently met at present in the summer in the North Fork of the Cache la Poudre River between the reservoirs, there is sufficient evidence for deleterious effects on fish species to warrant cautious management strategies in the future regarding thermal regimes.

Data on thermal maxima are much more common for fishes than those on thermal minima. This large discrepancy could be explained by several factors. First, it is relatively difficult to test lower thermal tolerances of fishes because they often approach

0ºC, and these temperatures are difficult to create and maintain in the laboratory (see Coleman and Fausch 2007b). Second, there is a stubborn perception that high temperatures are more limiting than lower temperatures, even though more fish kills are caused by low temperatures than extremely high temperatures (Beitinger 2000). Third, most regulatory guidelines for fish thermal limits are based solely on thermal maxima (McCullough et al. 2009). For example, the database recently developed by the Colorado Division of Wildlife, and used for regulation, contained sparse or no data on thermal minima for most species in the North Fork, including Iowa darter, longnose sucker, common shiner, bigmouth shiner, creek chub, and longnose dace (Todd et al. 2008).

This study focused on the potential effects of the least visible result of hypolimnial release dams, but the other obvious changes caused by dams cannot be ignored. Flow regime, connectivity, sediment transport, and the fish assemblage have all been altered drastically from their historical states. For example, impoundments serve as suitable source habitats for introduced fishes, all of which may compete or prey on native fishes at various life history stages. Furthermore, the reaches downstream of the dams provide habitat where nonnative brown and rainbow trout thrive and most likely prey on native fish, which have little to no evolutionary history with these highly piscivorous fishes. Finally, many of these fish are at the western edge of their natural distribution and likely have unique genetic adaptations to the harsh environment, some of which may be lost due to recent anthropogenic modifications of the environment. Synergistic effects of these various factors could also induce further loss in these fish populations.

The implications of this study expand beyond the Front Range of Colorado. As human populations and demand for water increase in the western United States, it is to be expected that the number and size of reservoirs will increase, and often cause adverse effects on native stream fish assemblages. Several of the transition zone fish species are glacial relicts at the fringe of their natural distribution and are likely distinct from other populations found in the Great Lakes and Mississippi River basins (Scheurer et al. 2003). Comprehending the mechanisms that shape native stream fish communities will be crucial in attempts to develop management strategies at the proper scales (Fausch et al. 2002). By recognizing the needs of these distinct transition zone stream fishes for key factors such as thermal regimes, conservation measures can be refined to enhance their persistence.

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References cited

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, Wisconsin.

Beitinger, T.L., W.A. Bennett, and R.W. McCauley. 2000. Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. Environmental Biology of Fishes 58: 237-275.

Bestgen, K.R., K.D. Fausch, and S.C. Riley. 1991. Rediscovery of a relict southern population of lake chub, *Couesius plumbeus*, in Colorado. The Southwestern Naturalist 36:125-127.

Calhoun, S.W., E.G. Zimmerman, and T.L. Beitinger. 1982. Stream regulation alters acute temperature preferenda of red shiners, *Notropis lutrensis*. Canadian Journal of Fisheries and Aquatic Sciences 39:360-363.

Carlander, K.D. 1969. Handbook of freshwater fishery biology. Volume 1. The Iowa State University Press, Ames, Iowa.

Clarkson, R.W. and M.R. Childs. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River basin big-river fishes. Copeia 2:402-412.

Coleman, M.A. and K.D. Fausch. 2007a. Cold summer temperature limits recruitment in age-0 cutthroat trout in high elevation Colorado streams. Transactions of the American Fisheries Society 136: 1231-1244.

Coleman, M.A. and K.D. Fausch. 2007b. Cold summer temperature regimes cause a recruitment bottleneck in age-0 Colorado River cutthroat trout reared in laboratory streams. Transactions of the American Fisheries Society 136: 639-654.

Dunnigan, J.L., and C.L. Sinclair. 2008. Home range and movement patterns of burbot in Koocanusa Reservoir, Montana, USA. Pages 43-54 *in* V.L. Paragamian and D.H. Bennett, editors. Burbot: ecology, management, and culture. American Fisheries Society, Symposium 59, Bethesda, Maryland.

Etnier, D.A., and W.C. Starnes. 2001. Fishes of Tennessee. University of Tennessee Press. Knoxville, Tennessee.

Fausch, K.D. 2007. Introduction, establishment and effects of non-native salmonids: considering the risk of rainbow trout invasion in the United Kingdom. Journal of Fish Biology 71:1-32.

Fausch, K.D. and K.R. Bestgen. 1997. Ecology of fishes indigenous to the central and southwestern Great Plains. Pages 131-166 *in* F.L. Knopf and F.B. Samson, editors. Ecology and conservation of Great Plains vertebrates. Springer-Verlag, New York.

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52: 483-498.

Halligan-Seaman water management project. www.halligan-seaman.org. September 2009.

Harig, A.L., and K.D. Fausch. 2002. Minimum habitat requirements for establishing translocated cutthroat trout populations. Ecological Applications 12:535-551.

Helfman, G.S. 2007. Fish conservation. Island Press. Washington, D.C.

Hubert, W.A., and K.M. Gordon. 2007. Great Plains fishes declining or threatened with extirpation in Montana, Wyoming, or Colorado. Pages 3-13 *in* M.J. Brouder and J.A. Scheurer, editors. Status, distribution, and conservation of freshwater fishes of western North America: a symposium proceedings. American Fisheries Society, Symposium 53, Bethesda, Maryland.

Kendeigh, S.C. 1961. Animal ecology. Prentice-Hall. Englewood Cliffs, NJ.

Li, H. 1968. Fishes of the South Platte River basin. Masters Thesis. Colorado State University. Fort Collins.

McCullough, D.A., J.M. Bartholow, H.I. Jager, R.L. Beschta, E.F. Cheslak, M.L. Deas, J.L. Ebersole, J.S. Foott, S.L. Johnson, K.R. Marine, M.G. Mesa, J.H. Peterson, Y. Souchon, K.F. Tiffan, W.A. Wurtsbaugh. 2009. Research in thermal biology: burning questions for coldwater stream fishes. Reviews in Fisheries Science 17: 90-115.

Paragamian, V.L., and V.D. Wakkinen. 2008. Seasonal movement of burbot in relation to temperature and discharge in the Kootenai River, Idaho, USA and British Columbia, Canada. Pages 55-77 *in* V.L. Paragamian and D.H. Bennett, editors. Burbot: ecology, management, and culture. American Fisheries Society, Symposium 59, Bethesda, Maryland.

Paragamian, V.L., B.J. Pyper, M.J. Daigneault, R.C.P. Beamesderfer, S.C. Ireland. 2008. Population dynamics and extinction risk of burbot in the Kootenai River, Idaho, USA and British Columbia, Canada. Pages 213-234 *in* V.L. Paragamian and D.H. Bennett, editors. Burbot: ecology, management, and culture. American Fisheries Society, Symposium 59, Bethesda, Maryland.

Paragamian, V.L., and M.J. Hansen. 2009. Rehabilitation needs for burbot in the Kootenai River, Idaho, USA and British Columbia, Canada. North American Journal of Fisheries Management 29:768-777.

Platania, S.P., T.R. Cummings, and K.J. Kehmeier. 1986. First verified record of the stonecat, *Noturus flavus* (Ictaluridae), in the South Platte River system, Colorado, with notes on an albinistic specimen. The Southwestern Naturalist 31: 553-555.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47: 769-784.

Roberts, J.H. and G.D. Grossman. 2001. Reproductive characteristics of female longnose dace in the Coweeta Creek drainage, North Carolina, USA. Ecology of Freshwater Fish 10:184-190

Schlosser, I.J. 1995. Critical landscape attributes that influence fish population dynamics in headwater streams. Hydrobiologia 303:71-81.

Simon, T.P., and D.J. Faber. 1987. Descriptions of eggs, larvae, and early juveniles of the Iowa darter, *Etheostoma exile* (Girard), from Lac Heney, Quebec. Canadian Journal of Zoology 65:1264-1269

Schuerer, J.A., K.R. Bestgen, and K.D. Fausch. 2003. Resolving taxonomy and historic distribution for conservation of rare Great Plains fishes: Hybognathus (Telostei: Cyprinidae) in eastern Colorado basins. Copeia 2003:1-12.

Smith, R.K., and K.D. Fausch. 1997. Thermal tolerance and vegetation of Arkansas darter and johnny darter from Colorado plains streams. Transactions of the American Fisheries Society 126:676-686.

Stewart, K.W. and D.A. Watkinson. 2004. The freshwater fishes of Manitoba. University of Manitoba Press.

Stockwell, C.A., A.P. Hendry, and M.T. Kinnison. 2003. Contemporary evolution meets conservation biology. Trends in Ecology and Evolution. 18: 94-101.

Todd, A.S., M.A. Coleman, A.M. Konowal, M.K. May, S. Johnson, N.K.M. Vieira, and J.F. Saunders. 2008. Development of new water temperature criteria to protect Colorado's fisheries. Fisheries 33:433-443.

Tsai, C. 1972. Life history of the Eastern johnny darter, *Etheostoma olmstedi* Storer, in cold tailwater and sewage-polluted water. Transactions of the American Fisheries Society 1:80-88.

Walford, C.D., and K.R. Bestgen. 2008. The nonnative Iowa darter (*Etheostoma exile*) established in the Yampa River, Colorado and Green River, Utah. The Southwestern Naturalist 53: 529-533.

Wismer, D.A. and A.E. Christie. 1987. Temperature relationships of Great Lakes fishes: a data compilation. Great Lakes fishery commission special publication 87-3. 165 p.

Woodling, J. 1985. Colorado’s little fish: a guide to the minnows and other lesser known fishes in the state of Colorado. Colorado Division of Wildlife, Denver.

Table 1. Native fishes of the North Fork of the Cache la Poudre River, Colorado collected in the segment between Halligan and Seaman Reservoirs, between 1959 and 2009.

Family	Species	Scientific name	Conservation Status	Last Seen
Catostomidae	longnose sucker	*Catostomus catostomus*	-	2006[2]
Catostomidae	white sucker	*Catostomus commersoni*	-	2009[3]
Cyprinidae	fathead minnow	*Pimephales promelas*	-	2009[3]
Cyprinidae	longnose dace	*Rhinichthys cataractae*	-	2009[3]
Cyprinidae	bigmouth shiner	*Notropis dorsalis*	-	1959[1]
Cyprinidae	common shiner	*Luxilus cornutus*	state threatened	1959[1]
Cyprinidae	creek chub	*Semotilus atromaculatus*	-	2009[3]
Percidae	johnny darter	*Etheostoma nigrum*	-	2009[3]
Percidae	Iowa darter	*Etheostoma exile*	species of concern	2006[2]

[1]Collected by Frank Cross, University of Kansas Ichthyological Survey
[2]Collected by Ken Kehmeier, Colorado Division of Wildlife monitoring
[3]Collected by Ken Kehmeier and Kurt Fausch, CSU Fish Conservation Class FW400

Table 2. Lower incipient lethal temperatures for the native fishes of the North Fork of the Cache la Poudre River, Colorado (compiled by Carlander 1969). Numbers within boxes show the acclimation temperatures (°C) tested. Yellow shading shows the assumed range of lower incipient lethal temperatures over the range of acclimation temperatures tested. Blue shading shows the fishes for which no data exist.

	Temperature (C°)												
SPECIES	0	1	2	3	4	5	6	7	8	9	10	11	12
White sucker			20	20			25						
Longnose sucker													
Longnose dace													
Creek chub	15	20	22		25								
Bigmouth shiner													
Iowa darter													
Johnny darter													
Common shiner	15	20	20	20	20	20	20	25					
Fathead minnow			20								30		

Lower Incipient Lethal Temperature with Acclimation Temperature

Lacks Data

Table 3. The relationships of growth and temperature for native fishes of the North Fork of the Cache la Poudre River, Colorado. All values were estimates from laboratory studies compiled by Wismer and Christie (1987). Optimum (O) is the temperature at which maximum growth rate occurs. The lower limit (LL) is the point below which no growth is possible. The upper limit (UL) is also shown if it was explicitly stated, rather than assumed. Blue shows the fishes for which data do not exist.

	Temperature (C°)																														
SPECIES	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
White sucker													LL												O	O	O	O		UL	
Longnose sucker																															
Longnose dace		LL																													
Creek chub																															
Bigmouth shiner																															
Iowa darter																															
Johnny darter																															
Common shiner																															
Fathead minnow								LL																		O	O				

LL=Lower Limit

UL=Upper Limit

O=Optimum

Within Tolerable Range

Lacks Data

Table 4. Spawning and hatching as a function of temperature for native fishes of the North Fork of the Cache la Poudre River, Colorado. Yellow shows the temperature range where spawning is known to occur. The symbol H shows known hatching temperatures which may overlap with spawning temperatures. The symbol O stands for the optimum temperature at which spawning events occur most frequently. No data were found for bigmouth shiner.

	Temperature (C°)																														
SPECIES	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
White sucker[1]											O	O			H	H	H														
Longnose sucker[1]						O						H	H	H	H																
Longnose dace[1]															H	H	H														
Creek chub[2]														O	O	O	O	O													
Bigmouth shiner																															
Iowa darter[2]*														H	H	H	H														
Johnny darter[1]														H	H	H	H	H	H	H	H	H	H	H	H						
Common shiner[1]																			O	O	O										
Fathead minnow[1]																									H	H	H				

H=Hatching

O=Optimum Spawning

Within Tolerable Range of Spawning

Lacks Data

[1]Wisman and Christie 1987
[2]Becker 1983
*Simon and Faber 1987

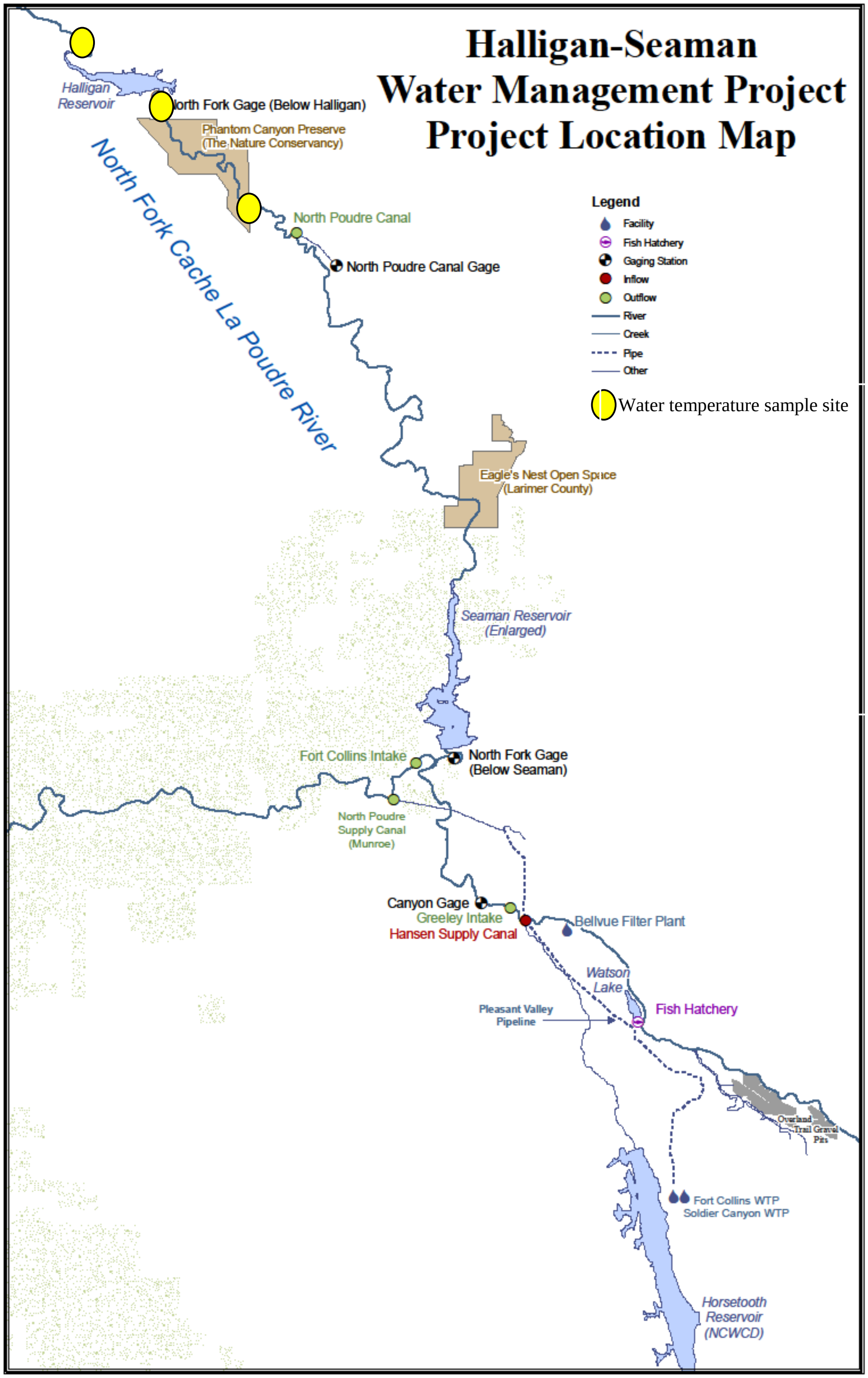

Figure 1. The North Fork Cache la Poudre River and Halligan-Seaman Water Management Project location map with water temperature sampling sites from 2003.

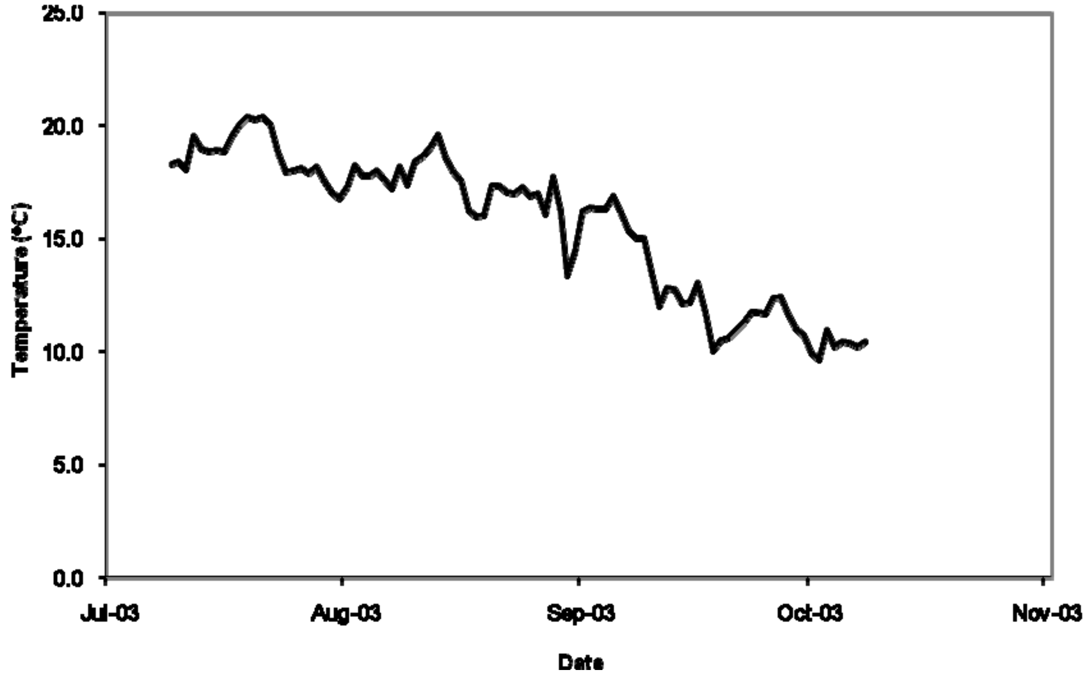

Figure 2. Average daily water temperatures in the North Fork of the Cache la Poudre River above Halligan Reservoir in 2003.

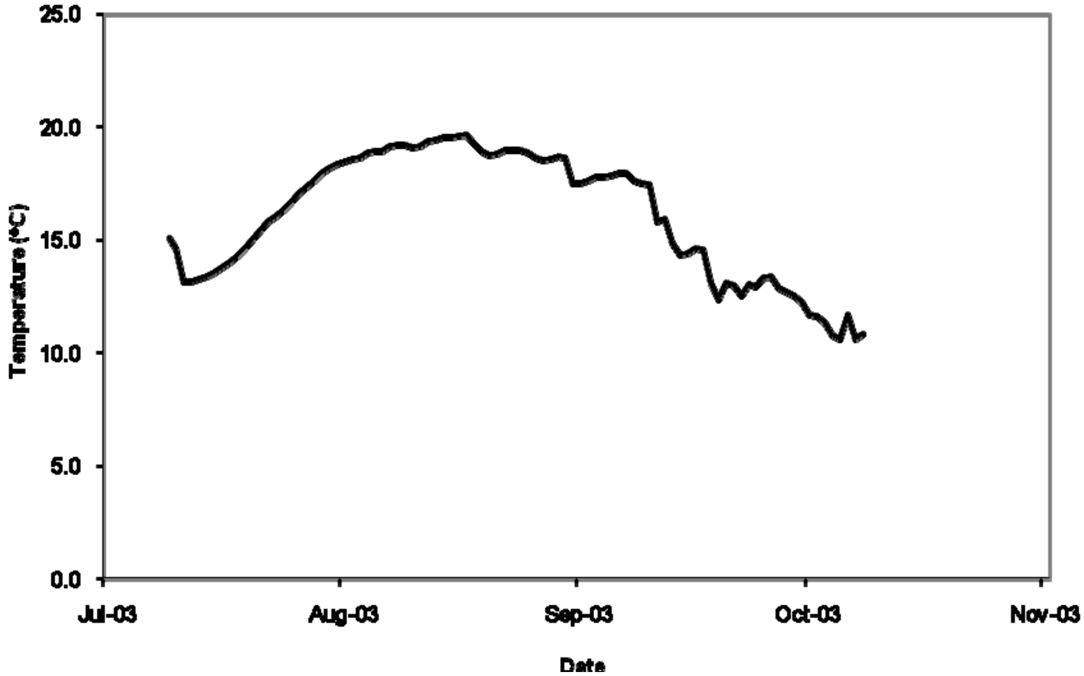

Figure 3. Average daily water temperatures in the North Fork of the Cache la Poudre River below Halligan Reservoir in 2003.

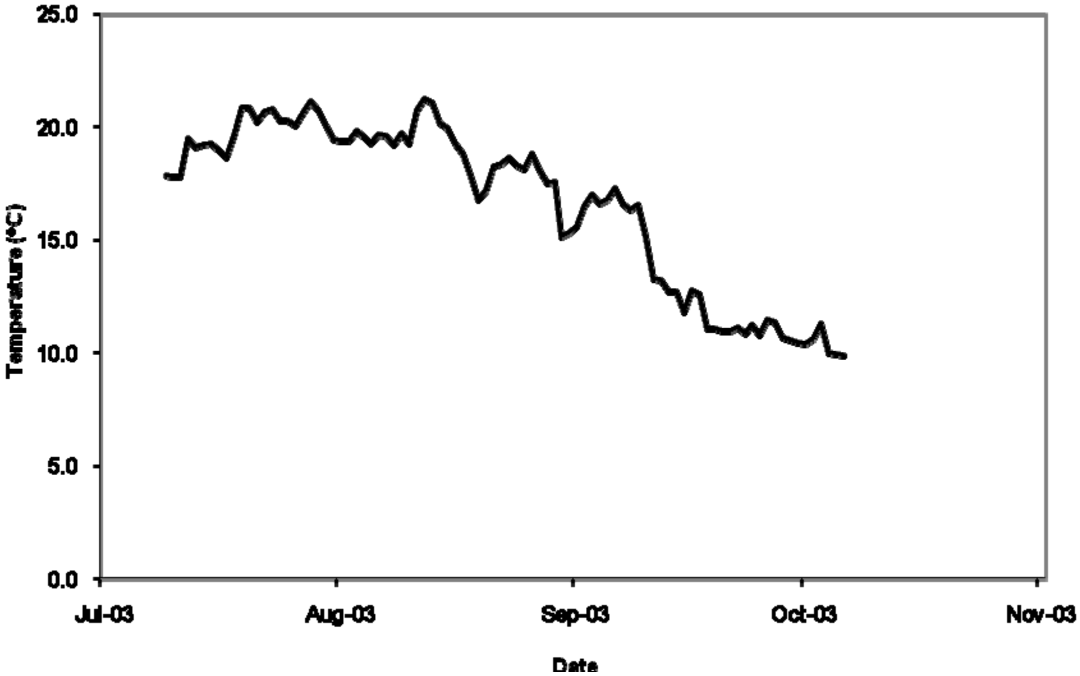

Figure 4. Average daily water temperatures in the North Fork of the Cache la Poudre River below Phantom Canyon in 2003.

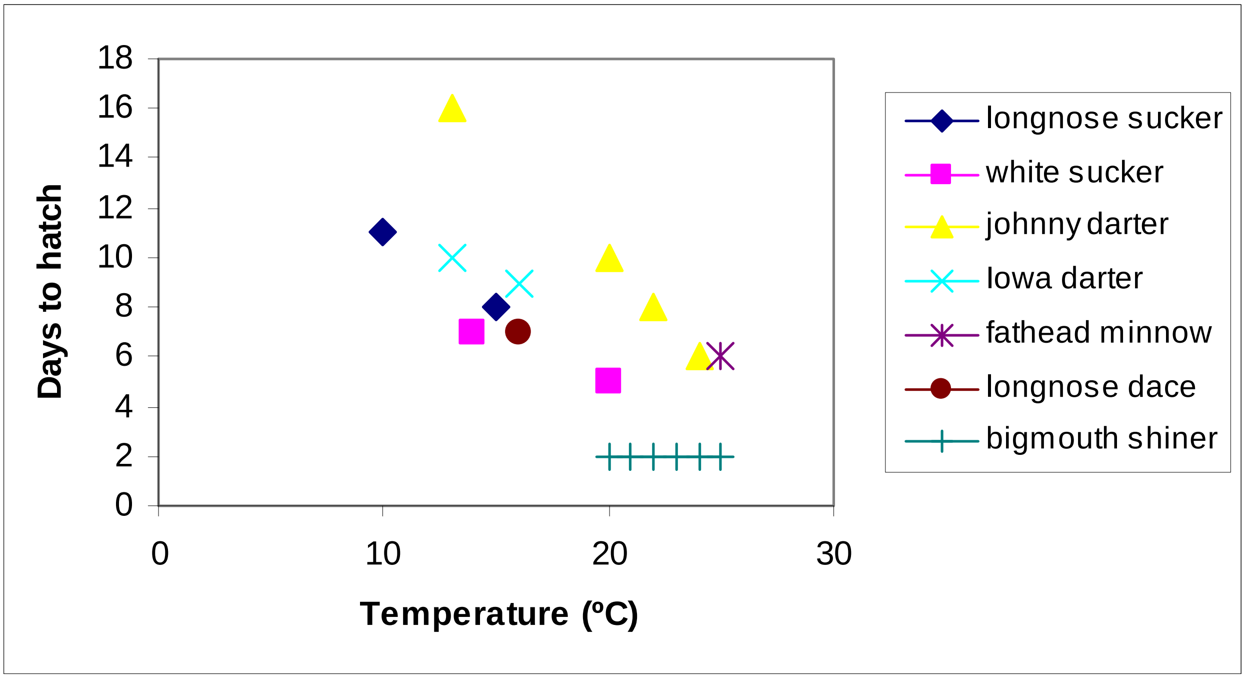

Figure 5. The number of days required for eggs to hatch as a function of water temperature in native fishes found in the North Fork of the Cache la Poudre River, Colorado (data from Carlander 1969, Becker 1983).

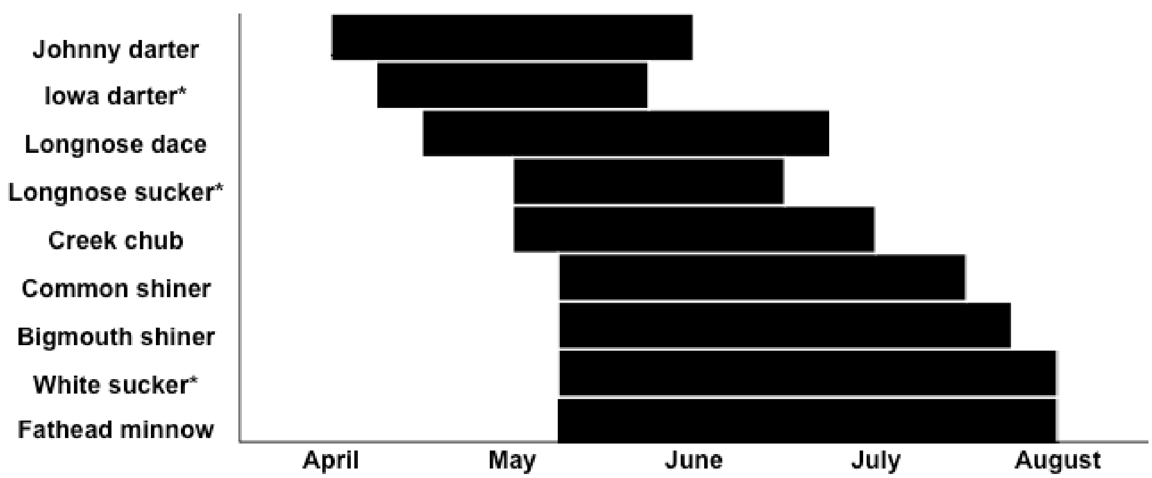

Figure 6. A phenology of spawning periods for the native fishes of the North Fork of the Cache la Poudre River, Colorado (Becker 1983). An asterisk (*) denotes species for which data were available on spawning period from Colorado (Carlander 1969; Faber and Simon 1987).

Appendix I

Life History of Native Fishes in the North Fork Cache la Poudre River

Sucker Family (Catostomidae)

Catostomus catostomus – longnose sucker

Longnose suckers spawn over gravel from mid-April to June in Colorado and when coexisting with white sucker, spawn earlier. This earlier spawning at colder temperatures could explain why longnose sucker are found at higher elevations than white sucker (Li 1968; Carlander 1969). Males mature sexually at age 2 and females at age 3 in Colorado (Carlander 1969). It is probable that longnose suckers would use the reservoirs within the drainage when possible and use the stream mainly for spawning and rearing (Stewart and Watkinson 2004). Longnose sucker are widespread in North America, ranging from Alaska south to Colorado, and east to Maryland and Labrador (Becker 1983). Colorado is the southernmost state within the native range of the longnose sucker.

Catostomus commersoni – white sucker

Spawning occurs over gravel and coarse sand from late-May into August in Colorado (Carlander 1969). White sucker reach sexual maturity at age 2 in males and age 4 in females and have been reported to live to age 17 in Colorado (Carlander 1969; Etnier and Starnes 2001). Natural hybrids of white and longnose suckers are known to occur although different spawning times could act as a preventative mechanism (Stewart and Watkinson 2004). White suckers have one of the most widespread ranges of suckers occurring from Labrador southward to New Mexico and north to the Northwest

Territories and British Columbia. White sucker can also be important energy sources for the ecosystem. They are widespread in Colorado and are tolerant of a wide range of environmental conditions (Becker 1983).

Minnow Family (Cyprinidae)

Luxilus cornutus – common shiner (**a threatened species in Colorado**)

Spawning occurs from late May to mid-July over gravel substrates in Wisconsin and is often associated with nest building species such as creek chub (Becker 1983). This species prefers coarse substrates for nest building and clear waters. The average life span is four years with some individuals reaching age 6 and in one case, age 9. Sexual maturity is reached at age 2 or age 3.

Common shiner are abundant throughout the Great Lakes and Mississippi River basin but also includes a range spanning from Newfoundland to Ontario and south to Kansas. This fish is a glacial relict and Colorado is the westward extent of their distribution. Listed as Threatened species in the state of Colorado, the beginning of a continuing decline of common shiners was documented by Li (1968). Their distribution within the state presumably shifted upstream to cleaner portions of the South Platte basin with more consistent flow, although it has not been collected in the North Fork of the Cache la Poudre since 1959.

Notropis dorsalis – bigmouth shiner

The limited reproductive biology data suggests spawning occurs from late May to early August in the Midwest (Becker 1983). There have been no studies conducted on the spawning habits of this species. Bigmouth shiner prefer gravel and sandy substrates in clear water. Rainfall and possibly flood events are also thought to cue spawning in this species. The average bigmouth shiner lives to age 2 with some reaching age 4 (Carlander 1969; Becker 1983). Sexual maturity is thought to be reached at age 2; it was suggested that bigmouth shiners matured at age-1 in Missouri (Becker 1983).

Bigmouth shiner show disjunct distributions throughout the Great Lakes basin and are found from Minnesota to Missouri within the Mississippi River basin. The Front Range in Colorado and Wyoming is the westward limit of distribution of the bigmouth shiner (Becker 1983). In midwestern U.S. and Canadian streams, bigmouth shiner often can attain high abundance and therefore could act as a significant source of energy and nutrient flow within the fish community (Stewart and Watkinson 2004).

Pimephales promelas – fathead minnow

Fathead minnow spawn on sand from May through August and can spawn multiple times (Carlander 1969). However, in Colorado plains streams they likely spawn any month that water temperatures are suitable (K. Fausch and K. Bestgen, unpublished observations). Maturity appears variable at age 1 to age 2 but has been recorded as early as age 0 as far north as Minnesota (Carlander 1969; Becker 1983). Fish often live to age 2 with few individuals surviving to age 3. The fathead minnow is one of the most abundant and widespread cyprinids in North America. Their range spans from the Maine to California and from Alberta southward to Mexico, because of its wide range of tolerances to various water quality parameters and habitats (Becker 1983).

Rhinichthys cataractae – longnose dace

Longnose dace spawn between May and July throughout their range and can spawn multiple times in a season over coarse sand and gravel substrates (Roberts and Grossman 2001). Fish live to age 4 and mature at age 2 (Becker 1983). This species favors riffles and rocky substrate and is tolerant of a wide range of turbidity and temperature (Stewart and Watkinson 2004). The longnose dace is the most widely distributed cyprinid in North America occurring from the Northwest Territories and the Pacific Northwest in the U.S. east to Labrador, and south to Mexico (Roberts and Grossman 2001).

Semotilus atromaculatus – creek chub

Creek chub spawn from May to July in gravel nests created by males (Becker 1983). Creek chub can reach age 8 although few live past age 4. Maturity is reached at age 1 in females and age 3 in males, which could possibly account for faster growth of males. Creek chub are an efficient predator on invertebrates and small fish, making them an intermediate and top predator in small stream food webs (Stewart and Watkinson 2004). This species prefers cool, and clear to slightly turbid water with coarse gravel and sand substrates. Creek chub are found from Quebec to Florida and westward to Wyoming (Becker 1983).

Darter Family (Percidae)

Etheostoma exile – Iowa darter (**a species of special concern in Colorado**)

This species occurs in cool, clear, slower-moving streams and rivers with aquatic vegetation. It can reach age 4 although most populations are composed mainly of age 1 and age 2 fish (Becker 1983; Woodling 2006; Walford and Bestgen 2008). Adult fish spawn at temperatures from 12º-15ºC from late April to early June in Colorado (Simon and Faber 1987). Adhesive eggs are attached to vegetation and exposed tree roots.

The Iowa darter is thought to be a glacial relict at the western edge of its range, native only to the South Platte River basin in Colorado (Scott and Crossman 1973; Walford and Bestgen 2008). The natural distribution extends from the Great Lakes basin to Alberta and south to Colorado. A Colorado state species of special concern, Li (1968) documented a decline of this fish in the South Platte basin in the 1960's, presumably from habitat degradation.

Etheostoma nigrum – johnny darter

Spawning generally occurs from April through June over sand (Becker 1983). Johnny darters may reach sexual maturity at age 1 with life-spans rarely reaching age 3. Unlike Iowa darters, johnny darters prefer habitat with sandy substrate and no vegetation cover. Johnny darters are habitat generalists which could explain their widespread distribution throughout North America from northern Ontario south to Alabama, west to Colorado and east to North Carolina. Their generalist nature could also explain high abundances in the South Platte River basin of northeast Colorado (Becker 1983; Smith and Fausch 1997).

Appendix 5 – Links to online slideshows on particular technical issues

1. Slides on methods used to estimate impacts to flow on the mainstem Poudre River
https://docs.google.com/present/edit?id=0AcmzlqeCX-sMZGZ0bTl6OHhfMjlmd2dibXZnMg&hl=en

2. Slides on methods used to estimate potential daily variations in flow
https://docs.google.com/present/edit?id=0AcmzlqeCX-sMZGZ0bTl6OHhfMGM4amp4OGN0&hl=en

3. Description of the default preferred alternative
https://docs.google.com/present/edit?id=0AcmzlqeCX-sMZGZ0bTl6OHhfMjFjY2pjN2RnZg&hl=en

4. Description of the unconstrained version of the shared vision model
https://docs.google.com/present/edit?id=0AcmzlqeCX-sMZGZ0bTl6OHhfOTQ1MmpweDdncQ&hl=en