Prescribed Streamflow to Improve Juvenile Steelhead Habitat

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ABSTRACT

Summer baseflows are declining across the Pacific Northwest as a result of earlier spring snowmelt events and decreasing snowpack. These flows are critical to maintain suitable rearing habitat for many salmonid species. In Troy, Idaho, effluent waters from the city waste water treatment plant have been documented to support perennial flow conditions maintaining 6 km of salmonid rearing habitat. Despite low dissolved oxygen concentrations created from instream nitrification of ammonia in the effluent, the highest juvenile steelhead densities in the Potlatch River Basin are found within this effluent dominated stream. The objectives of this study were to monitor water quality conditions as a response of summer baseflow augmentation upstream and downstream of an effluent discharge point, quantify instream losses and create a reservoir management plan to improve salmonid summer rearing conditions. Instream losses were determined per habitat reach as well as the total distance of 10 km between Big Meadow Reservoir, a municipal drinking water supply, and the effluent point. A release of 0.21 cfs maintained 100% habitat connectivity for 10 km and kept water quality conditions upstream of the effluent point in compliance with state standards for cold water biota, a beneficial use of the system. While dissolved oxygen concentrations of effluent receiving waters improved, summer baseflow augmentation is not a feasible solution to keep effluent receiving waters in compliance with state standards. Model results indicate 100% habitat connectivity and a non-effluent dominated system can be achieved through a baseflow augmentation campaign 5 out of 10 years under 50% less reservoir consumption and 7 out of 10 years with 70% reduction of reservoir consumption concurrently maintaining 25% of the reservoir as backup reserves for the city. Model results under downscaled Representative Concentration Pathways (RCP) 4.5 and 8.5 trajections and modest population growth over the next 30 years suggest that 65% reduction in reservoir consumption would permit baseflow augmentation feasibility 5 out of 10 years.

An investigation was pursued to examine the best methods for promoting water conservation. As a result, an example proposal focusing on middle school education was established highlighting the value of teaching science with a holistic systems perspective in an immersive gaming environment (i.e. a video game). This application based approach may improve student motivation to dive into the fundamentals of scientific subjects and promote scientific disciplines as a potential career choice.

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CHAPTER 1: INTRODUCTION

Climate trends and anthropogenic influences are altering many temperate waterways with adverse effects on ecological communities (Poff et al. 2006). In the Inland Pacific Northwest, Mediterranean climate patterns consisting of wet winters and dry summers, dictate spring snowmelt contributions of up to 75% of total runoff (Fritze et al. 2011). Climatic shifts have predicted and documented increased fractions of rain driven precipitation regimes reducing annual snowpack and exacerbating snowmelt events (Knowles et al. 2006). Spring runoff in mountain climates are repeatedly documented to occur earlier in the water year resulting in earlier baseflow reduction and reduced habitat availability for aquatic assemblages (Hamlet et al. 2007). Several studies have shown the long term declines in summer flows across the Pacific Northwest over the past fifty years (Luce and Holden 2009; Leppi et al. 2012). Sohrabi et al. (2012) conducted an extensive trend analysis of historic (1962-2008) climate extremes and associated effects on regional drought throughout Idaho. In general, these analyses indicate decreased temperature ranges, increased daily maximum and minimum temperatures, and decreased frequency of frost days that lead to decreased amounts of snow pack, as well as increased frequency, amount and duration of precipitation in Northern Idaho.

In addition to reductions in baseflow, many streams are affected by more direct human induced alterations such as dam construction and effluent waters. Western states rely on lotic waters for drinking, irrigation and hydropower by capturing spring melt events through the implementation of dams. As these systems are becoming increasingly over allocated, there is a growing trend of effluent dominated and dependent streams with respect to aquatic habitat availability (Sánchez-Murillo et al. 2013; White 2011; Brooks et al. 2006). An effluent-dominated system is described as effluent receiving waters consisting of greater than 50% flow contribution from a waste water treatment plant, whereas an effluent-dependent system is defined as 100% flow contributions derived from the effluent for a prolonged period of time (Sánchez-Murillo et al. 2013).

As low flow conditions persist, the challenge to maintain water quality regulations for cold water biota, a dominant aquatic species in the Pacific Northwest, is becoming more apparent both upstream and downstream of point source pollution. Streamflow and water quality parameters critical for cold water biota, such as Dissolved Oxygen (DO) and water temperature, are directly linked. Factors that dictate DO in streams are both biotic (algae, bacteria and macrophytic growth) and abiotic (flow, light, temperature, and nutrients) (Chapra 2008). Low flow conditions are characterized by a shallow water column that permits greater water temperature fluctuation throughout the day, which in turn result in increased diurnal DO variability. Additionally, the lack of algal photosynthesis at night further reduces nocturnal DO concentrations. Non-oxidized nutrient loads can exacerbate low DO levels during the bacterial conversion process to oxidized forms, blurring the distinction between abiotic and biotic factors. This reduction in DO as a result of nutrient loading is known as a DO sag, of which several factors determine its extent and severity including nutrient concentrations, temperature, pH and discharge from both the effluent and upstream of the effluent point. Many small rural communities have recently been opting to land apply their waste since it is often a cheaper alternative than the necessary upgrades to keep waste water facilities in compliance with state and federal water quality standards. However, the practice of waste water land application in Mediterranean climates such as those in the Pacific Northwest may further reduce critical salmonid rearing habitat availability by further declining the amount the streamflow and wetted habitat during critical rearing months (Sánchez-Murillo et al. 2013).

Steelhead trout (Oncoryhnchus *mykiss*) are listed as threatened under the Endangered Species Act (ESA) in the lower Clearwater and Snake River drainages. Steelhead trout are an anadromous species, referring to their life cycle of rearing in fresh water streams and migrating to the ocean after two to three years. Since the engineering feats for hydropower and flood control of the 20th century, anadromous salmonid populations in the Pacific Northwest are estimated to occupy less than 60% of historic breeding habitat (Peery 2012). In 1996 the National Research Council estimated historic steelhead trout populations 45% extinct, 10% threatened or endangered, 27% are under special concern and in 18% the status is uncertain.

In addition to the negative impacts of dams on salmonids, human induced alterations to the hydrology of rearing habitat (high mountain streams), such as water extraction, timber harvest and cattle grazing are severally impairing the integrity of water quality parameters essential for suitable recruitment amongst the population (Hartson and Kennedy 2012; Richter and Kolmes 2005). Important variables that dictate juvenile salmonid presence and productivity are depth, substrate, cover, competition, temperature and dissolved oxygen (DO) levels (Bjornn and Reiser 1991). Juvenile steelhead have a threshold of 22 degrees Celsius before the metabolism becomes affected and the fish become stressed (Bjornn and Reiser 1991, Richter and Kolmes 2005). Prolonged periods of high temperatures or low dissolved oxygen can restrict growth rates and may result in mortality. High temperatures cause fish to feed more often or endure weight loss due to greater costs of living (Boughton et al. 2007). It is well known that greater growth rates as juveniles translate to higher survival and fecundity rates among species. Biotic factors such as densities and competition dictate growth rates, as well as abiotic factors such as temperature and habitat quality. Every natural system allows for a carrying capacity or a maximum amount of body mass per unit area dependent on the limited availability of energy inputs (i.e. food). In other words, a system can support so many grams of a species, be it small populations of larger individuals or larger populations of smaller individuals. Density-dependent variables such as competition for suitable habitat and food availability, can negatively affect fish production especially in systems with extreme variability in flows (Bjornn and Reiser 1991). Reductions in streamflow has a direct effect on all previously mentioned physical limiting factors including higher water temperatures, embedded substrate composition, low DO levels, and restricted habitat connectivity (Poole and Berman 2001; Poff et al. 2006). Moreover, Hartson and Kennedy (2012) found an order of magnitude difference in juvenile steelhead densities between sites with in-streamflow reductions and unaltered hydro-systems in Lapwai Creek, a tributary of the Lower Clearwater River. Three systems in the lower Clearwater and Snake River basins maintain relatively strong wild steelhead populations; Asotin Creek, WA., Lapwai Creek, ID., and the Potlatch River, ID. These lower drainages contain many similar limitations to juvenile steelhead productivity, specifically low summer flows and high water temperatures (Mayer and Schuck 2004; Bowersox 2006, 2007, 2008; Hartson and Kennedy 2012).

The amount of discharge required to maintain suitable aquatic habitat is a function of downstream losses and water quality criteria thresholds. Environmental flows (“e-flows”), defined as the timing, quality and minimal quantity of water flow required to sustain fresh water ecosystems and the societies that depend on these ecosystems (Poff et al. 2010) is a relatively new concept gaining momentum in recent years (Arthington et al. 2006). E-flows are designed to maintain biologic diversity in streams affected by human alterations. The e-flow concept has evolved since its beginning from minimal flow requirements to represent a natural variable flow regime (Poff et al. 2010). The complexities of designing flow requirements for the wide array of systems influenced by human activities are expensive and require a stream by stream approach with close reference to the organisms present. For example, many dams in the Pacific Northwest release water during spring conditions to encourage adult salmonid upstream migration as well as juvenile salmonid out migration in the fall (Halls and Welcomme 2004). Clean Water Services of Portland, Oregon (Smith and Ory 2005) conducted an extensive socio-economic hydrologic model assessing the feasibility of flow augmentation to improve effluent outfall conditions and even purchased water rights to conduct baseflow augmentation to improve salmonid rearing conditions. Likewise, baseflow augmentation has been pursued in Elgin Creek to improve juvenile salmonid rearing by the city of Surrey, British Columbia (Ham 2006). Several entities have taken a landscape approach to augment baseflow through the management of riparian vegetation (Bohm 2007, Jigour 2008) and few have manipulated storm flow capture to maintain baseflow augmentation campaigns through improved or increased water storage.

The opportunity to augment summer baseflow through the utilization of reservoirs presents a viable option to improve anadromous salmonid rearing habitat. To explore the feasibility of baseflow flow augmentation requires an understanding of the impacts of climatic variability on upstream flows to a reservoir. Without historic observed data, distributed hydrologic modeling (DHM) can be used to capture impacts of climate and management on water supply to a reservoir. Distributed hydrologic modeling (DHM) incorporates landscape scale parameters to predict runoff patterns throughout a catchment. In the Pacific Northwest DHMs range from snowmelt driven, large scale models (Snowmelt Runoff Model SRM and Variable Infiltration Capacity VIC) (Luce et al. 1999; Abdulla et al. 1996) to research based models (Distributed Hydrology Soil Vegetation Model DHSVM) (Wigmosta et al. 1994; Storck et al. 1998) and management models (Soil Moisture Routing SMR Frankenberger et al. 1999; and Water Erosion Prediction Project WEPP (Flanagan and Nearing, 1995). Typically, DHM is utilized to simulate the effects of climate and management on streamflow from a watershed using either using raster or hillslope units. One of the challenges in using models, especially in DHMs is calibration. The Soil Moisture Routing model (SMR) is a management based DHM that predicts soil moisture, surface runoff, evapotranspiration (ET), and interflow throughout a specified catchment (Frankenberger et al. 1999) using readily available data with minimal calibration. It has been used successfully in the Pacific Northwest to mimic surface runoff from agricultural and forest dominated landscapes (Brooks et al. 2007; Djksma et al.2011).

The Potlatch River Basin (PRB) is a focus watershed in the Clearwater Basin because it has one of the most viable populations of wild A-run steelhead trout in the lower Clearwater drainage (Bowersox 2008) and is a good example of steelhead habitat limited by low summer flows. The PRB has undergone severe hydrologic alterations due to early 20th century logging practices and livestock grazing that have impacted channel function, stability and flow dynamics. It has been hypothesized that these actions have exacerbated high flashy peak flows that prevent groundwater recharge and retard summer base flows, limiting the quality and quantity of summer rearing habitat for juvenile steelhead (A. Connor, personal communication). Many streams either completely dry or offer only isolated pools during late summer months. Juvenile steelhead, between the ages of 0 and 2, must survive critical summer months in isolated pools with poor water quality (i.e. warm temperatures, low dissolved oxygen). Limiting factors to steelhead productivity documented in the Potlatch River include: extreme flow variation, high summer water temperatures, lack of riparian habitat, high sediment loads, and low densities of in-stream structures (Bowersox 2008). This is in concurrence to the typical description of flashy systems that maintain baseflow conditions in the thalweg of a scoured stream bottom.

In particular the West Fork Little Bear (WFLB), a tributary of the Potlatch River provides and interested case study where steelhead habitat has been greatly affected by human alterations. A Total Maximum Daily Load (TMDL) was established in 2008 with beneficial uses supporting cold water biota, salmonid spawning and secondary recreation contact in the WFLB. The WFLB was found to have bacteria, nutrient and sediment pollutants (Idaho Dept. of Envir. Quality 2008). During late summer months water temperatures have been documented to be well above state standards of 22 degrees Celsius maximum daily temperature for cold water biota. Excessive nutrient loads from the WWTP cause nitrification to occur in stream, consequently lowering DO levels below the state standard for cold water biota of 6 mg/L for a length of 1.3 km below the effluent point (Sánchez-Murillo 2010). The Environmental Protection Agency (EPA) established that total phosphorus levels of 0.1 mg/l to be a national standard in 1986. The WFLB TMDL has documented NO_3+NO_2 levels as high as 19mg/l, NH_3 levels as high as 11 mg/l, Total Phosphorus concentrations exceeding 5 mg/l and DO levels as low as 2.32 mg/l.

Despite the poor water quality conditions, the effluent produced by the city of Troy Waste Water Treatment Plant (WWTP) provides juvenile salmonids some of the only substantial habitat in an otherwise desiccated system during late summer months in the WFLB (Sanchez-Murillo 2010). Consistently, WFLB has been found to support some of the highest juvenile densities in the Potlatch River basin despite poor water quality parameters created by the effluent (Bowersox 2007, 2008). In 2009- 2010, Sánchez-Murillo (2010) conducted an extensive water quality and ecological assessment on the effluent produced from the WWTP illustrating that the most pressing impairment to be addressed are the low DO levels created by in-stream nitrification occurring as a result of high ammonia concentrations. Utilizing a QUAL2K model, Sanchez-Murillo predicted that an increase of upstream flow as little of 0.05 cfs above the discharge point, roughly equivalent to the magnitude of flow leaving the WWTP, for a one to two month period during the late summer would bring DO levels into compliance with state standards for cold water biota.

The city of Troy will likely be required by the Clean Water Act (CWA) to improve in-stream DO concentrations by reducing nutrient loads. One management option is to upgrade the WWTP to reduce nutrient loads by 50%; the estimated cost is between 1 and 3 million dollars (Sanchez-Murillo 2010). A second option is to apply waste to the surrounding agricultural fields; estimated cost 1 million dollars and loss of juvenile steelhead habitat. The third option is upstream flow augmentation using Big Meadow Creek reservoir, a tributary of the WFLB, located approximately 10 km upstream of the WWTP effluent point.

OBJECTIVES

The overall goal of this study is to investigate the feasibility of releasing water from Big Meadow Creek reservoir during low flow summer months to preserve and improve steelhead habitat both upstream and downstream of the city of Troy waste water treatment plant. The feasibility analysis includes the following major objectives:

1) Quantify in-stream water losses between Big Meadow Reservoir and the city of Troy WWTP.
2) Quantify the effects of baseflow augmentation on water quality and habitat both upstream and downstream of the WWTP effluent point.
3) Evaluate historic and future water supply to the reservoir using Distributed Hydrologic modeling.
4) Assess the current and long term feasibility of baseflow augmentation using reservoir management considering climate variability and water demand.

Additionally, a multi-disciplinary proposal was developed as a part of this study to increase awareness of water resource issues amongst the global population utilizing emerging technologies, Science Education Research and a potential collaboration between University of Idaho Colleges and Washington State University.

STUDY AREA

This study focused on the West Fork Little Bear Creek watershed within the Potlatch river basin in north Idaho, figure 1. Instream loss assessments were specifically on the Big Meadow Creek tributary which consists of a longitudinal geomorphic gradient (figure 2) characterized by three distinct reaches depending on geology, stream slope and vegetation, making up a total of 10 km collectively. The stream ecosystem can be generally lumped into three major land types based on geomorphology and

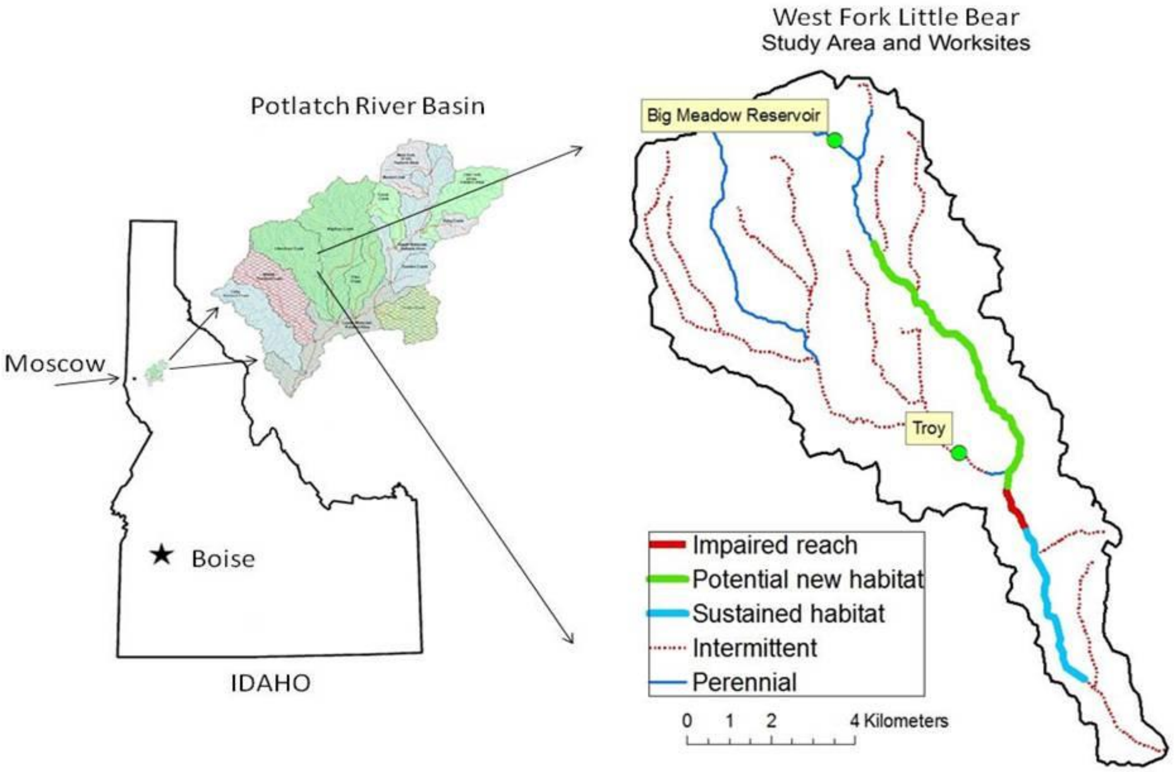


Figure 1: Study area in regional context.

vegetations: Mountain forested reach, Meadow-agricultural dominated reach and a canyon reach (see Figure 2). Each of these land types are described below and photographs can be seen in appendix 1-12.

1) Mountain-forested reach consisted of a granite bedrock composition and granite bolder substrate with average stream slopes ranging from 4-6%. The vegetation primarily consisted of relatively old growth Western Red Cedar and Douglas Fir, 2) Meadow-agricultural reach consisting of loam soils and restrictive clays. Average stream slopes ranged from 0.1-0.5%. Vegetation in the meadow reach is dominated by Reed's Canary Grass and Alder, and 3) Canyon reach geology represented basalt bedrock and cobbles characterized by scoured (basalt bedrock) and depositional areas (basalt cobbles) resulting in large hyporheic storage potential. Average stream slope varied from 1.6-3% and the vegetation consisted primarily of Black Willow, Alder and Ponderosa Pine.

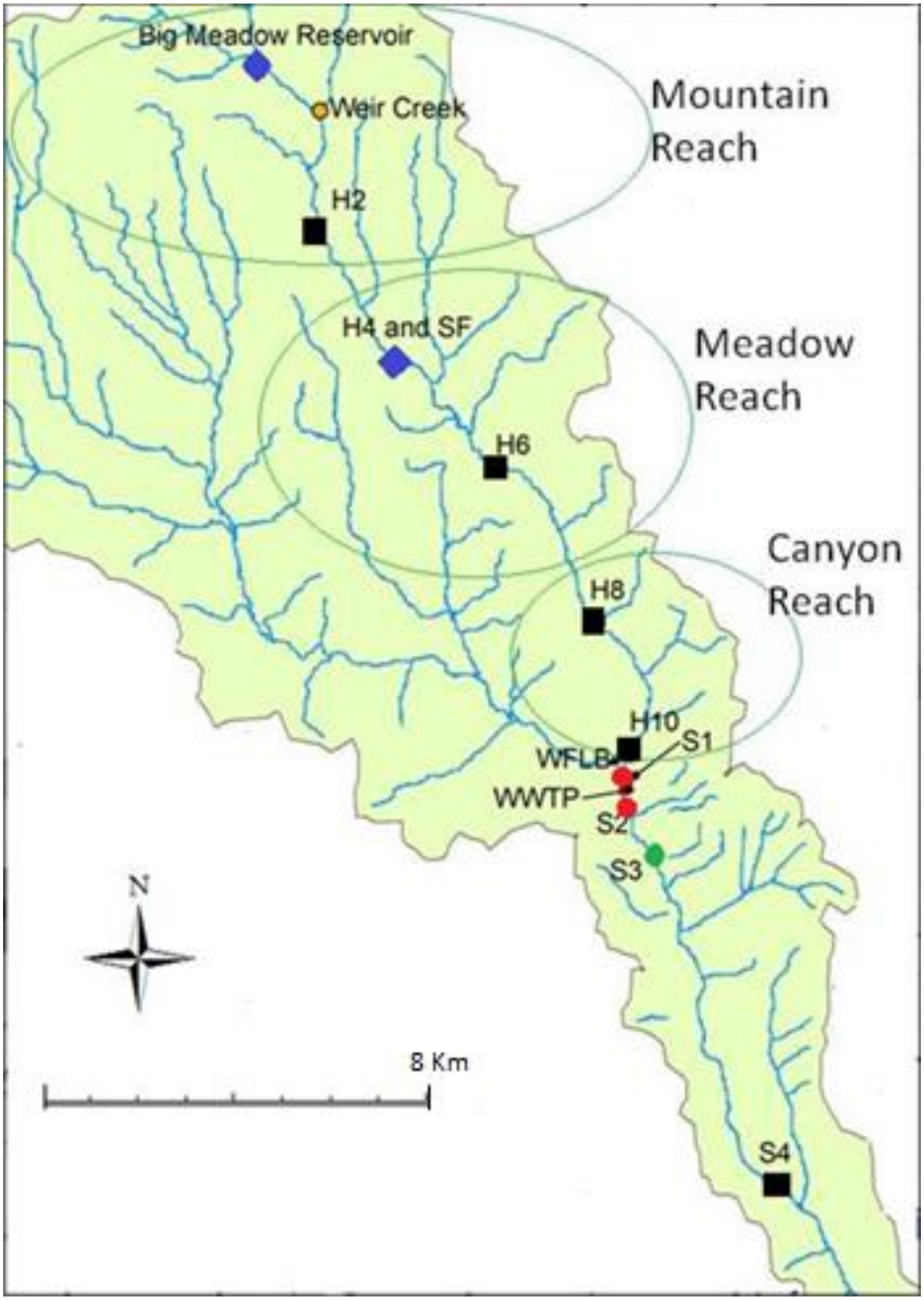


Figure 2: Study sites in the West Fork Little Bear watershed. Blue diamonds represent flow release points, black squares represent continuous flow and weekly water quality sampling sites, green circles represent only water quality monitoring and red circles represent continuous DO and streamflow monitoring stations.

City of Troy water supply and demand

The city Troy, Idaho relies partially on groundwater and surface water to meet its water demand. The Big Meadow Reservoir located on the southeastern slope of Moscow Mountain provides the city much of its drinking water. At full capacity the reservoir is approximately 76 thousand cubic feet (5.7 million Gallons), see appendix 13 and 14 for bathometric surveys and GIS analysis. Big Meadow creek at the inlet of Big Meadow Reservoir provides perennial flow to the reservoir. The city continuously pumps water from the reservoir to a Sand Filter (SF) located approximately 4 km downstream of the reservoir. The pipes between the reservoir have aged and city of Troy officials indicate (D. Haskell, personal communication) that a minimal amount of water must always be pumped through the lines to reduce pressure build up and prevent water losses. The SF has a maximum production capacity of 95 gpm. Water that exceeds the capacity of the SF before infiltration through the sand is released directly back into Big Meadow Creek at location H4 and SF (see figure 2) through a telescoping valve.

In addition to surface water, the city of Troy pumps groundwater from three wells, Twin Creek, Big Meadow and Duthie which can provide up to 120, 60, and 35 gpm, respectively (D. Haskell, personal communication). The wells pump water from a confined aquifer located within Wanapum and Grande Ronde Basalt flows bound by granitic bedrock and interlaced with horizontal alluvium (prehistoric stream channels).

Water Demand

Historic records provided by the City of Troy indicate that the majority of water demand is satisfied by the Big Meadow Creek reservoir. Sixteen years of water consumption data was available for analysis including the source from which the water was derived. Figure 3 illustrates the amount of water derived from each source accumulated throughout the calendar year. Since the Twin Creek well was drilled in 2010 the water demand from the reservoir has decreased. Figure 4 represents average monthly demand from each source prior to the installation of Twin Creek well capable of producing 95 gpm. Figure 5 represents 2010 through 2013 average monthly demand for each source. As a part of this study the city of Troy agreed to reduce reservoir consumption and rely on the groundwater wells during the 2012 and 2013 summer periods. Average reservoir use during July through September decreased 66 percent after the implementation of Twin Creek Well; however during the study period aquifer consumption could not adequately support total demand (D. Haskell, personal communication), which combined with exploratory releases, limited the extent of flow augmentation release periods. A review of the historic well pumping data indicated that the city wells could potentially meet all of the current water demand during late summer periods without relying on the reservoir for drinking water, see Figure 6. The maximum well water supply curve in Figure 6 was generated by identifying the maximum water use for each specific well during the respective month.

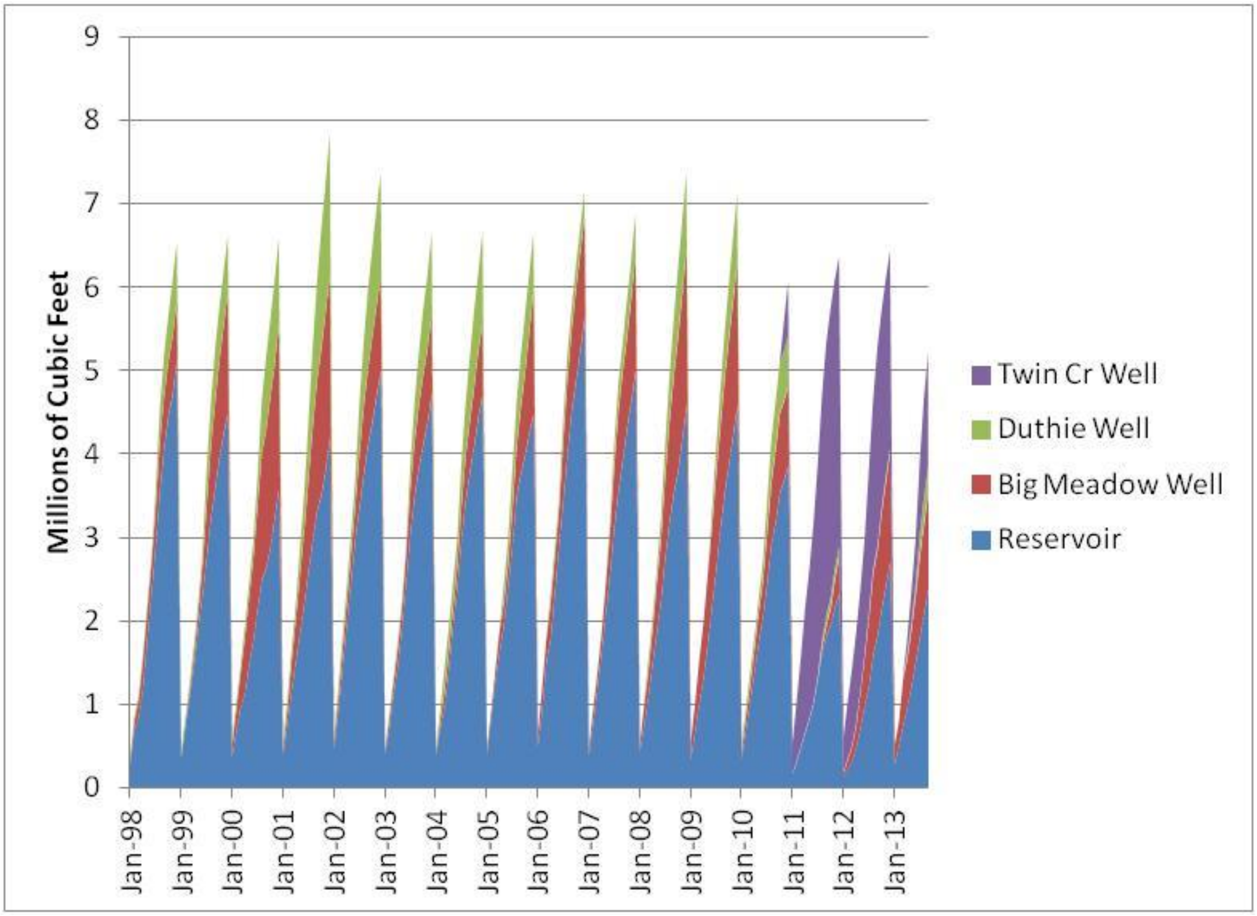


Figure 3: Accumulated water demand from the city of Troy wells and Big Meadow Creek reservoir.

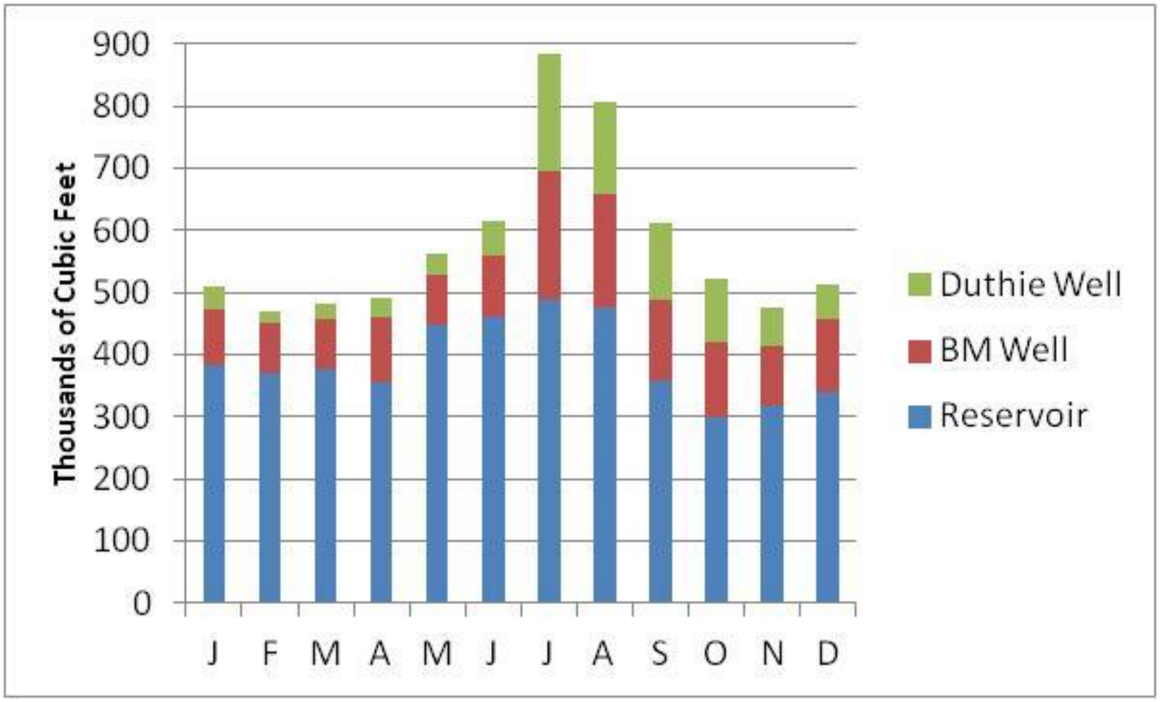


Figure 4: Average monthly demand from City of Troy drinking water sources before the installation of Twin Creek Well for years 1998 through 2010.

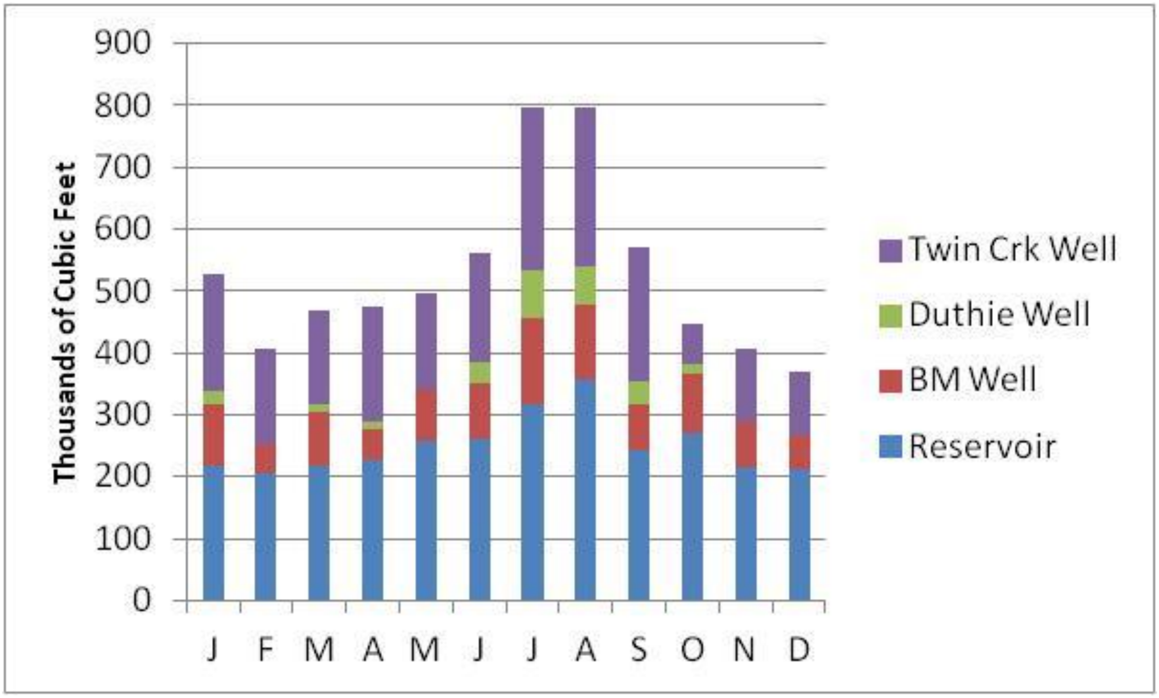


Figure 5: Average monthly demand from each water source after installation of Twin Creek Well for years 2010 through 2013.

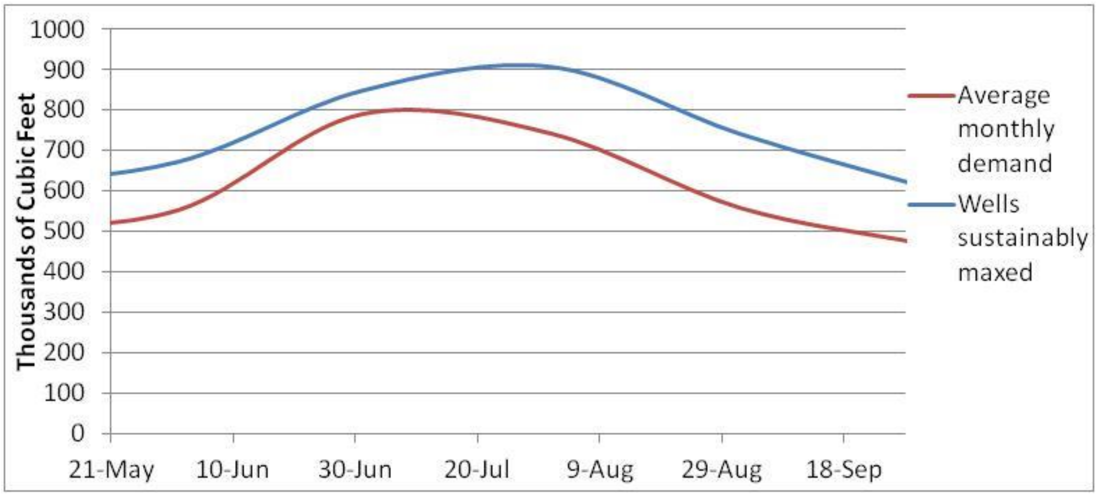


Figure 6: Sustainable flow rates summed for each well (taken from observed values) compared with a 12 year average of total consumption demand.

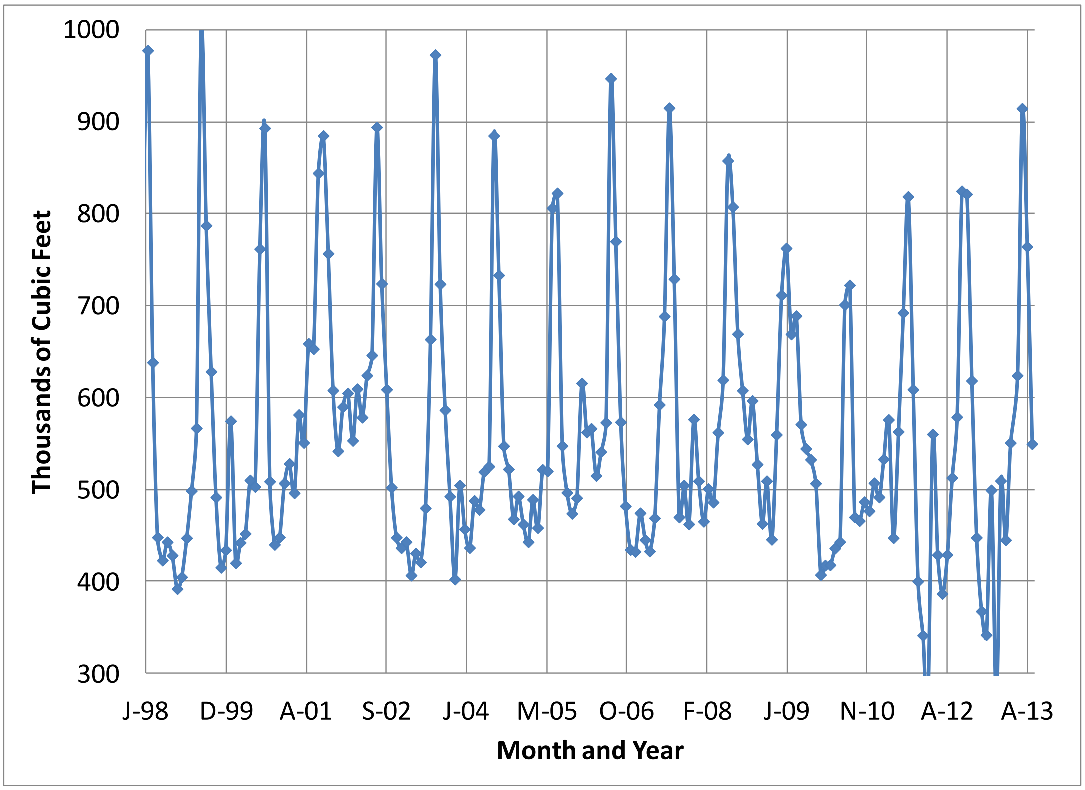


Figure 7: Monthly water demand.

Total water consumption in summer months is nearly double the demand during winter (figure 7). Interestingly, no agricultural irrigation occurs in the area leaving industrial (e.g. cedar mill), municipal, and residential use (e.g. lawn watering) as the primary consumers of water.

CHAPTER 2: METHODS

The overall feasibility and the impacts of late summer flow augmentation required water quantity and water quality monitoring, hydrologic modeling of the upstream watershed and the reservoir response, as well as an assessment of the long term probability of success in both current and future scenarios. The approaches for each of these major tasks are described below.

WATER QUANTITY AND QAULITY MONITORING

Both streamflow and water quality were monitored throughout Big Meadow creek a distance of 10 km between the reservoir and the confluence with the western tributary of West Fork of Little Bear (WFLB) creek. The western tributary of the WFLB flows directly through the city of Troy and functioned as a control stream in this study since it did not receive upstream flow augmentation. In addition a total of 6 km of stream were monitored below the confluence point. This includes the effluent directly from the WWTP and 200 meter downstream of the effluent point (figure 2). Pressure sensors were installed every 2 km from the reservoir down to the confluence on WFLB as well as approximately 200 m downstream of this confluence (S1) and recorded fifteen minute average water depth at each location. S1 was equipped with a Campbell Scientific CR10X data logger measuring DO levels (using Campbell Scientific Model # CS511) every fifteen minutes. Weekly manual DO and water temperature were obtained using a YSI ProODO probe, and EC and pH readings were collected using a Hannah Instrument model #991300 hand held sensor at each site. Continuous streamflow was monitored at 12 locations through rating curves which relate depth of water recorded by the pressure sensors to stream discharge. Rating curves were established at each monitoring location based on a minimum of 10 measurements. Appendix 15 through 21 expresses the established rating curves, power fit and average error associated with discharges less than, or equal to 0.3 cfs for each worksite. When water depths exceeded 0.2 feet, discharge was calculated using the velocity area method (Herschy 2008). Stream velocity was measured using a Marsh-McBirney Incorporated Flo-Mate Model 2000 current meter. When water depth dropped below 0.2 feet, the minimum limit of the Flo-Mate, the slug salt injection method was used to establish discharge measurements (Day 1977, Moore 2003, Tazioli 2011). Manual electrical conductivity measurements in 2012 and automated EC measurements in 2013 were used to monitor changes in salt concentration during each measurement which then were used to calculate flow (see Tazioli 2011). A six inch Parshall flume equipped with a pressure sensor was used to measure discharge directly below the reservoir. Likewise, a two inch Parshall flume was used to measure continuous discharge directly below the sand filter. Hobo water temperature data loggers were installed at every location, recording average water temperature every 30 minutes.

Monitoring Downstream of the WWTP

Total effluent discharge from the WWTP and total discharge in the creek were measured at 200 m, 1.3 km, and 6 km distances downstream of the effluent discharge point (points s2, s3, and s4 respectively). Discharge point (S2), and a location approximately 6 km below the discharge point (S4) was measured using continuously recording pressure sensors (see figure 2). The effluent discharge point was equipped with a 2" H flume. Campbell Scientific CR10X data loggers measuring DO levels (using Campbell Scientific Model # CS511) every fifteen minutes were installed at S2 and 1.3 km below the effluent point (S3). Additionally, weekly DO, water temperature, EC and pH were measured at each location. Weekly water samples taken from the WWTP and S2 were analyzed for Nitrite-Nitrate, Ammonia and Total Phosphorous. Samples were collected in polyethylene bottles, preserved with sulfuric acid and frozen to prevent nitrification of ammonia. Samples were sent to the University of Idaho Analytical Science Laboratory with detection limits of 0.01 mg/l for Total Phosphorus and 0.1 mg/l for Nitrite-Nitrate and Ammonia. Ammonia toxicity levels for early-life stages of salmonids were determined following USEPA (1999).

Baseflow Augmentation

Instream water losses along Big Meadow Creek were quantified using streamflow measurements at each of the gauging stations during late summer controlled release experiments. The goals of these experiments were to release water until steady-state, equilibrium conditions were achieved at each monitoring location and document water quality response. Baseflow augmentation was conducted from two separate locations (Big Meadow Reservoir and the Slow Sand Filter, see figure 2) to explore all feasible augmentation release scenarios. Five flow augmentation campaigns were conducted over the two monitoring seasons, four directly from the reservoir and one from the sand filter. Due to inconsistent sand filter influence during 2013 reservoir augmentation, the system was divided such that the sand filter was considered the primary release point to determine subsequent downstream losses. Equilibrium conditions during each augmentation event were defined by plateaus in the hydrograph at each monitoring location.

Instream Loss Analysis

Total streamflow losses were assessed between the reservoir and a distance 10 km downstream of the reservoir (i.e. approximately 500 meters upstream of the WWTP). Total water losses were quantified during flow release experiments throughout each study reach. Water losses were determined by calculating the difference in streamflow through each reach.

Several techniques were used to quantify the water loss flow paths within each geomorphic stream reach. Water losses through any particular stream reach can occur through evaporation, transpiration, and deep recharge/percolation to groundwater systems. It is assumed that daytime declines in streamflow occur due to ET (Gribovszki et al. 2010).A similar approach of Bond et al. (2002) was used to estimate bulk evapotranspiration (ET) losses at each stream monitoring station based on diurnal stream flow fluctuations. The volume of water lost to ET can be calculated by the difference in daily maximum flows and the diurnal decline in streamflow, see Figure 8. Losses of streamflow by percolation to groundwater systems were estimated using a similar analysis of the diurnal fluctuations. Groundwater losses per reach were calculated as the difference between maximum and minimum streamflow between upstream and downstream stream monitoring stations during steady-state conditions (figure 9).

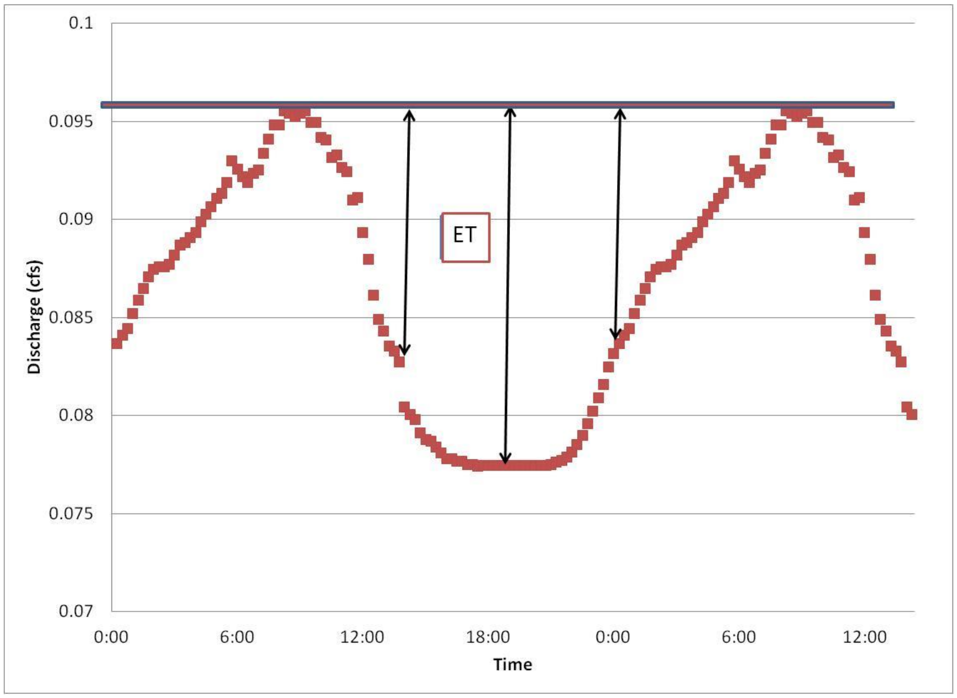


Figure 8: Conceptual diagram for quantifying ET.

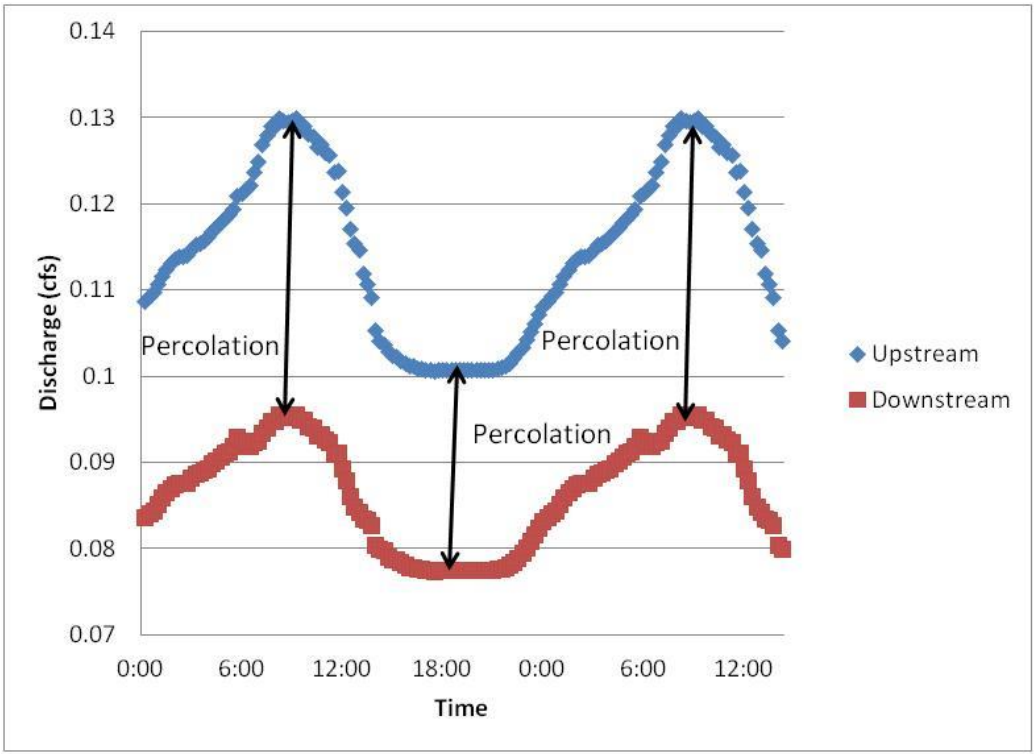


Figure 9: Conceptual diagram of quantifying percolation.

Reach scale evaporative water losses were determined following the approach of Gibson et al. (2008) through analysis of $\delta^{18}O$ and δ^2H signals ratio (δ), in stream water samples; where $\delta^{18}O=O^{18}/O^{16}$ and $\delta^2H= H^2/H^1$ respectively. For the purposes of quantifying evaporation, only $\delta^{18}O$ values were utilized in our analysis. As water evaporates lighter H^1 and O^{16} molecules are lost to vapor and heavier H^2 and O^{18} water molecules remain in solution resulting in an enriched or more positive $\delta^{18}O$ and δ^2H , where H^1 and O^{16} is derived from a designated standard Vienna Standard Mean Ocean Water 2 (VSMOW2). The amount of water that evaporates is directly proportional to the change in enrichment relative to the input $\delta^{18}O$.

Automated ISCO and Sigma samplers were placed at the top and bottom of each reach at continuous flow monitoring stations. The mountain segment lacked pressure transducers in 2013, therefore evening and early morning flow measurements were conducted to capture diel streamflow fluctuations using the salt injection method. Automated samples were taken every hour for 24 hours and replicated two days later under the same released flow. Samples were preserved with a ¼ inch of mineral oil to prevent further evaporation. Stable isotope analysis was conducted at the University of Idaho Stable Isotope Laboratory using a Cavity Ring Down Spectroscopy system (Picarro, CA).

The Craig-Gordon model (Equation 1) was performed using on site water temperature, air temperature and relative humidity data to establish percentages of evaporative losses per geomorphic reach. Atmospheric vapor isotopic signatures for δ^{18}O, a needed parameter of the model, were estimated using the approach taken by Horita and Wesolowski (1994) (Equation 4). For further investigation of evaporative calculations see Moravec 2010 and Gibson 2007.

$$\mathrm{E/I_{18O}} = \frac{(1-RH\%)}{RH\%} * \left(\frac{\delta out-\delta in}{D^{*}-\delta \mathrm{out}}\right) * 100 \tag{1}$$

In this relationship $\mathrm{E/I_{18O}}$ is the fraction of total water which has evaporated over a specific stream reach*,* *RH* is the relative humidity, *δin and δout* are Oxygen 18 samples from the upstream and downstream location respectively. *D** defines the limiting isotopic enrichment (the amount of enrichment if all the water evaporated) using RH and the isotopic signal of vapor determined by Equation 2:

$$D^{*} = \frac{RH\% * eK + e^{*}}{RH\% - e^{*}} \tag{2}$$

Where *eK* represents the kinetic separation factors attributed to stream impacts on vapor moisture composition and molecular diffusion coefficients taken from Gibson 2008:

$$eK = Ck\theta(1 - RH) \tag{3}$$

For open-water bodies *Ck* is approximately 14.3% and ϑ is a weighting factor of 1 for small streams. In equation 2, *e**represents the average $\delta^{18}O$ signal of atmospheric vapor estimated from the Horita Equation:

$$e^{*} = -7.685 + 6.7123\left(\frac{10^{3}}{T}\right) - 1.6664\left(\frac{10^{6}}{T^{2}}\right) + 0.35041\left(\frac{10^{9}}{T^{3}}\right) \tag{4}$$

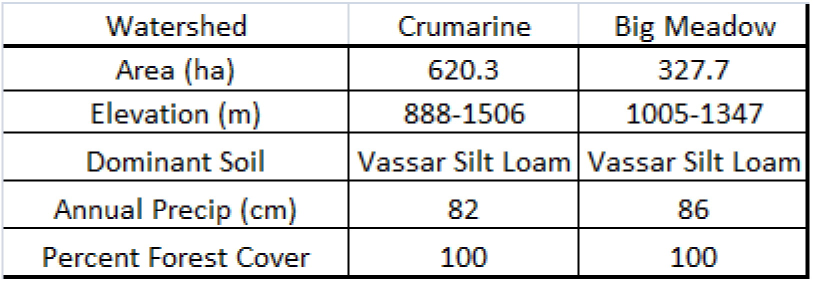
The inability to obtain real time atmospheric vapor signal is a potential limitation, yet the results offer insights to potential evaporative drivers with respect to habitat reach classification.

MODELING

Assessing the feasibility of flow augmentation using Big Meadow creek reservoir required an understanding of upstream contributions to the reservoir. Without observed streamflow data in the watershed a distributed hydrologic model was used to predict upstream flows based on historic and future climate data. The model was developed and the accuracy assessed using historic data from the

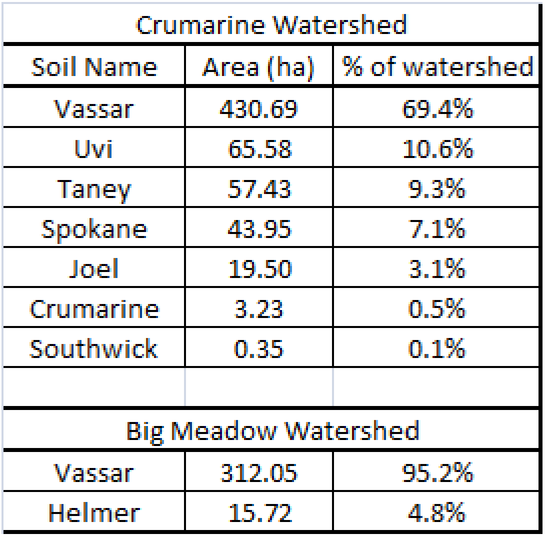
Crumarine creek watershed located approximately 10 km west of Big Meadow creek, see Figure 10. Crumarine creek has very similar characteristics to the watershed draining to the Big Meadow creek reservoir, see Table 1. With confidence in the reliability of the model in Crumarine creek, the model was then applied to the Big Meadow creek watershed. The model used in this study was the Soil Moisture Routing (SMR) model. SMR is a distributed hydrologic model originally developed at Cornell University (Frankenberger et al. 1999) and modified for the Palouse region (Brooks et al. 2007; Dijksma et al. 2011). The model operates in the Geographical Resources Analysis Support System (GRASS) a raster and vector Geographic Information System (GIS) program integrating data visualization and image processing subsystems. The model simulates a daily water balance for each grid cell in a (30 x 30 m) raster map based on soils, topography, vegetation, and climate information. Soil properties are acquired from the Soil Survey Geographic Database (SSURGO) and include hydraulic conductivity, depth to restrictive layer, type of restrictive layer, saturated moisture content, field capacity, and percent rock fragment. This study uses a modified version of the Brooks et al. (2007) SMR model in a forested catchment incorporating a two layered soil characterization based on SSURGO soil data. Climate inputs for the model include precipitation, potential evapotranspiration and daily maximum, minimum and average air temperatures.

Table 1: Paired watershed characteristics.



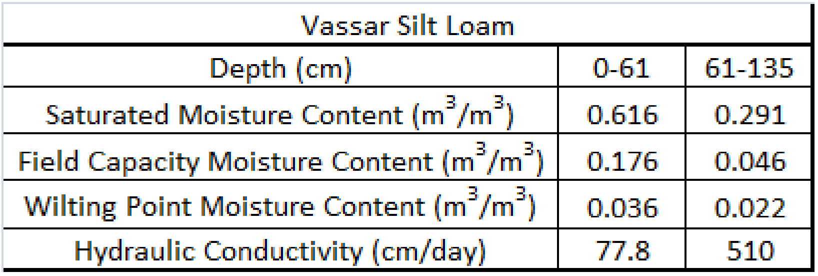
Watershed	Crumarine	Big Meadow
Area (ha)	620.3	327.7
Elevation (m)	888-1506	1005-1347
Dominant Soil	Vassar Silt Loam	Vassar Silt Loam
Annual Precip (cm)	82	86
Percent Forest Cover	100	100

Table 2: Watershed soil classification, area and percent abundance.



Crumarine Watershed		
Soil Name	Area (ha)	% of watershed
Vassar	430.69	69.4%
Uvi	65.58	10.6%
Taney	57.43	9.3%
Spokane	43.95	7.1%
Joel	19.50	3.1%
Crumarine	3.23	0.5%
Southwick	0.35	0.1%
Big Meadow Watershed		
Vassar	312.05	95.2%
Helmer	15.72	4.8%

Table 3: Vassar Silt Loam characteristics.



Vassar Silt Loam		
Depth (cm)	0-61	61-135
Saturated Moisture Content (m^3/m^3)	0.616	0.291
Field Capacity Moisture Content (m^3/m^3)	0.176	0.046
Wilting Point Moisture Content (m^3/m^3)	0.036	0.022
Hydraulic Conductivity (cm/day)	77.8	510

The accuracy of the model was assessed using daily historic flows collected at Crumarine creek gauging station between 1956-1983 and 2011-2013 as well as snow water equivalent data collected at the Moscow Mountain SNOTEL site between 2000 and 2013. Note: monitoring at the Crumarine creek gauging station was re-initiated in 2011 through a separate funded project.

The accuracy of the SMR model was first assessed using the 2011-2013 streamflow and SWE data. Input for the model included 30 m resolution soils, topography, and vegetative cover data. Precipitation and temperature were distributed spatially using weather data collected at the University of Idaho co-op weather station (mean elevation above sea level 810.7 m) and the Moscow Mountain SNOTEL station (1432 meters elevation). It was assumed precipitation and temperature varied linearly with elevation between each of these stations following a lapse rate approach. Two approaches were used to establish these lapse rates. The first varied the lapse rates each day based on daily observed precipitation and temperature collected at each station, this is referred to as the Dynamic Lapse Rate (DLR) model. The second approach fixed the precipitation and temperature lapse rate based on long term annual average observed precipitation and temperature data at each of these stations and is referred to as the Static Lapse Rate (SLR) model. The advantage of the DLR model would be to better capture variability in precipitation from individual storms. For example some storms may hit the lower station and not the upper station. The limitation of the DLR approach for long comparisons with streamflow at Crumarine creek was that daily data does not exist prior to 2000 at the Moscow SNOTEL and therefore cannot be used to simulate historic conditions. Therefore the DLR model was used to provide confidence that the model was fundamentally sound while the SLR model was necessary to assess the performance of the model using historic Crumarine creek data.

Each soil type in the watershed was aggregated into two soil layers based on soil characteristics for each soil horizon. In general the distinction between soil layers was defined by rock content with upper soil horizons (typically 0-50 cm) having fewer rocks than lower soil horizons (50-150 cm). These forest soils are often described as ‘ash capped’ soils with a silt loam upper horizon and a weathered granite/metamorphic subsoil. Each soil type and layer were designated specified saturated moisture content, field capacity moisture content, wilting point moisture content and hydraulic conductivity taken from SSURGO soils data (table 2 and table 3).

The degree day method was used to simulate snowmelt similar to the approach taken by Djksma et al. (2011). The melt coefficient K factor (cm/C/day) and the base temperature (T-base (C)) were determined by minimizing the sum of squared errors between observed SWE at the Moscow Mountain SNOTEL and simulated daily snow water equivalents (SWE) using the solver optimization algorithm in excel. The model distinguishes the proportion of total precipitation which is rain or snow based on maximum and minimum temperature thresholds fixed in the model at 2.5 and 0.0 degrees Celsius similar to previous studies (Auer 1974, Dai 2008, Kienzle 2008, and Lundquist et al. 2008).

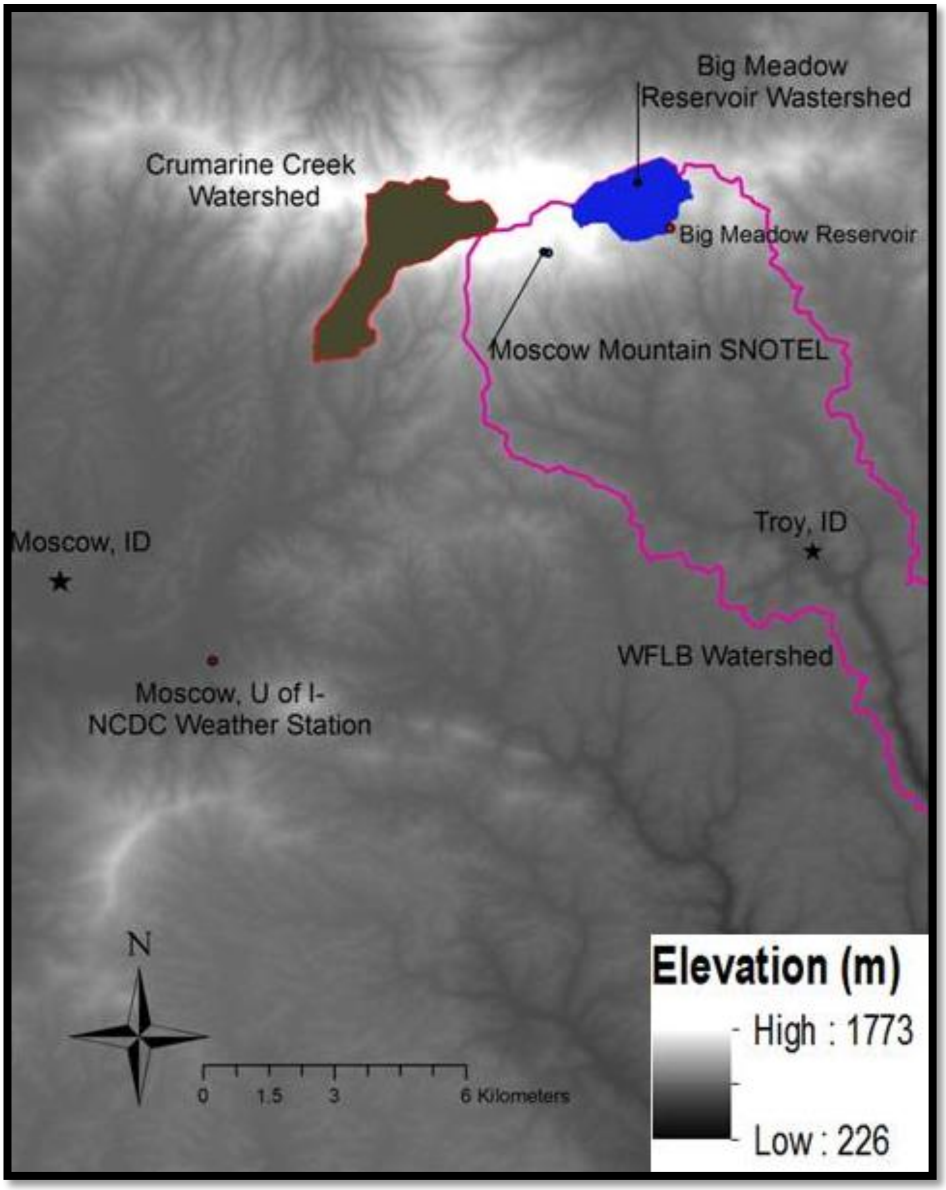


Figure 10: Modeled watersheds (solid color) and weather stations.

BASEFLOW AUGMENTATION FEASIBILITY ANALYSIS

The feasibility of flow augmentation as a viable option for maintaining perennial flow in Big Meadow creek and preserving acceptable water quality downstream of the city of Troy WWTP was quantified in terms of risk and return period. The feasibility of reservoir augmentation was based on the following primary factors: 1.) availability of upstream flow to the reservoir, 2.) demand for water from the reservoir from the city of Troy, 3.) loss of streamflow between the release point and the WWTP, and 4.) the size of the reservoir. The first was determined by simulating reservoir levels and flow release based on simulated upstream contributions from the SMR model and monthly average water demand of the reservoir from historic records. The feasibility of a particular scenario was described in terms of risk and return period.

Climate scenarios

The SMR model was used to estimate historic and future changes in the upstream supply of water for two climate scenarios. The two scenarios are taken from downscaled (4 km) Representative Concentration Pathways (RCP) projections 4.5 and 8.5 from Multivariate Adaptive Constructed Analogs (MACA) (Abatzoglou and Brown 2012). These scenarios represent two commonly used radiative forcing values, or radiant energy received and reflected into space (W/m^2) by the year 2100. The values 4.5 and 8.5 represent the associated percent increase in W/m^2, where 8.5 represent's the current global radiative forcing trajectories and 4.5 represents a stabilizing scenario.

Water demand/consumption scenarios

Since the feasibility of the flow augmentation is closely related to the consumptive demand for the water in the reservoir, three water demand scenarios were considered. The first assumed no change in the water demand for the reservoir water according to city records before the twin creek well was installed (i.e. pre-2010). This scenario is referred to as *historic demand*. The second scenario considered was a 50% reduction in demand from the reservoir relative to the historic demand scenario referred to as *50% less demand*. This was roughly equivalent to the decline in water demand for the reservoir water since the Twin Creek well was installed. A third scenario was *60% less reservoir* demand and referred to as *60% less demand.*

Reservoir Routing

A simple daily mass balance model was developed to calculate total streamflow downstream of the reservoir (Q_{out}), see equation 6,

$$Q_{out} = Q_{in} - Q_d - (S_t - S_{t-1})/t \qquad (6)$$

where: Q_{in} = upstream inflow to the reservoir

Q_d = flow diverted to the city of Troy for consumption

S_t = Water storage in the reservoir at time t

S_{t-1} = Water storage in the reservoir at time t-1

t = time step of the model (daily)

The total downstream flow is composed of both water released for flow augmentation (Q_a) and excess water released (Q_e) when the reservoir capacity (S_{max}) is exceeded, see equations (7) and (8).

$$Q_{out} = Q_a - Q_e \tag{7}$$

where

$$Q_e = \max(0, (S_t - S_{max})/t - Q_a) \tag{8}$$

For emergencies when the city of Troy may need some late summer water from the reservoir (e.g. well pumps break or need serviced), a minimum storage amount in the reservoir (S_{min}) was always maintained which limited Q_a based equation 9.

$$(S_t - S_{min}) / t - Q_a > 0 \tag{9}$$

This simple mass balance approached was used to track water storage in the reservoir for a wide range of various water demand, supply, and consumption scenarios.

Exceedance flows

The effect of various climate and water demand scenarios on the overall availability of water for downstream flow augmentation was quantified using the concept of exceedance flows. Percent exceedance flows represent the relative frequency a given flow will be exceeded (i.e. a 70% exceedance flow will be surpassed 70% of the time, or 7 out of 10 years). The exceedance percentage for a particular flow rate is calculated by ranking the discharge for each specific day in a year for all years in an entire flow record and dividing by the total number of years in the record plus 1, see equation 10 below (Chow 1964).

$$Exceedance\ Percentage = \frac{Rank}{(n+1)} \tag{10}$$

CHAPTER 3: RESULTS AND DISCUSSION

INSTREAM LOSSES

Equilibrium conditions during baseflow augmentation experiments express a very strong relationship between augmented discharge and subsequent down streamflow. Figure 11 clearly shows this relationship when releasing from the reservoir, that a flow release of 0.21 cfs will maintain 100% wetted connectivity between the release point and H10, the most downstream monitoring location before the confluence with the WFLB.

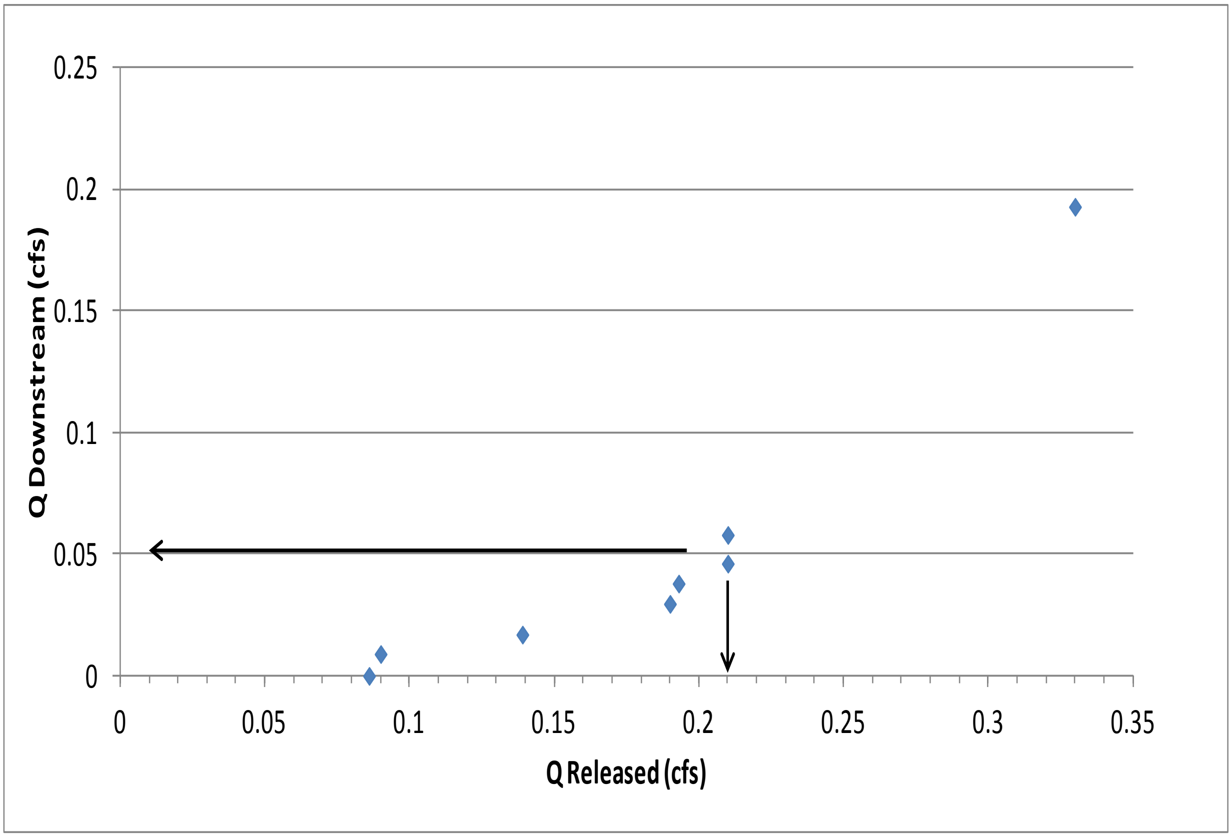


Figure 11: Released discharges from the reservoir (x-axis) and the amount of discharge remaining in the stream at H10 (y-axis).

Total losses between the reservoir and H10 are approximately 0.14 cfs on average. For example, in 2012, a release of 0.19 cfs from August 9th through August 13th resulted in a 0.14 cfs loss of streamflow at H10. Likewise, a release of 0.34 cfs from August 13th through August 15th resulted in a 0.13 cfs reduction in streamflow between the reservoir and H10 (figure 12). Steady-state conditions at H10 during the 0.34 cfs flow augmentation campaign did not persist long enough to ensure that equilibrium was achieved due to pressure to reduce baseflow augmentation from the City. However, a reservoir release from August 12th to August 15th in 2013 confirmed equivalent instream losses (figure 13) during a 0.21 cfs release. Delineated flow loss values (i.e. values of ET, percolation and evaporation) when releasing from the reservoir can be found in appendix 32. Figure 11 represents estimated steady-state conditions when augmentation occurred directly from the reservoir and expresses the amount of flow reaching H10 at various augmentation campaigns. There is a strong exponential relationship that can be used to quantify stream losses and predict the amount of downstream flow.

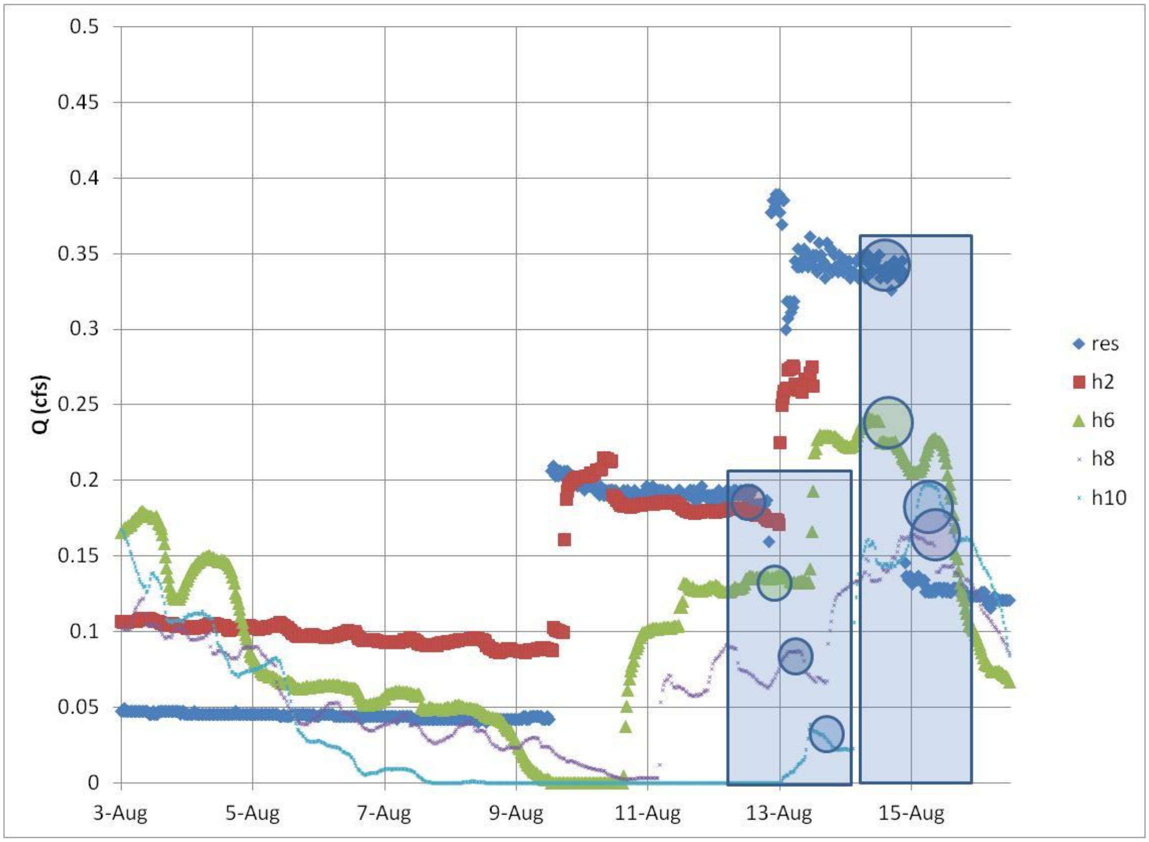


Figure 12: 2012 longitudinal hydrographs at incremental controlled releases where colored circles represent flows at equilibrium for each release and the rectangles represent the general time period of equilibrium.

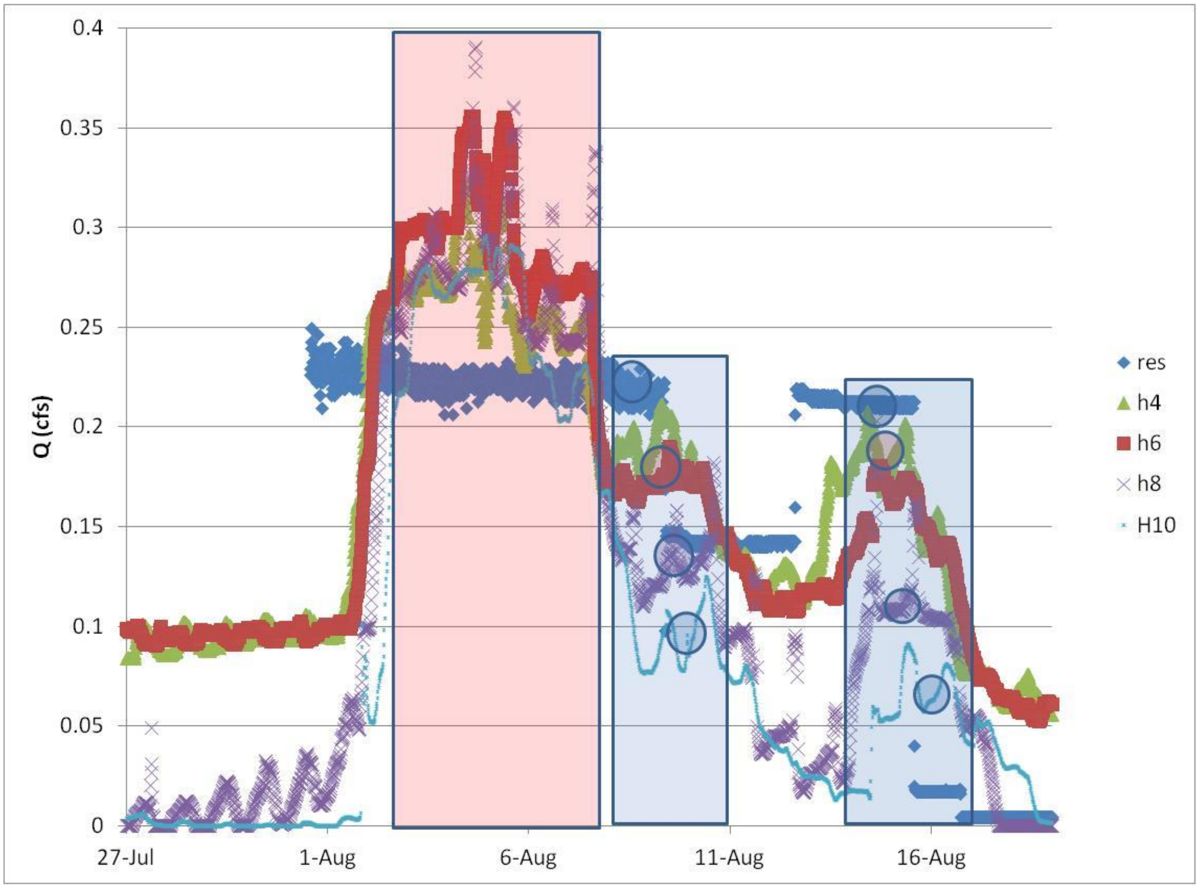


Figure 13: 2013 longitudinal hydrographs of the Reservoir release where the circles represent equilibrium conditions, the red rectangle signifies the influence of precipitation.

Flow augmentation campaigns from the sand filter occurred on two occasions (8/31/12-9/20/12 and 7/20/13-8/9/13). In the 2012 field season, parts of Big Meadow creek completely dried for extended time periods and there were large lag times between active flow augmentation and downstream response as much of the initial water released went to fill as hyporheic stream storage (figure 14). Lag times may further be exacerbated by ET reductions, as well as the time required to fill interstitial spaces (i.e. instream pools). Of 0.14 cfs released during September 2012 from the sand filter, 0.13 cfs were lost between the sand filter and H10 (figure 14). In 2013, flow release to the creek from the sand filter varied in response to variable rates drawn by the city for water consumption from the sand filter and therefore conditions in the creek were not consistent which limited our ability to confidently determine total downstream losses. It was estimated by subtracting spot measurements of sand filter inputs that average instream water losses were approximately 0.14 cfs. City managers were unable to lessen demand from the sand filter during these times, which led to insufficient discharge to maintain wetted habitat at H10 (figure 12). Figure 15 expresses augmented flows from the sand filter and subsequent downstream flows at equilibrium conditions.

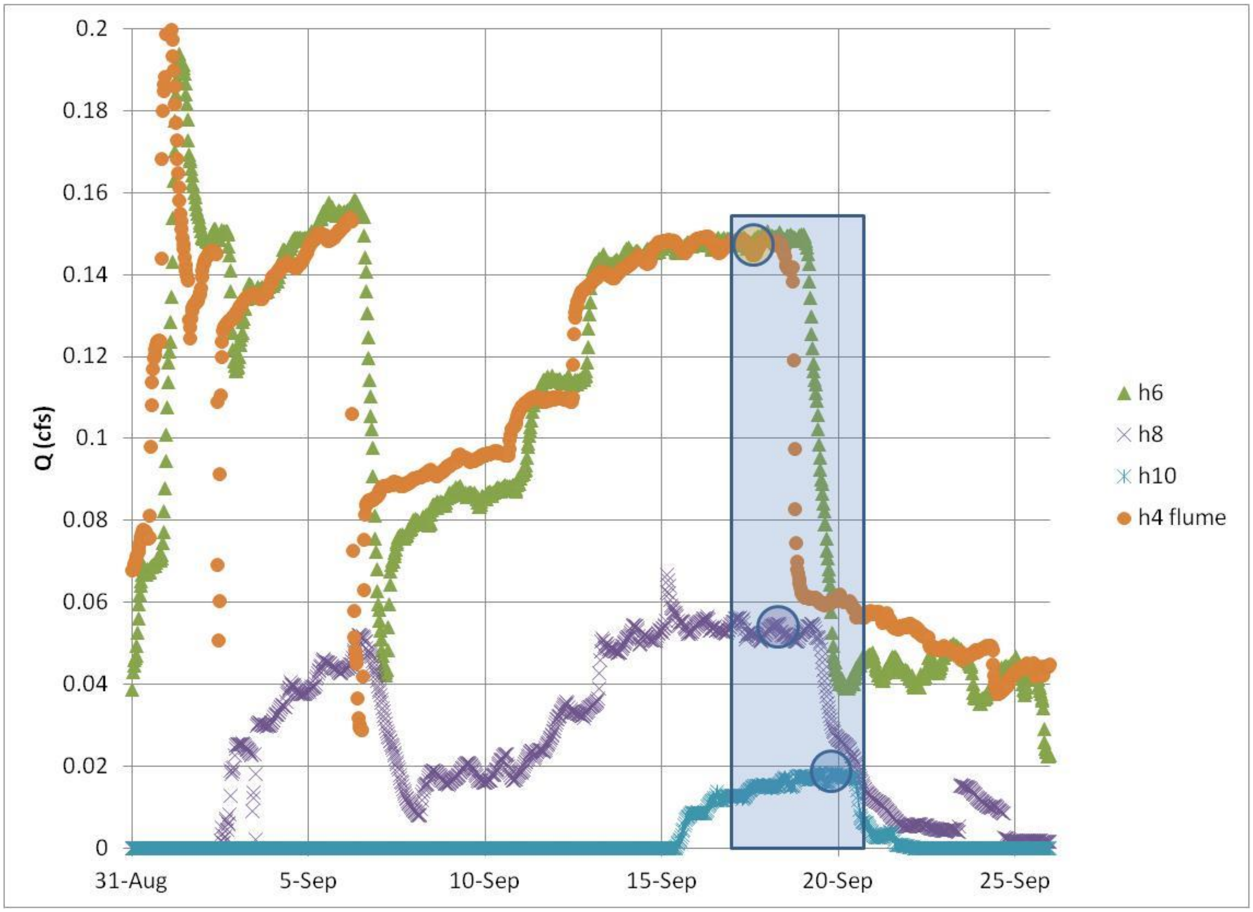


Figure 14: 2012 Longitudinal hydrographs of SF release where circles represent equilibrium conditions (all h4 flume flows above the black line is active flow release).

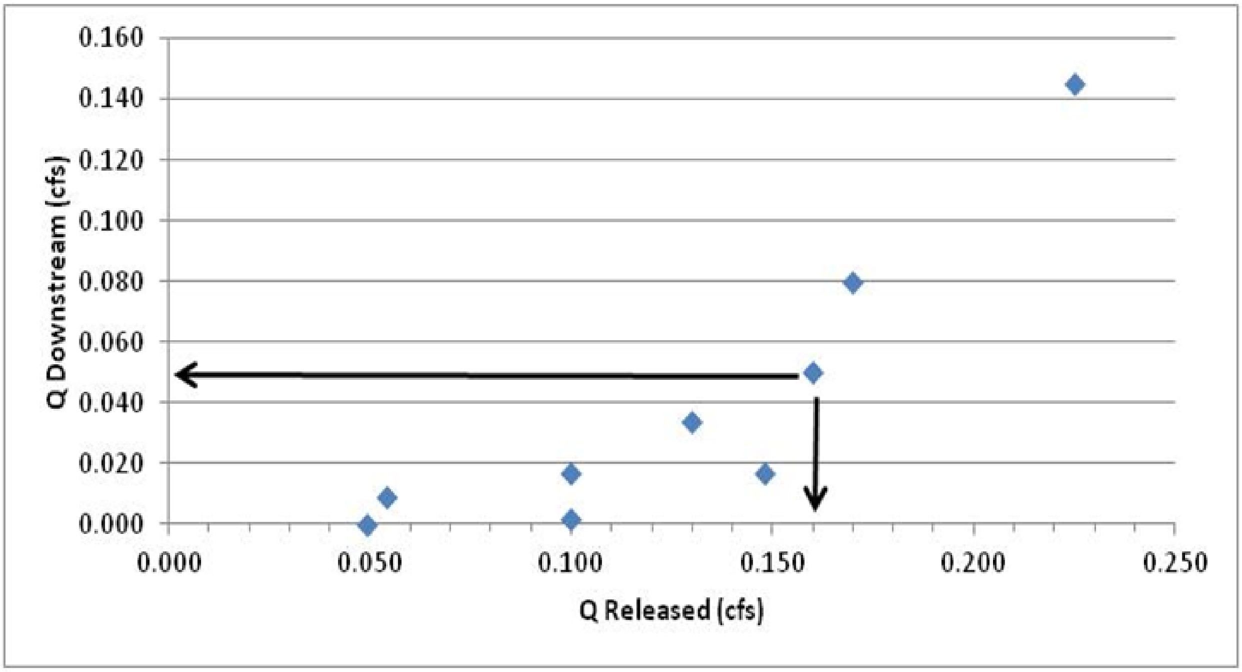


Figure 15: Released discharges from the sand filter (x-axis) and the amount of discharge remaining in the stream at the most downstream location (y-axis).

Specific flow release values and delineation when releasing from the sand filter are provided in appendix 33. These values were taken from estimating steady state conditions per augmented discharge depicted in figures 12, 13 and 14. Evaporative losses established from isotope analysis make up 7% of daytime streamflow on average. Raw isotopic data and calculated percent evaporative losses can be found in appendices 22 through 25. Figure 16 expresses delineated losses per habitat reach compared to total observed losses within each habitat reach. The summation of percolation and ET often exceeds the total loss measured throughout a specific reach and is likely due to the fact that the minimum and maximum streamflow values were used to estimate ET rather than the summation of the differences throughout the day. Percentages of stream losses are provided in appendix 34. Three equilibrium periods (out of six) express that ET and deep water losses (percolation) were the least within the meadow habitat reach (see appendix 35).

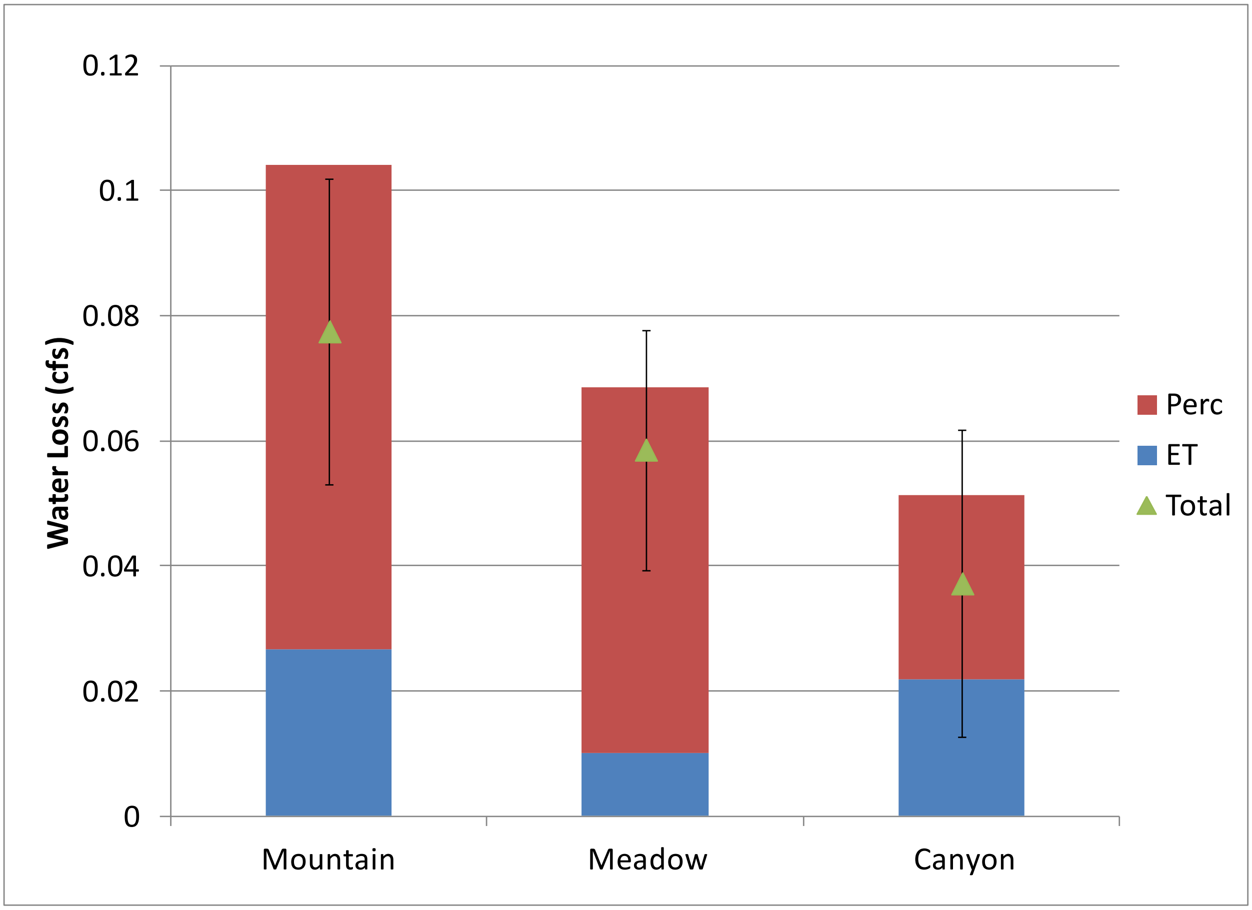


Figure 16: Average delineated losses and total losses in each habitat reach.

Mountain Reach:

Significant variably in ET reduction was observed in the mountain reach. This does not appear to be a result of actual ET reduction, but rather insufficient characterization of observed streamflow. As a result large variability is also observed in calculated percolation (see appendix 32). Percolation in the mountain reach ranged from 0.036 to 0.1 cfs with the higher percolation losses relating to higher hydraulic head. Mountain percolation losses are on average, highest compared to other habitat reaches (figure 16). This may support an aquifer recharge hypothesis that suggests regional basalt aquifers acquire the majority of water contributions from the granite-basalt interface (Dijksma et al. 2011). Further investigation is required to confirm that this is a valid observation, but would instigate baseflow augmentation campaigns to occur from the sand filter to avoid unnecessary instream losses.

Estimated ET at the bottom of the mountain reach was notably higher than at the top of the study reach during both isotopic analyses which support theories that catchment length is a major driver of diurnal streamflow fluctuation (Graham et al. 2013). At the top of the mountain reach ET accounted for 0.005 cfs and at the bottom of the reach ET accounted 0.054 cfs. Evaporation accounted for 0.006-0.022 cfs (see appendix 32). The current study used only daily maximum and daily minimum values to obtain estimates of ET due to significant lag times and short durations of steady-state conditions that jeopardized the validity of further investigation. A potential major limitation to this assumption is the affect of upstream diurnal signals on downstream monitoring locations potentially resulting in inaccurate estimation of ET at downstream locations. Furthermore, Graham et al. (2013) found the lag between actual transpiration and the timing of diurnal streamflow signals are not consistent throughout the summer season, which may explain the variability of our results.

The Meadow Reach:

The meadow reach begins directly below an unnatural input (slow sand filter over flow) that fluctuates erratically throughout the day depending on human water demand. Therefore, calculating missing streamflow due to ET was difficult. To minimize error H6, 2 km below the sand filter was used to calculate missing streamflow (figure 11). Values ranged from 0.003-0.019 cfs being utilized by ET. Some of this variability could be accounted for by unnatural fluctuations due to the sand filter or to upstream diurnal signal. However, these values also support Graham et al. (2013) that catchment hillslopes are a primary driver of diurnal streamflow fluctuations when considering subsurface lateral flow. Isotopic results indicate 0.011-0.015 cfs is lost to evaporation (appendix 32).

Percolation was difficult to delineate within this study reach. H8 was the only possible location to monitor the outflow of the meadow reach and is located approximately 1 km into canyon reach criteria. The transition is subtle, however substrate and stream width at H8 are well within the definition of canyon characterization of 4 percent stream slopes and large basalt cobble. Using this site to quantify percolation in the meadow reach indicate 0.02-0.06 cfs lost to percolation. Streamflow differences between H4 and H6, both continuous monitoring locations within the meadow study reach characterization, are indistinguishable.

Canyon Reach:

ET losses accounted for 0.005 to 0.033 cfs total fluctuation in streamflow. Losses to evaporation ranged from 0.009 to 0.012 cfs of daytime streamflow (appendix 30 and 33). Percolation in this reach ranged from -0.008 to 0.058 cfs. The negative value occurred when discharges entering the canyon reach exceeded 0.15 cfs and suggests that the study reach became a gaining stream. Because this flow release was so large and not sustainable at the current capacity of Big Meadow Reservoir, this observation only occurred once throughout the monitoring campaign.

Reservoir effect on baseflow:

By fitting a logarithmic decay function with observed baseflow data following the Depuit-Boussinesq equation (Tallaksen 1995), figure 17 expresses that the reservoir substantially reduces downstream baseflow by intercepting baseflow recession inputs to the reservoir.

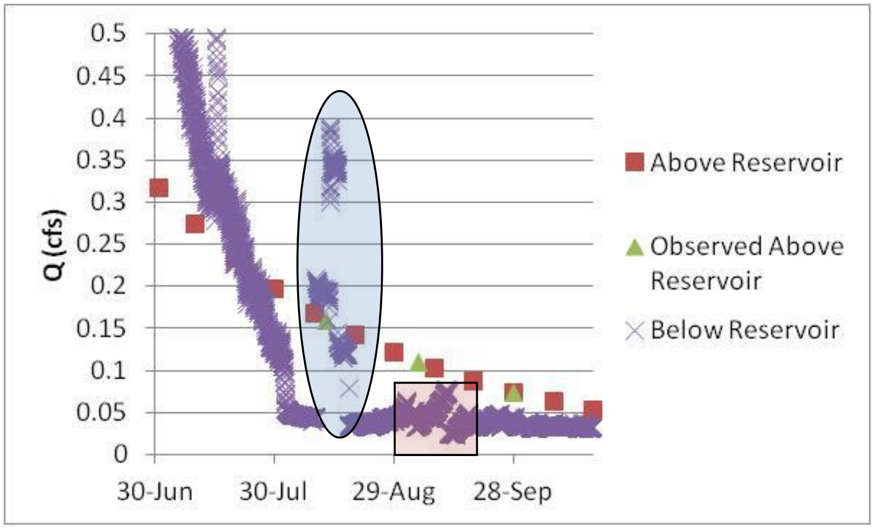


Figure 17: Depuit-Boussinesq equation applied to observed 2012 baseflow into the reservoir and flows directly below the reservoir without active flow augmentation. The blue oval represents active flow augmentation from the reservoir. The red rectangle shows a relationship that occurs between downstream flow below the reservoir when manipulating the flow to the sand filter through the pipeline.

Flow augmentation extended a minimum of 6 km below the effluent, a total on 16 km from the release point (figure 18). A precipitation event on August 2nd reduces the ability to examine the contributions from flow augmentation. Likewise, when considering other potential reservoirs in the region for flow augmentation, it is difficult to estimate the extent that flow augmentation would persist without the contribution of flow from the effluent. However, by examining figure 18, a discharge greater than 0.1 cfs is needed above the treatment plant to reach 6 km below the WWTP.

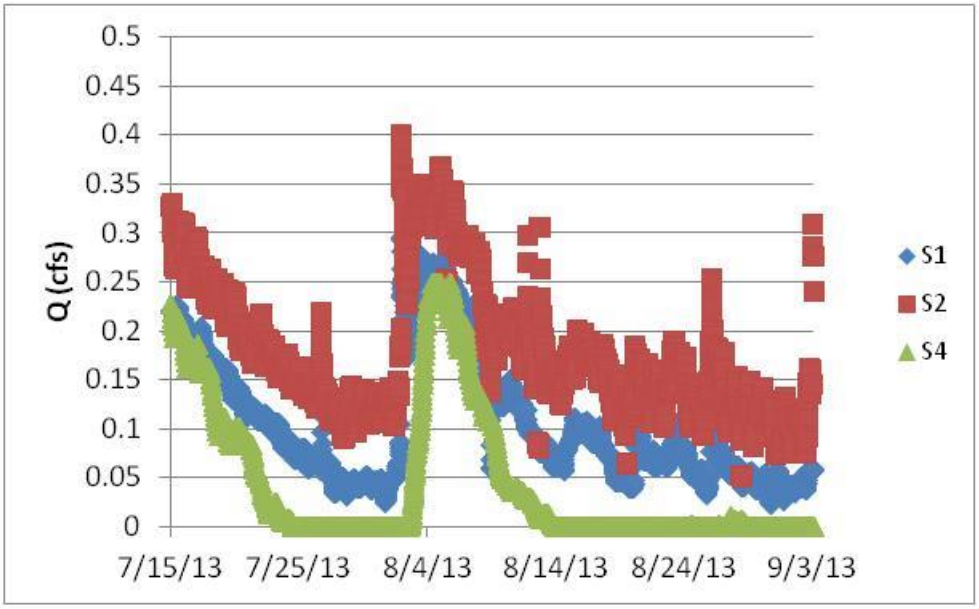


Figure 18: S4 response to flow augmentation.

WATER QUALITY RESPONSES TO LATE SUMMER FLOW AUGMENTATION

Water quality response to flow augmentation was quite apparent upstream of the WWTP however improvements in water quality downstream of the WWTP were not consistent and varied between the 2012 and 2013 water years. Effects of flow augmentation on water quality were assessed by identifying the minimum streamflow required to satisfy state water quality standards for temperature and dissolved oxygen at each of the monitoring stations, see figures 19 through 25. Using these minimum allowable flows at each location the minimum required discharge from the sand filter or reservoir could be calculated based on the assessment of water losses throughout the stream network as described in the previous section.

Without flow augmentation meadow and canyon reaches of Big Meadow creek would be predominantly dry offering isolated wetted habitat. Although perennial flow was sustained in parts of the upper forested reaches, Big Meadow Creek completely dried during both 2012 and 2013 when water was not being released to the creek. Therefore there is little to no viable summer rearing habitat for juvenile steelhead in Big Meadow creek without flow augmentation.

UPSTREAM OF THE EFFLUENT POINT

A controlled flow release of 0.21 cfs maintained 100% wetted habitat connectivity beyond the effluent discharge point. This release allowed water quality conditions to remain in compliance with state standards for cold water biota above the effluent point. Adopting the definition of environmental flows, the quantity of flow required to “sustain fresh water ecosystems” appears to be 0.21 cfs when releasing from the reservoir. Interestingly, this flow release is approximately equal to the observed flow draining into Big Meadow reservoir from mid-July to early September during the 2012-2013 study period. This implies that without the reservoir intercepting this water for human consumptive use, the watershed could potentially sustain perennial flow in Big Meadow creek.

Water quality response to flow augmentation upstream of the WWTP was most evident in observed DO concentrations. Water temperatures in the canyon reaches exceeded instantaneous criteria on two occasions (data not shown) while daily average water temperature never exceeded the beneficial use criteria of 19 degrees Celsius. Figures 19 through 25 express the flow requirements required to maintain state water quality standards (the black line) following the longitudinal habitat gradient. In the mountain reach (figure 19), steep stream slopes maintain sufficient aeration to keep DO levels in compliance with the state standards for cold water biota even at considerably low flow. The meadow reach (figures 20 through 22) requires at least 0.1 cfs to maintain DO levels above the state standard. The H10 station measurements at the bottom of the canyon reach (figure 24) suggest that a streamflow of 0.15 cfs is required to maintain DO levels above 6 mg/l. However, this station was located in a large pool where DO levels were highly stratified with depth. Measurements at the top of the pool were typically much higher than measurements at the bottom of the pool. By assuming the measurements at H10 misrepresent the average DO concentrations characteristic of the habitat reach, the upstream canyon site (H8) was used to determine discharge that maintained suitable DO.

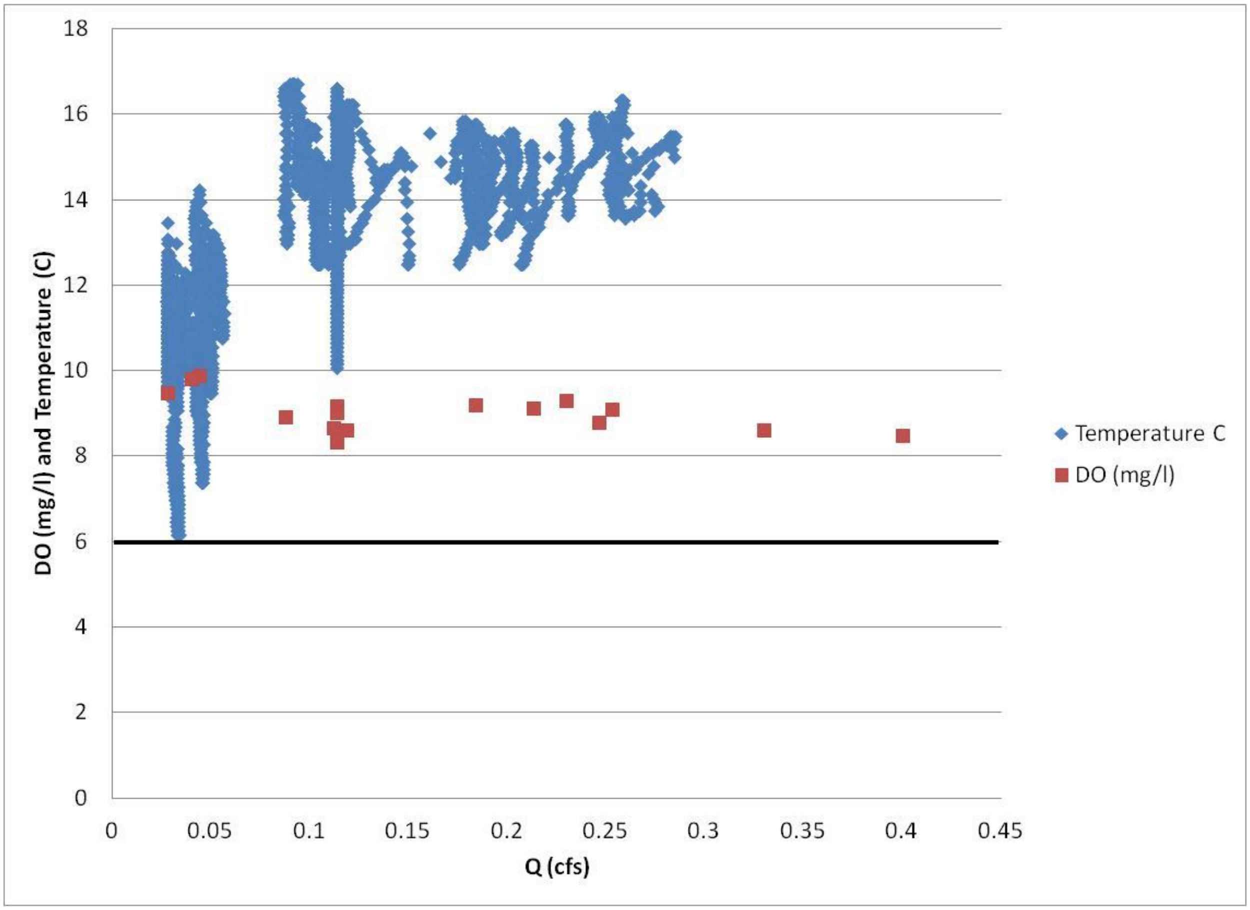


Figure 19: H2 water quality versus Stream flow.

Measurements at H8 (figure 23) indicate a minimum of 0.05 cfs flow is required to keep DO in compliance with state water quality standards within this habitat reach. Figure 25 shows the control site discharge remaining above critical levels to maintain quality habitat. Combining this information with instream loss delineation, a controlled release of 0.21 cfs from Big Meadow Reservoir would not only maintain 100% wetted connectivity for a minimum of 10 km, but also keep upstream water quality parameters in compliance with state standards. Flow augmentation from the sand filter reduces the total amount of flow required to sustain these “prescribed” flows. However, in 2013 the stream reach immediately upstream of the sand filter release point did completely dry for part of the summer. Although flow augmentation from the sand filter reduces water loss between the reservoir and the sand filter, upstream meadow and forested habitats may go dry during the summer.

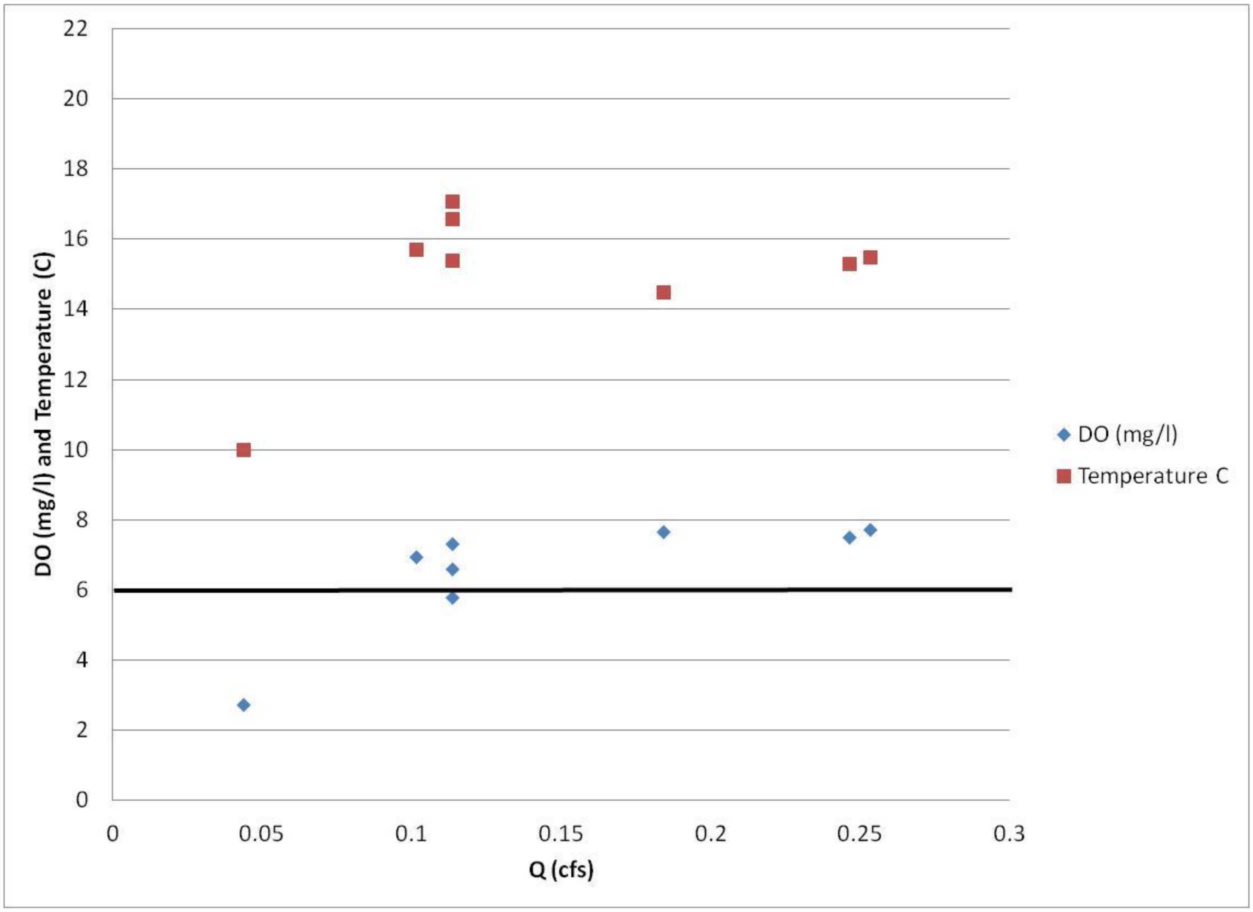


Figure 20: H3 water quality versus to stream flow.

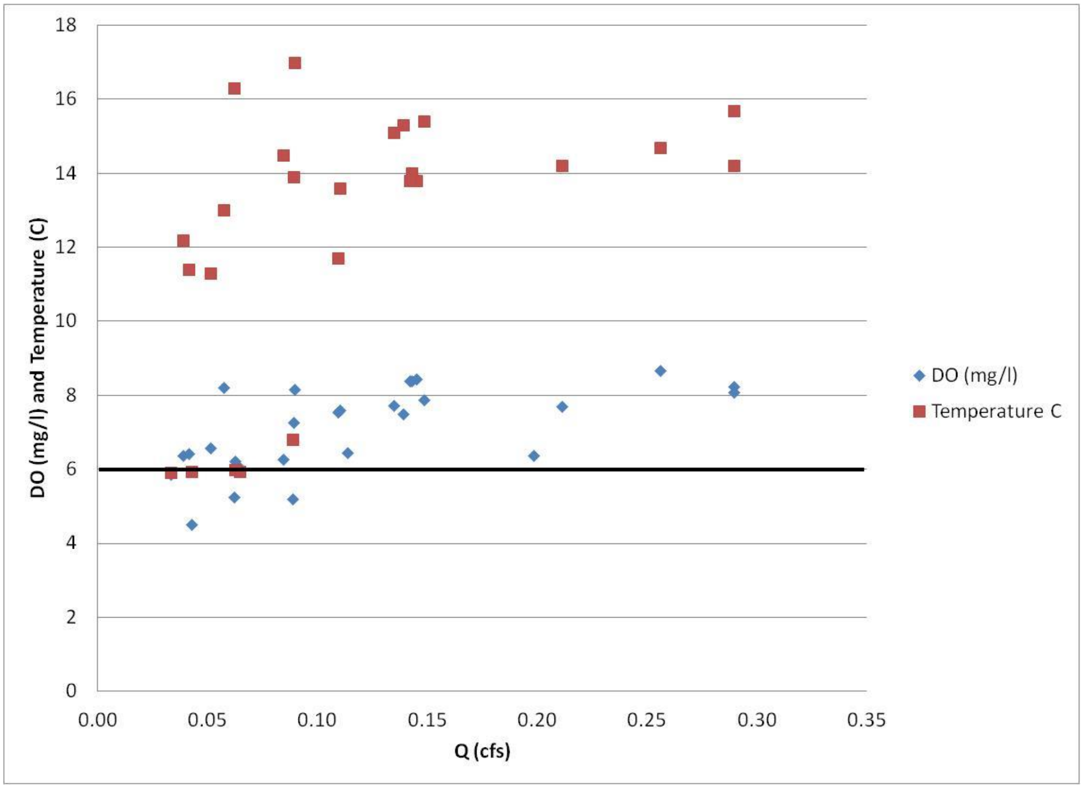


Figure 21: H4 Water quality versus stream flow.

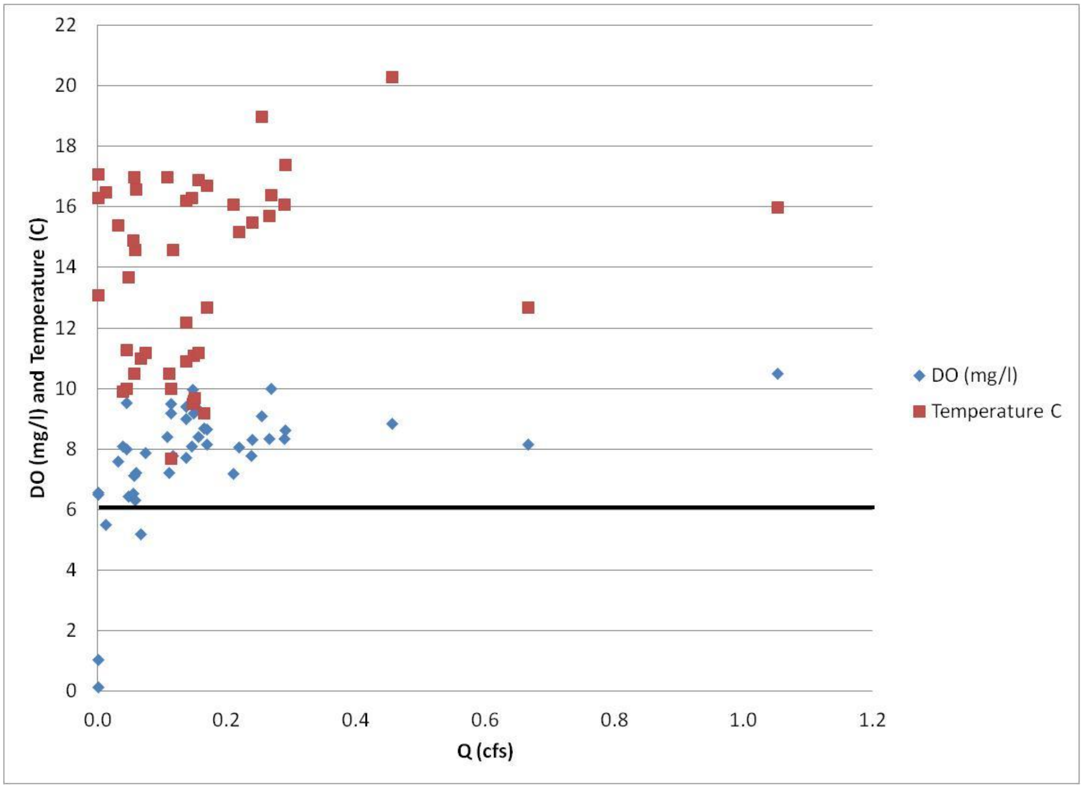


Figure 22: H6 water quality versus stream flow.

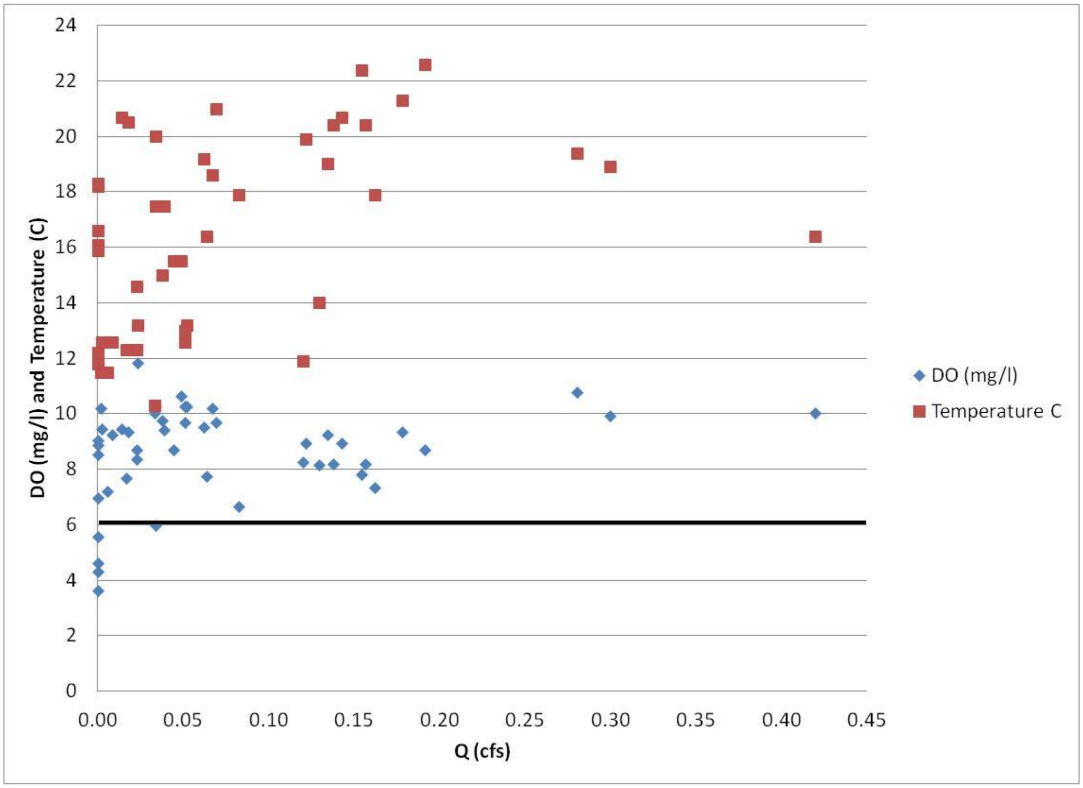


Figure 23: H8 water quality versus stream flow.

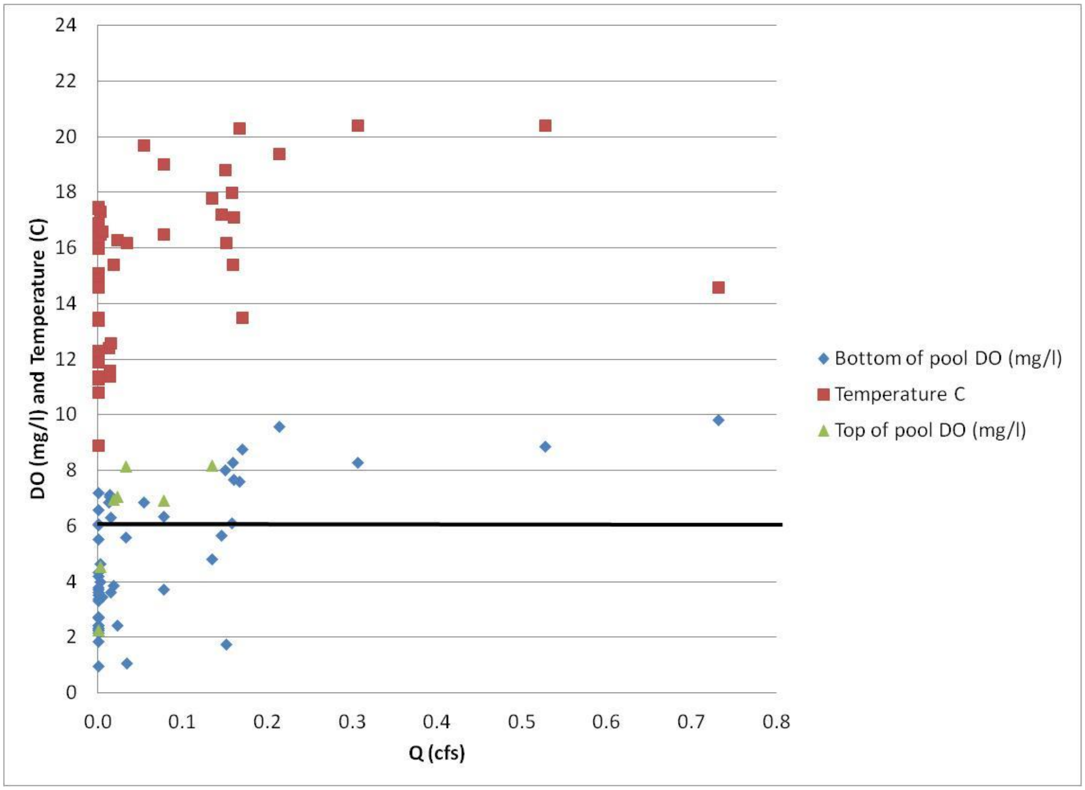


Figure 24: H10 water quality versus stream flow. This pool became highly stratified.

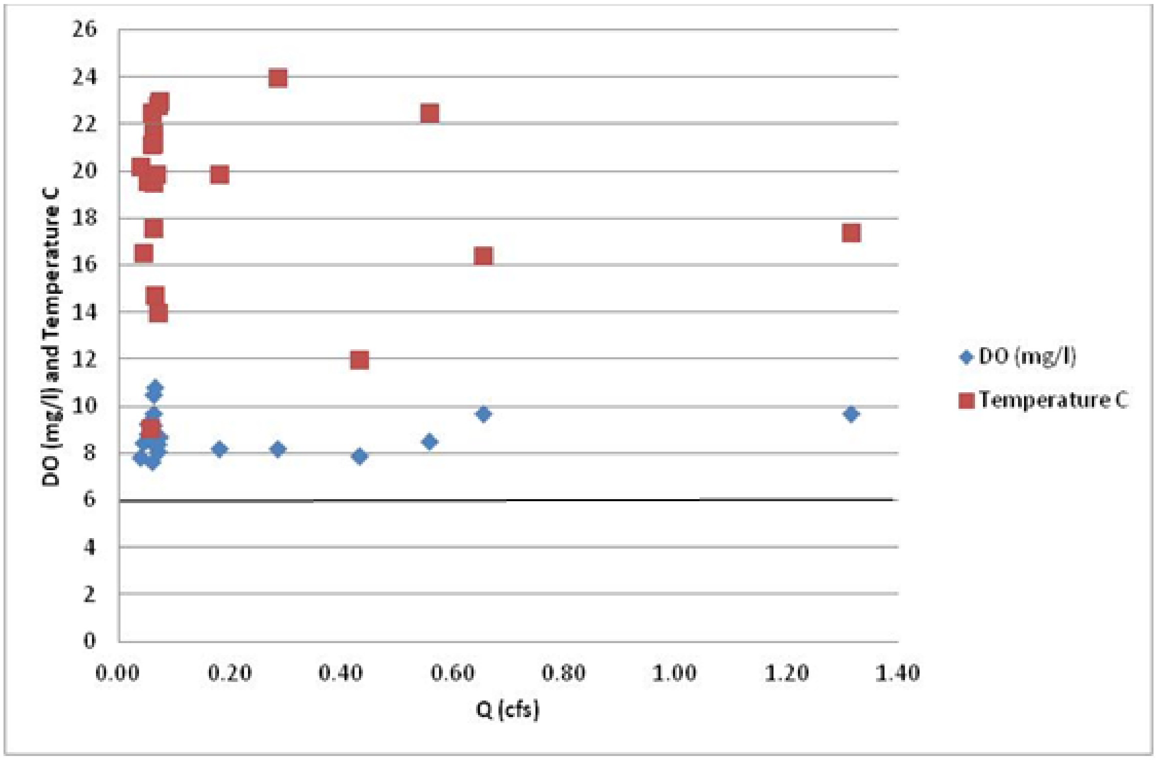


Figure 25: Control site, WFLB, water quality versus streamflow.

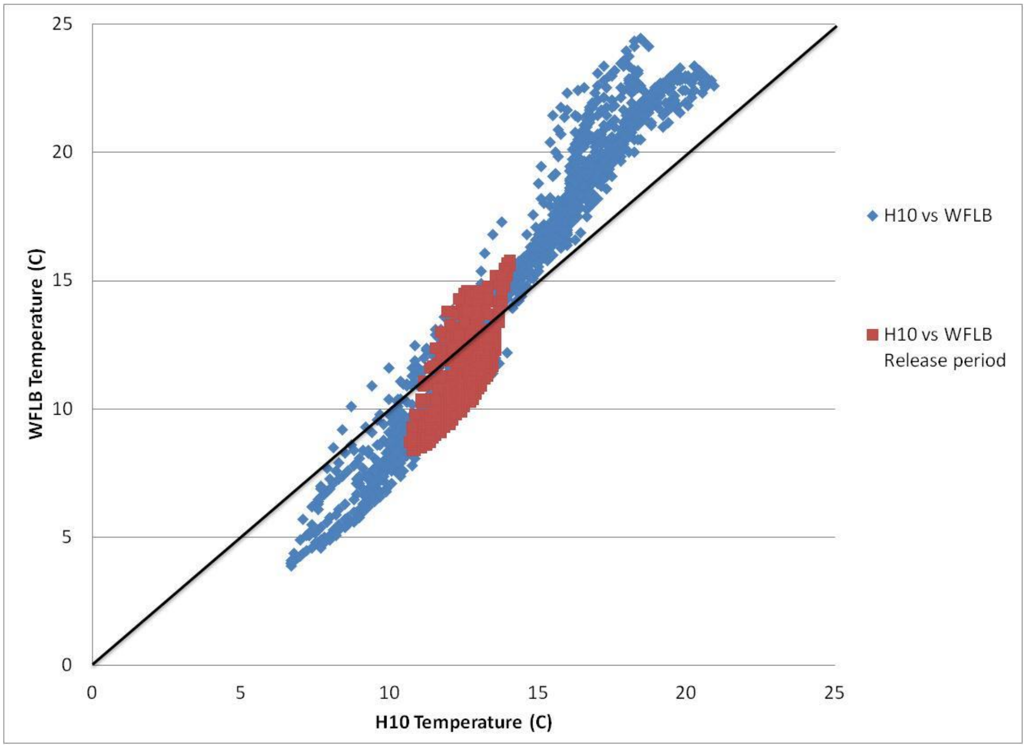


Figure 26: Water temperatures at H10 versus the control site 2012.

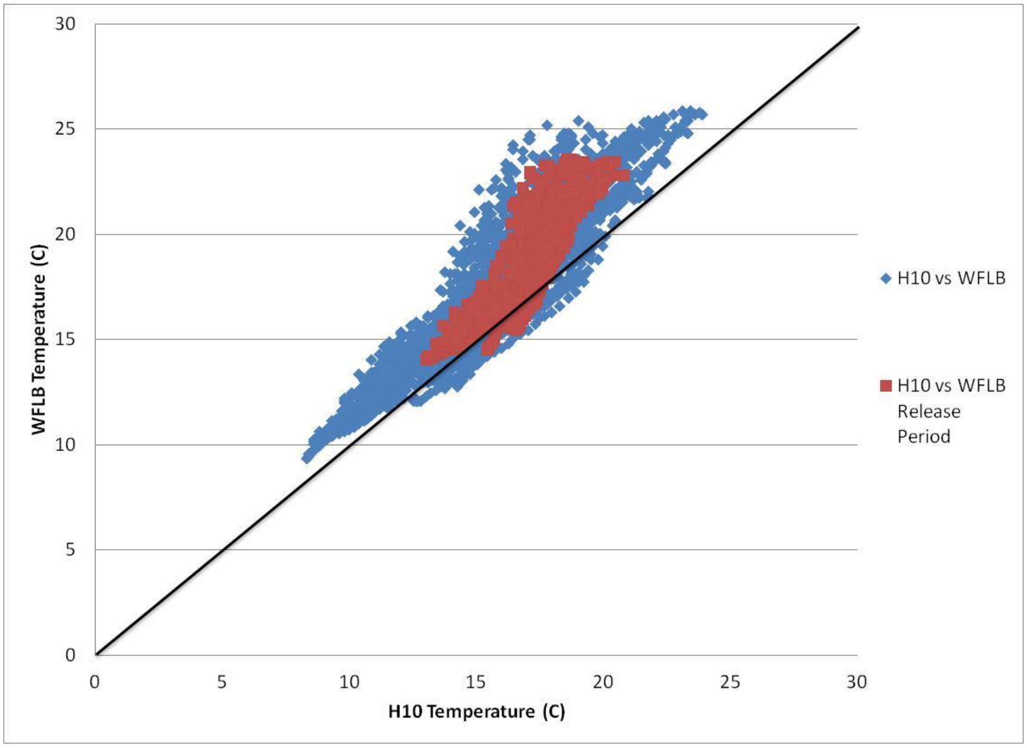


Figure 27: water temperature at H10 versus the control site 2013.

Automated water temperature measurements at the control site WFLB and H10 indicate water flow in Big Meadow Creek is typically cooler than the control site by as much as 8 degrees during warm summer months, see figures 26 and 27. Interestingly the relationship between water temperatures at each location varies from one year to the next during cooler conditions. As seen in figure 26, H10 was warmer than the WFLB location when water temperatures were less than 15 degrees during the 2012 year, whereas in 2013 H10 water temperature were cooler in this range during the 2013 year (figure 27). City officials indicate one of the pipes buried along the WFLB tributary was leaking water back to the creek during the summer of 2012 which could potentially explain the differences in these relationships between the 2012 and 2013 study years. Additionally, differences may persist due to missing water temperature data during the first release in 2012, hyporheic depletion and the contact of augmented flows on dry cobble stream beds and to the lack of consistency regarding the duration of flow augmentation campaigns.

Juvenile steelhead mortality was observed during the 2013 field season at station 1, upstream of effluent receiving waters. On the date mortality was observed, an average discharge of 0.04 cfs, maximum water temperatures of 19 degrees Celsius, and night and day DO concentrations ranging between 4.5 mg/l to 8.5mg/l, respectively were recorded at station 1.

DOWNSTREAM OF THE EFFLUENT POINT

The nutrient levels emitted from the effluent, and therefore water quality response to flow augmentation downstream of the effluent was quite different in each of the two monitoring seasons. The 2012 study year was characterized by low ammonia levels and high nitrate loads whereas ammonia loads in 2013 were much greater throughout much of the season (appendix 28 through 31). DO concentrations exceed 6 mg/l during the day throughout the 2012 season with nighttime observation dropping slightly below this state standard (figure 28). A flow release experiment on 8/12/2012 which provided 0.15 cfs of upstream flow above the WWTP during conditions when ammonia loads from the effluent were below 10 mg/l, succeeded in bringing nighttime DO concentrations near the state standard of 6 mg/l (figure 28).

In contrast with the 2012 season, DO levels in 2013 were below state standards throughout the day for several consecutive days on more than one occasion (figure 29). Daytime maximum DO levels would exceed 6 mg/l for much of the summer however nighttime and early morning DO concentrations dropped well below 6 mg/l. Monitoring data from the 2013 field season indicate only a slight increase in DO when upstream flow was as large as 0.25 cfs on 8/3/2013 when ammonia levels in the effluent were near 15 mg/l. DO levels did temporarily improve following the 8/1/2013 flow release after ammonia concentrations dropped to less than 1 mg/l. However DO levels again dropped well below 6 mg/l for much of August and September 2013 when flow augmentation ceased.

The amount of upstream flow required to bring effluent receiving waters to compliance is dependent on ammonia concentrations. The low ammonia levels in 2012 resulted in a relationship between DO at S2 and upstream flow (S1) as seen in figure 30. In 2013, the relationship between upstream discharge and DO can be seen in figure 31. All DO measurements at S2 are plotted against upstream flow (S1) and grouped by WWTP ammonia concentrations in figure 32 and suggests minimum flows needed to maintain compliance with state standards during an entire day.

Although there is no clear explanation for the different response from one year to the next, in 2013 the city of Troy hired a new consulting firm who managed the WWTP differently than in 2012. For example, aerators were turned off for extended periods of time in one or more of the pools in the 2013 season whereas aerators were constantly operating in 2012.

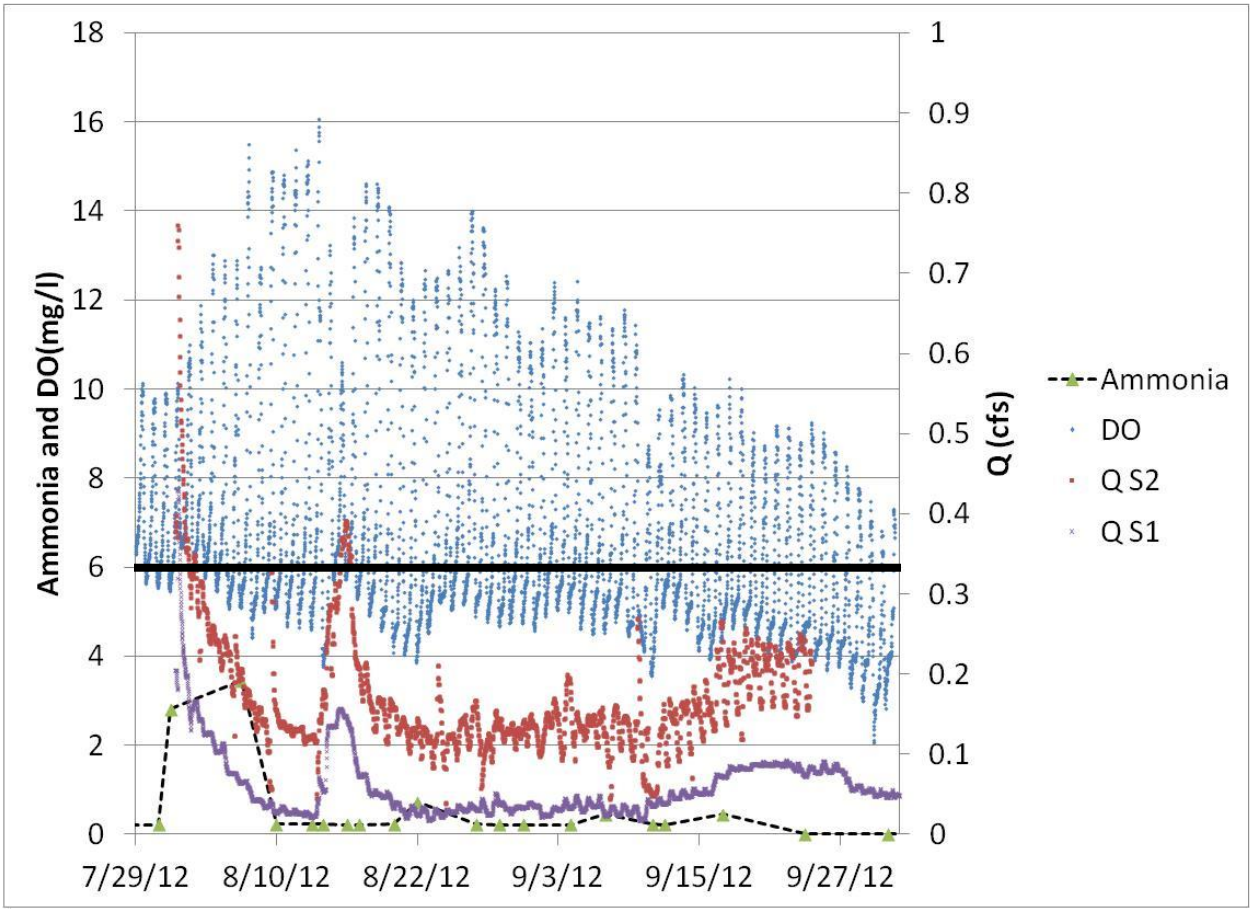


Figure 28: S2 Dissolved Oxygen, S2 ammonia, S2 Q (cfs) and S1 Q (cfs) 2012.

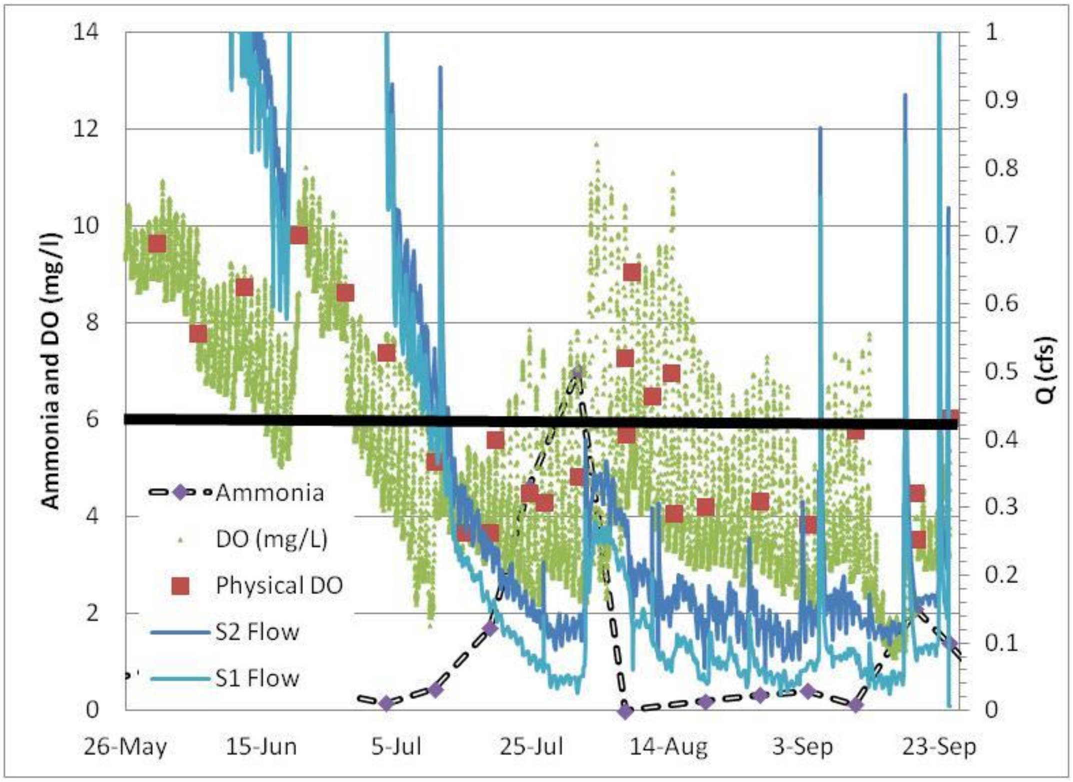


Figure 29: S2 Dissolved Oxygen, S2 ammonia, S2 Q (cfs) and s1 Q (cfs) 2013.

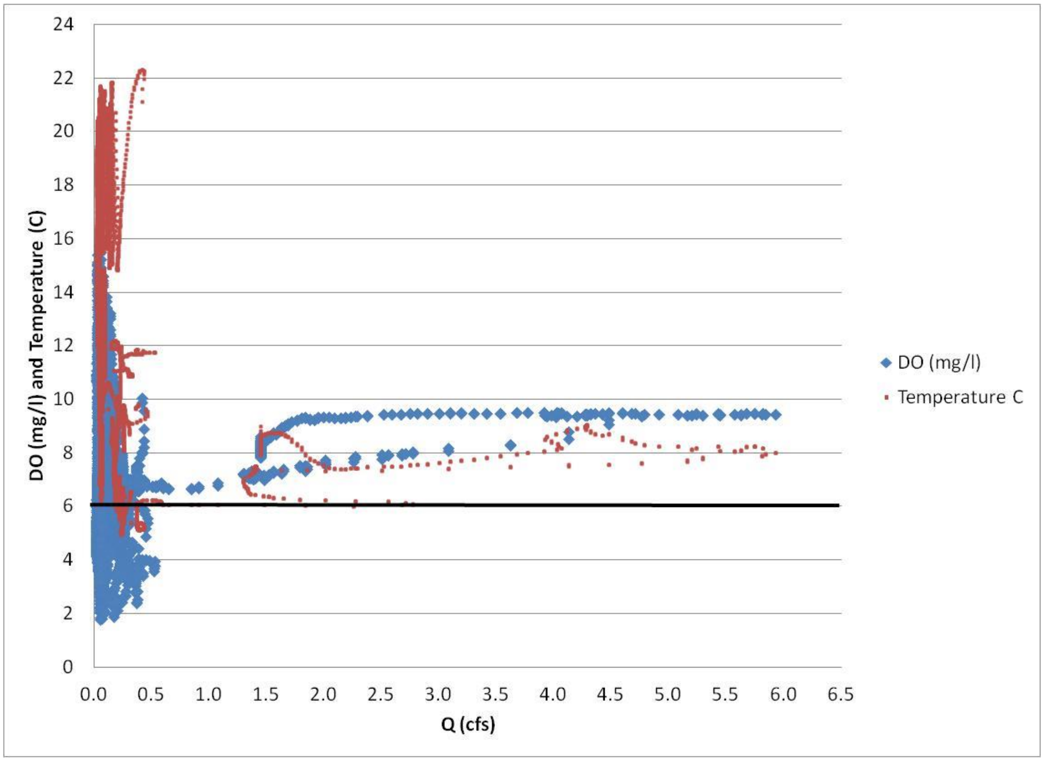


Figure 30: S2 DO and temperature versus upstream flow (cfs) 2012.

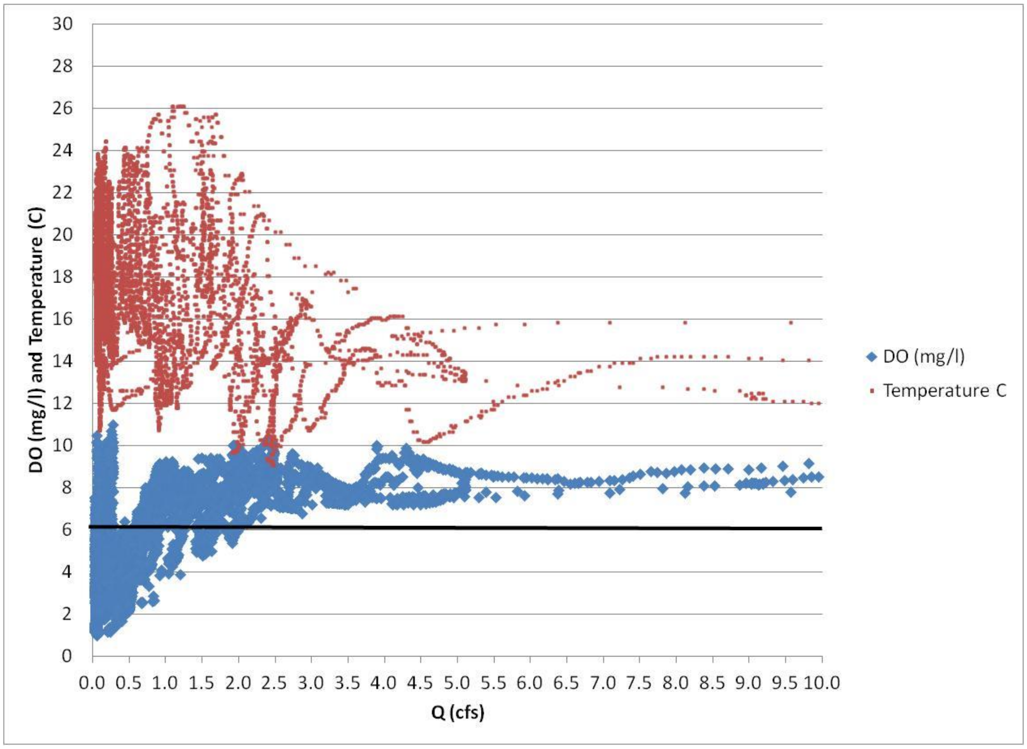


Figure 31: S2 DO and temperature versus upstream flow (cfs) 2013.

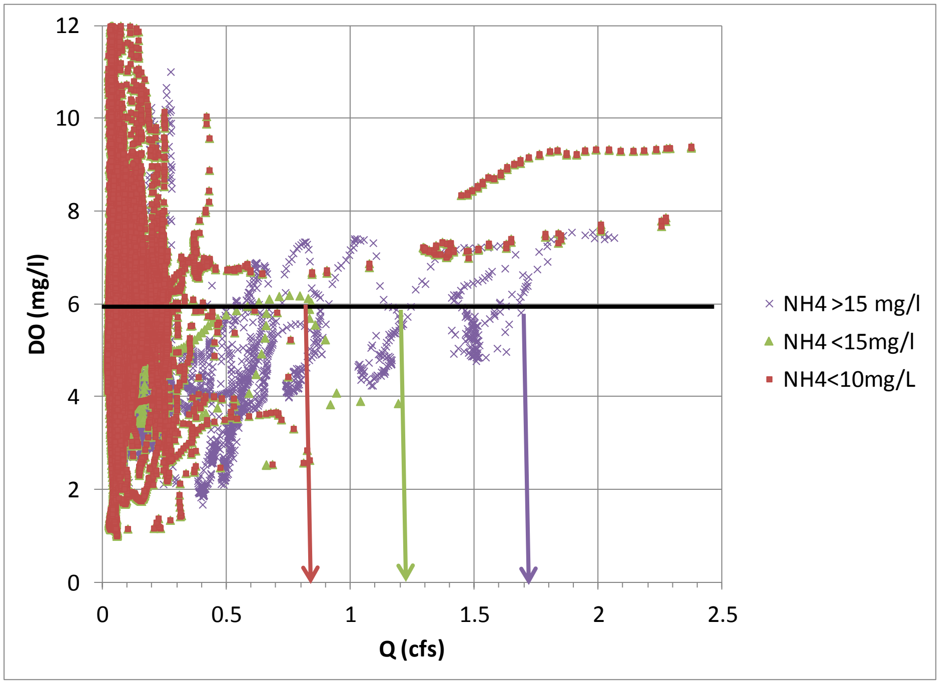


Figure 32: S2 DO vs S1 Q (cfs) grouped by ammonia concentrations.

Chronic ammonia toxicity was observed in the 2012 field season (figure 33) where S2 ammonia (green) is equivalent to the calculated chronic toxicity levels (red). In 2013 only chronic ammonia toxicity was observed for a short duration (figure 34). Juvenile steelhead mortality was observed 200 meters below the effluent point during the 2013 field season when DO concentrations averaged 4.3 mg/l and all 15 minute readings throughout the day were below 6 mg/l. Supporting Sánchez-Murillo (2010) findings, it is apparent that ammonia concentrations are the primary driving force causing depleted DO levels. The mixed results over this two year study period suggest further work is necessary to better understand the viability of flow augmentation for water quality compliance downstream of the WWTP discharge point. Flow augmentation upstream of the WWTP however would greatly increase and improve juvenile steelhead habitat in Big Meadow creek.

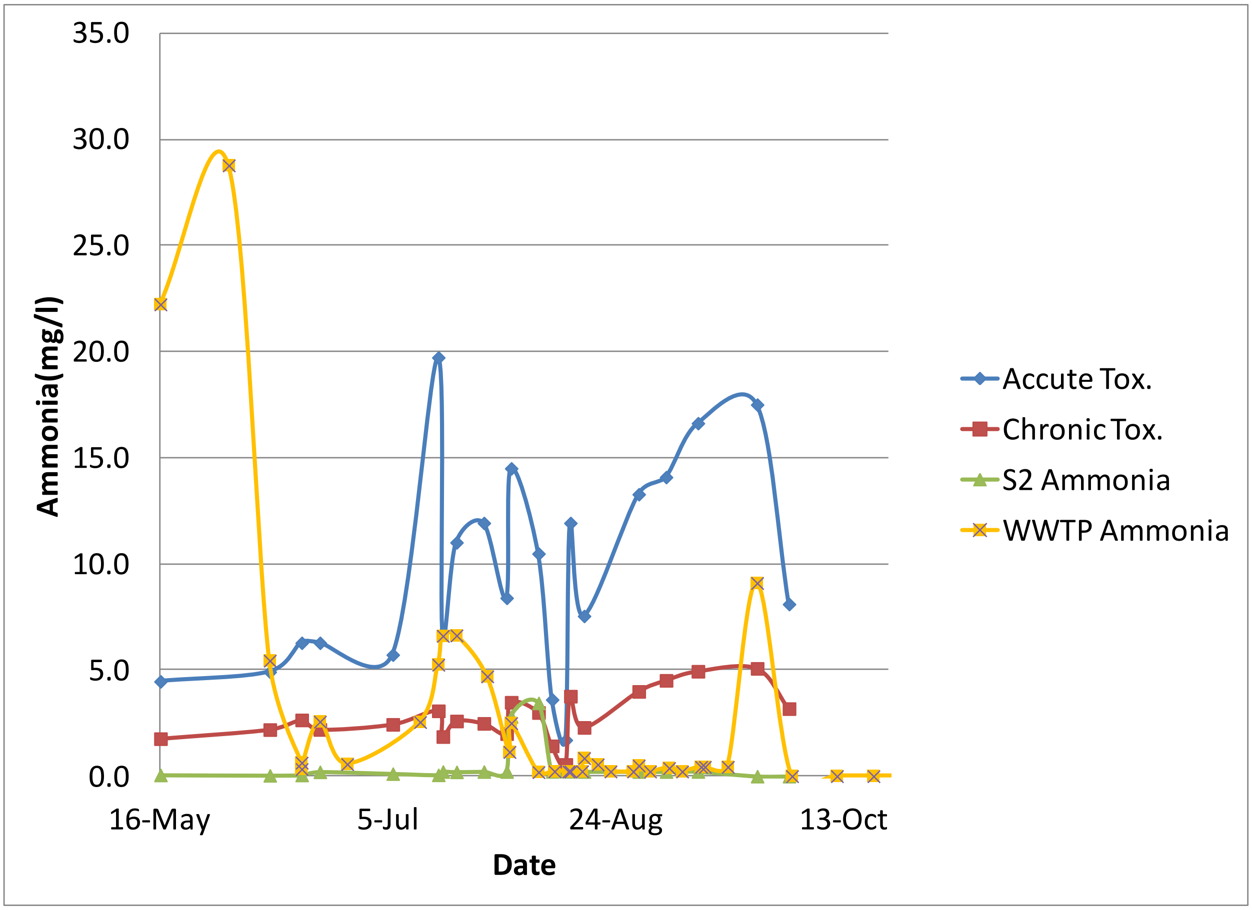


Figure 33: Ammonia toxicity 2012.

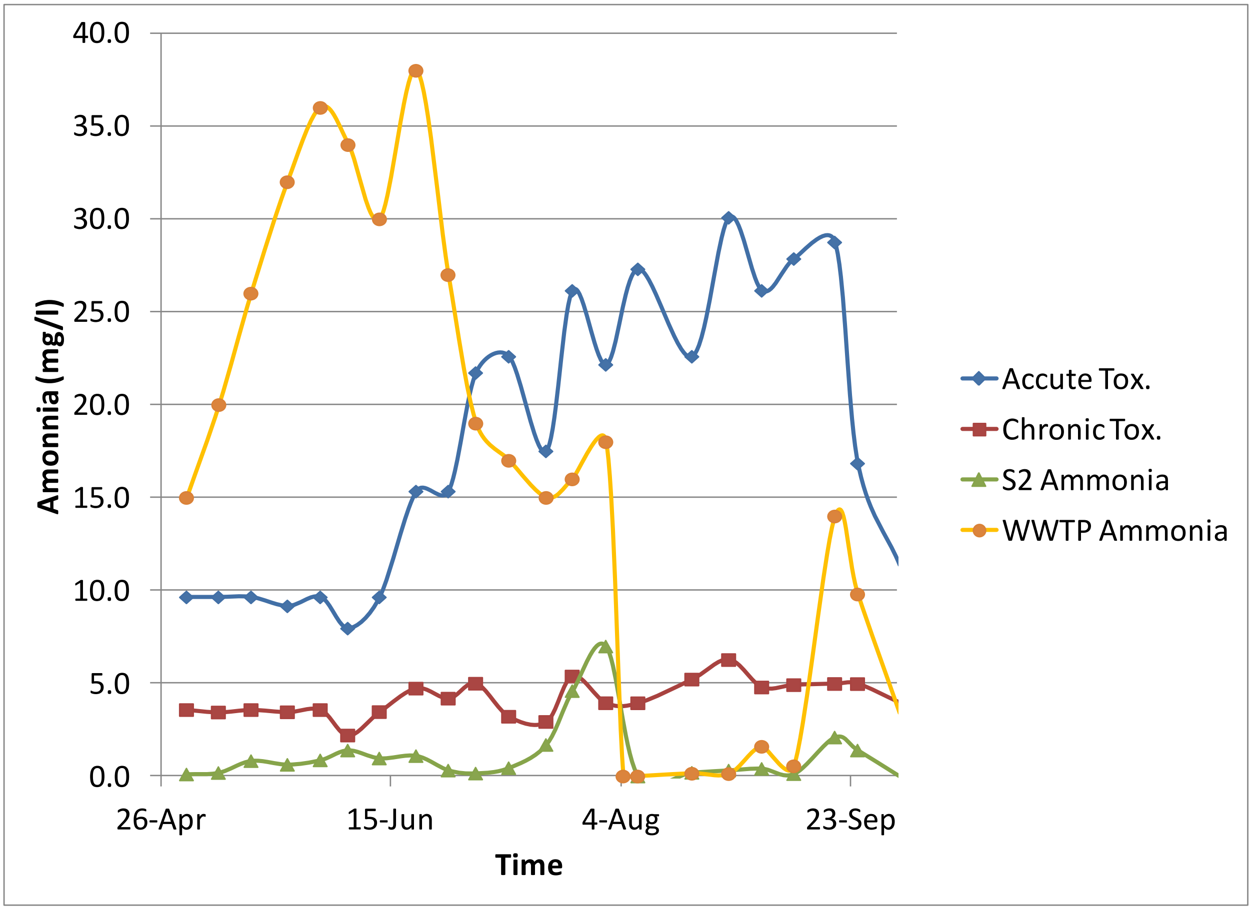
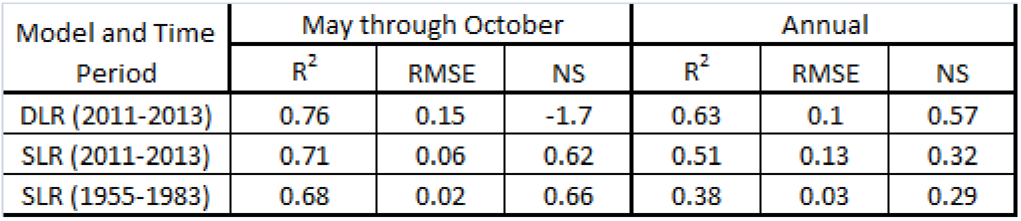


Figure 34: Ammonia toxicity 2013.

MODELING

Model performance was assessed using the coefficient of determination (R^2) describing the correlation between simulated and observed values; the root mean square error (RMSE) using the error between observed and simulated values to indicate that the model can reliably simulate streamflow within a specified cfs; and the Nash-Sutcliffe efficiency (NS) (Nash and Sutcliffe 1970) which represents a scaled, or normalized RMSE describing the models efficiency at predicting the observed variability relative to the observed mean during specified time periods. NS values between 0 and 1 are generally viewed as acceptable, whereas values less than 1 indicate that the observed mean is a better predictor of streamflow. Results of these statistical metrics both for annual time periods and summer months (May through October), for each modeling sequence can be seen in Table 4. Interestingly, the static lapse rate (SLR) model outperform the dynamic lapse (DLR) model during summer months and may potentially be associated with inversion effects. Clearly the DLR model outperforms SLR model outputs during annual analysis and can most likely be attributed to DLR increased capability to capture precipitation and snowmelt variability at higher elevations during winter months. The RMSE statistics indicate that the SLR model, on average, can reliably simulate streamflow during late summer months within 0.06 cfs. As seen in figure 35 simulated streamflow agrees well with observed data. However, both models tend to over predict streamflow during autumn months and may be attributed to the models inability to correctly capture forest canopy ET or incorrect soil depths. SLR model outputs using historic weather data are then compared to 1956-1983 intermittent streamflow values (figure 36).

Table 4: Model efficiency.



Model and Time Period	May through October			Annual		
	R^2	RMSE	NS	R^2	RMSE	NS
DLR (2011-2013)	0.76	0.15	-1.7	0.63	0.1	0.57
SLR (2011-2013)	0.71	0.06	0.62	0.51	0.13	0.32
SLR (1955-1983)	0.68	0.02	0.66	0.38	0.03	0.29

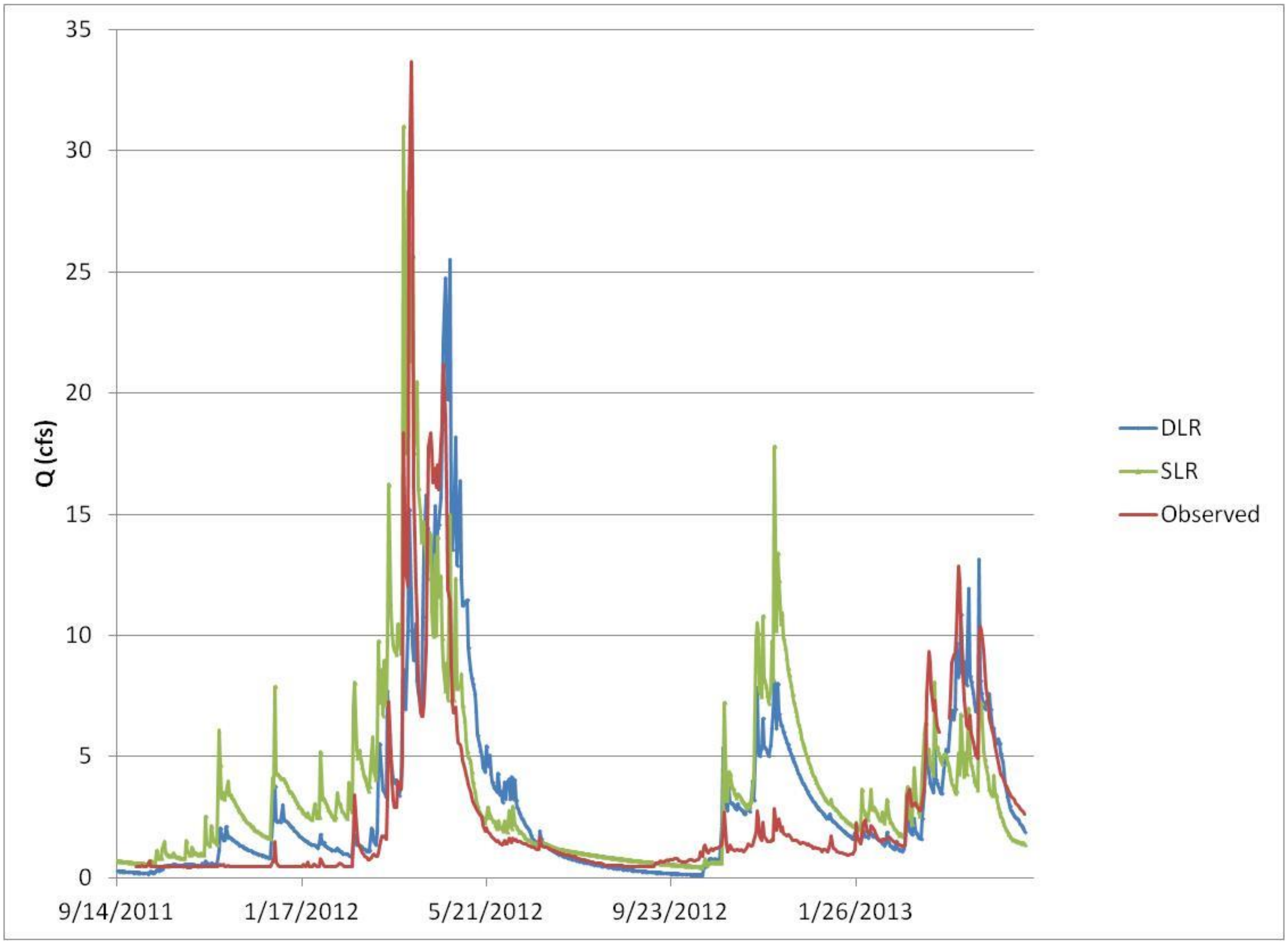


Figure 35: SMR modeled output with two elevations of weather inputs (DLR), and one lower weather input (SLR) compared to 2011-2013 observed streamflow.

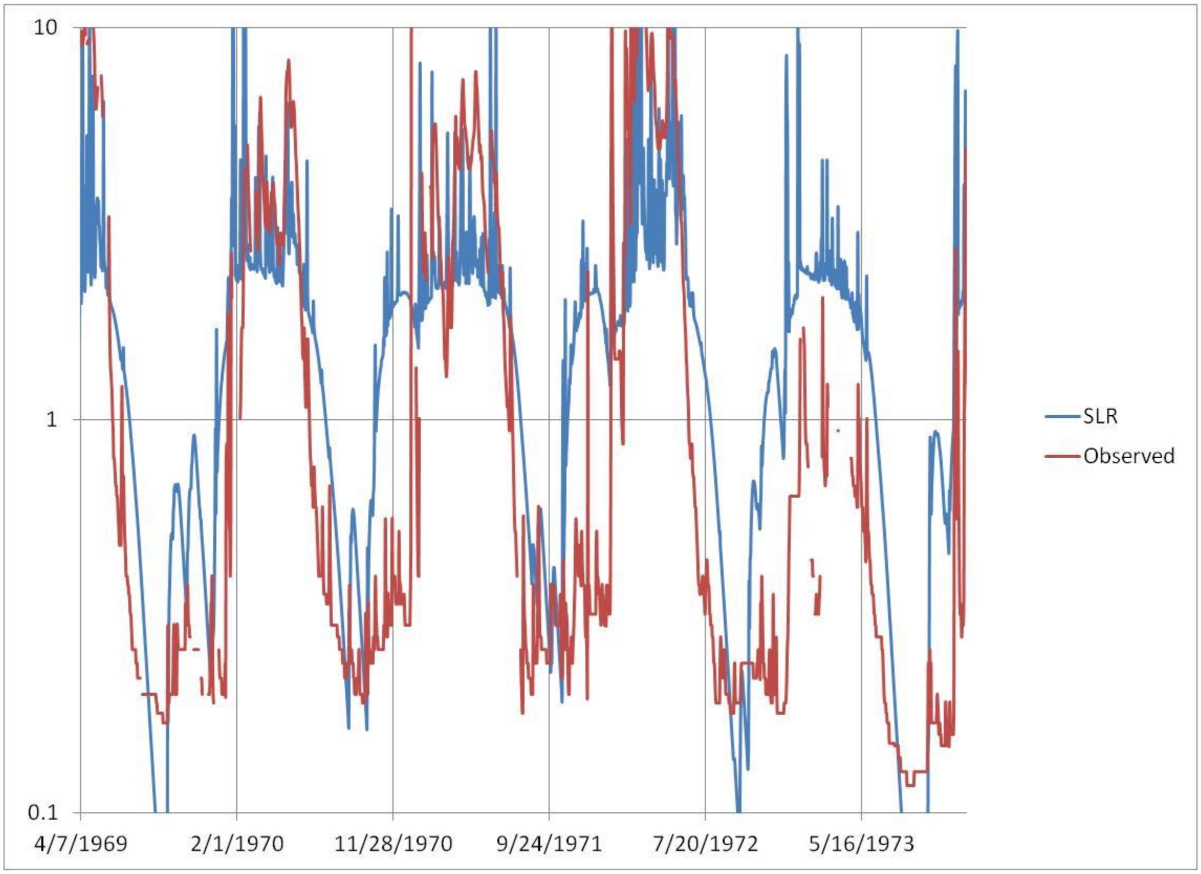


Figure 36: Observed historic Crumarine streamflow compared to SLR 1955-1983 model (example period).

Baseflow Augmentation Feasibility Analysis

The feasibility of Big Meadow Reservoir maintaining 100 % wetted habitat to the WWTP while satisfying citizen demand was determined using simulated streamflow. A total of ten scenarios were tested: No flow augmentation, pre-2010 historic consumption (historic demand), 50% reduction in reservoir consumption (50% less demand) and 60% reduction (60% less demand) in reservoir consumption (similar to 2012-2013 water demand) were applied to historic streamflow return periods (1955-1983) as well as two future climate scenarios. RCP 4.5 and 8.5 were the two climate scenarios applied to these reservoir demands at 30 to 40 year time increments. As seen in figure 37, the average daily flow to the reservoir as well as the 75 percent exceedance flow, or the flow rate that will be exceeded 7.5 years out of 10 on each individual day (based on 1955-1983 modeled data), is plotted against 60% less demand and total demand. Total demand clearly exceeds surface water supply to the city during an average water year (50% exceedance flow). During a 50% exceedance flow, the supply into the reservoir is less than total demand for 92 days. During a 75% exceedance flow, the supply to the reservoir is less than total demand for 112 days. This does not imply a dry reservoir. In fact the reservoir would be greater than 50% capacity if no flow augmentation was occurring. Without significant efforts to conserve reservoir water through more sustained aquifer use by the City of Troy, baseflow augmentation is only feasible 1 out 2 years. More work would be needed to determine if groundwater wells could provide the additional water necessary to reduce water demand from the reservoir by 70% to ensure baseflow augmentation 8 out of 10 years.

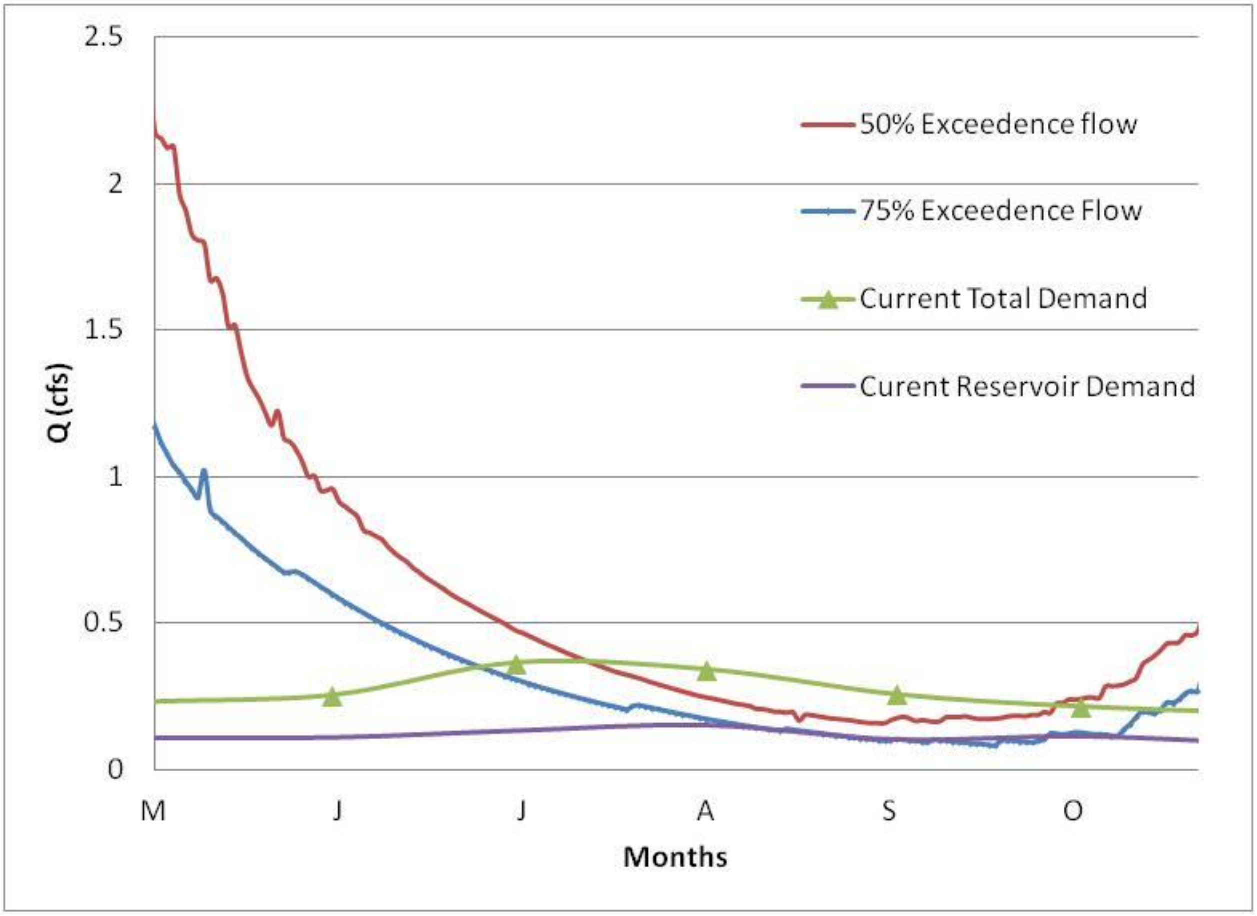


Figure 37: Average total monthly demand from the reservoir compared with the supply to the reservoir.

SMR model results show a clear effect of climate change on the annual distribution of water to the reservoir. Simulated streamflow for the 2013-2043 time period using both RCP 4.5 and 8.5 scenarios indicate earlier spring runoff and reduced late summer baseflow in comparison to the 50% exceedance flow for the 1955-1983 time period (figure 38). The difference in summer baseflow between the RCP 4.5 and 8.5 climate scenarios is minimal during the 2013-2043 time period, see figure 39.

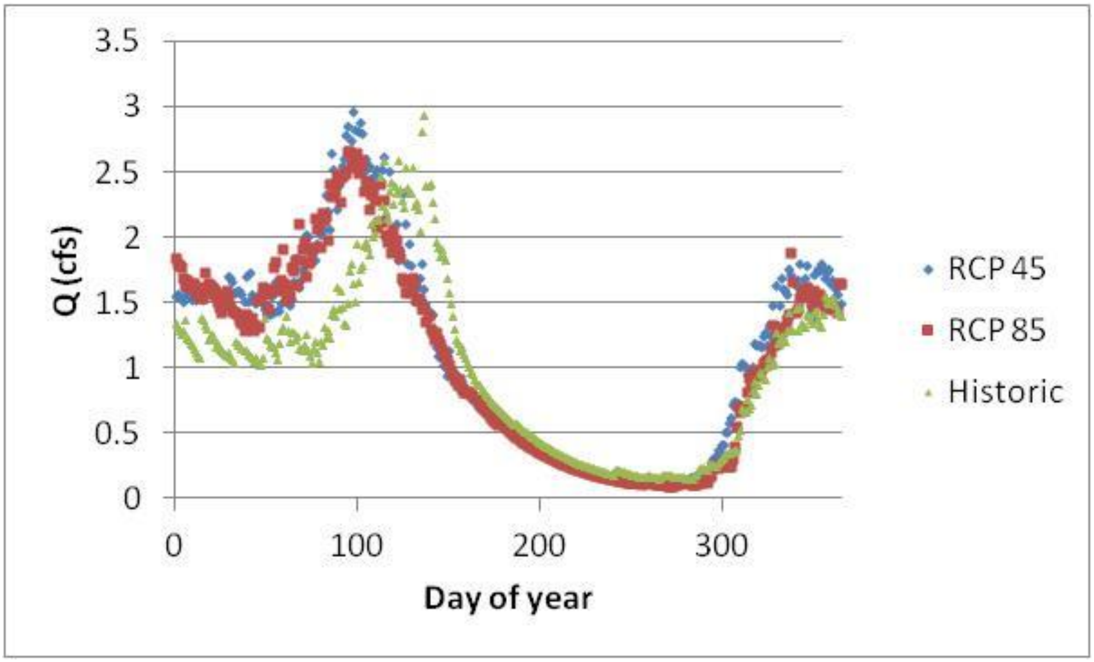


Figure 38: Historic, RCP 45 and RCP 85 median flow (50% exceedance).

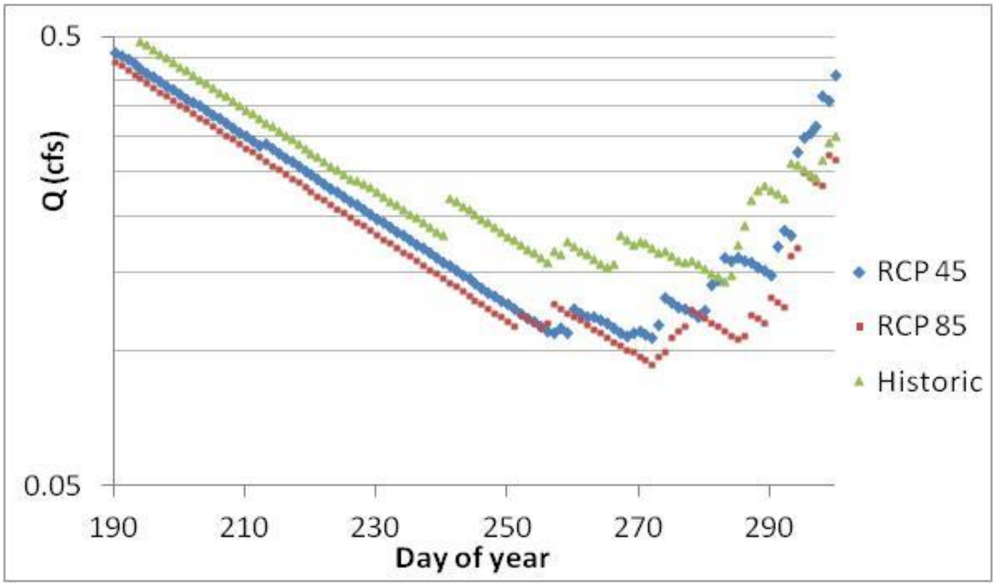


Figure 39: Baseflow recession Historic, RCP 45 and RCP 85 median flow (50% exceedance) in logarithmic scale.

The storage and release of water from the reservoir was calculated for the RCP 4.5 and 8.5 scenarios for various projected consumptive demand to quantify the feasibility of flow augmentation. The reservoir modeling scenarios assumed the reservoir would be used to maintain at least 0.21 cfs immediately downstream of the reservoir and flow release would be regulated such that 25% of the reservoir was preserved as backup reserve for the city. The feasibility was quantified by the probability of exceedance of a given flow. Figure 40 shows the simulated daily streamflow downstream of the reservoir for the 1955-1983 simulated 50% exceedance probability flows with historic demand. In comparison figure 41 shows the response in downstream flow assuming the city of Troy took measures to reduce water demand by 50% from the reservoir. As seen in table 5 and figure 41, reducing historic demand by 50% resulted in 100% wetted habitat for all summer days during the median flow year. The flat line (approximate Julian Dates 200-300) represents active flow augmentation.

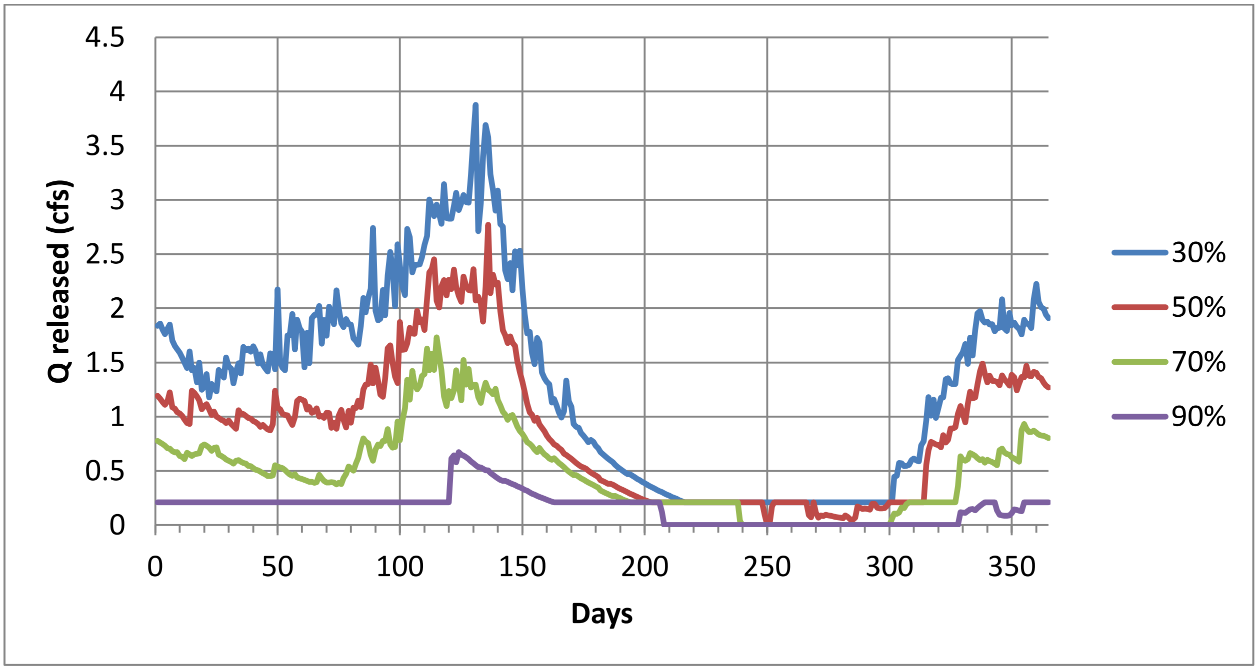


Figure 40: Daily discharge percent exceedance below the reservoir under historic demand and 0.21cfs flow augmentation.

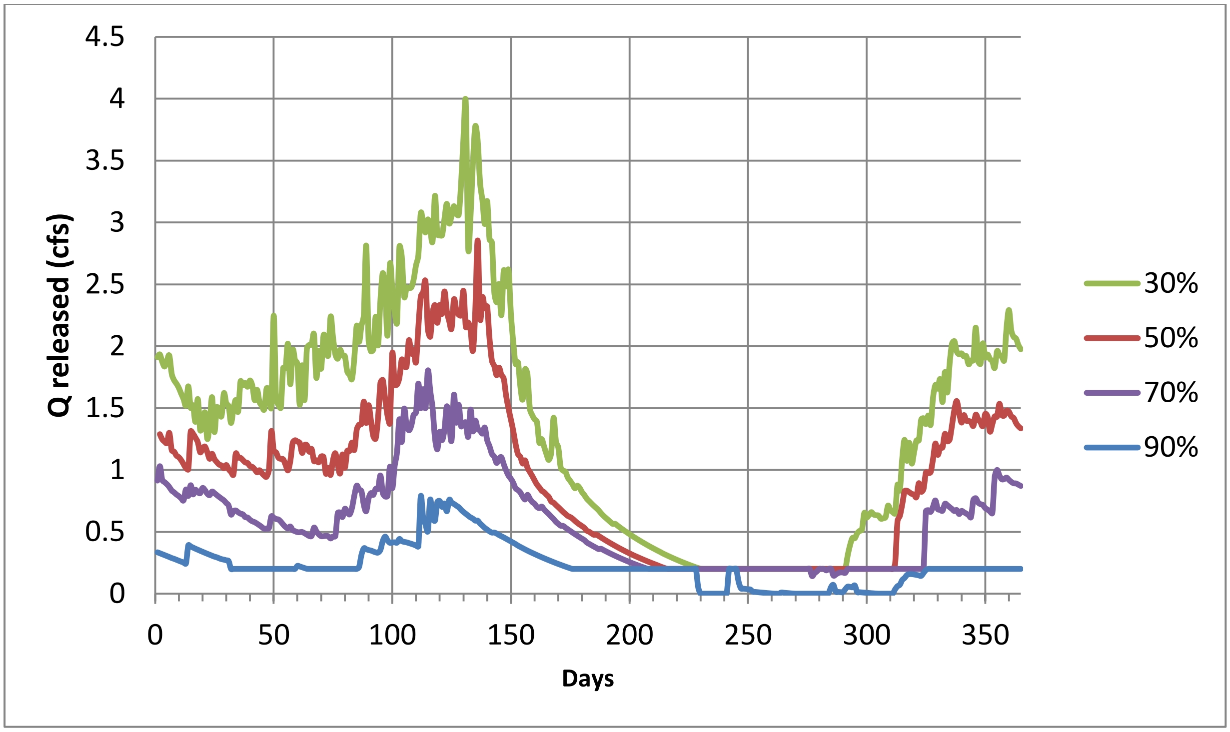


Figure 41: Daily discharge percent exceedance below the reservoir under 50% less demand and 0.21cfs flow augmentation.

Table 5: The simulated number of dry creek days using Historic percent exceedance flows, 0.21 release, 3 demand scenarios and a no release scenario.

Model SLR 1955-1983 Pecent Exceedance	Number of Dry Creek Days			
	Historic Conumption No Release	Historic Consumption 0.21 cfs Release	50% Less Reservoir Consumption and Release	60% Less Reservoir Consumption and Release
30%	67	0	0	0
50%	97	36	0	0
70%	113	69	10	4
90%	227	143	93	87

Modeled results for both RCP scenarios indicate progressively earlier baseflow recession and declining aquatic habitat. The simulated release of water from the reservoir to the creek for the two climate change scenarios were broken into 30 to 40 year time periods (1961-1999, 2000-2029, 2030-2059, and 2060-2100). The flat line at 0.21 cfs during summer days (approximate Julian dates 200-300) represents time periods of active flow augmentation. Stream discharge below 0.21 cfs indicate that 10 km of big meadow creek downstream of the reservoir will likely have stretches of inadequate flow and will potentially have dry reaches. Figure 42 represents downstream flow immediately below the reservoir under a 0.21 cfs flow augmentation campaign for the historic water demand and RCP 4.5 climate scenario. Figure 43 represents the same scenario except with 50% less demand. Likewise, figures 44 and 45 represent downstream flow directly below the reservoir under RCP 8.5 streamflow at incremental time steps, a 0.21 cfs flow augmentation, historic demand and 50% less demand, respectively. Table 6 directly expresses the number of days that the creek maintains less than 100% connectivity for each climate and consumptive scenario.

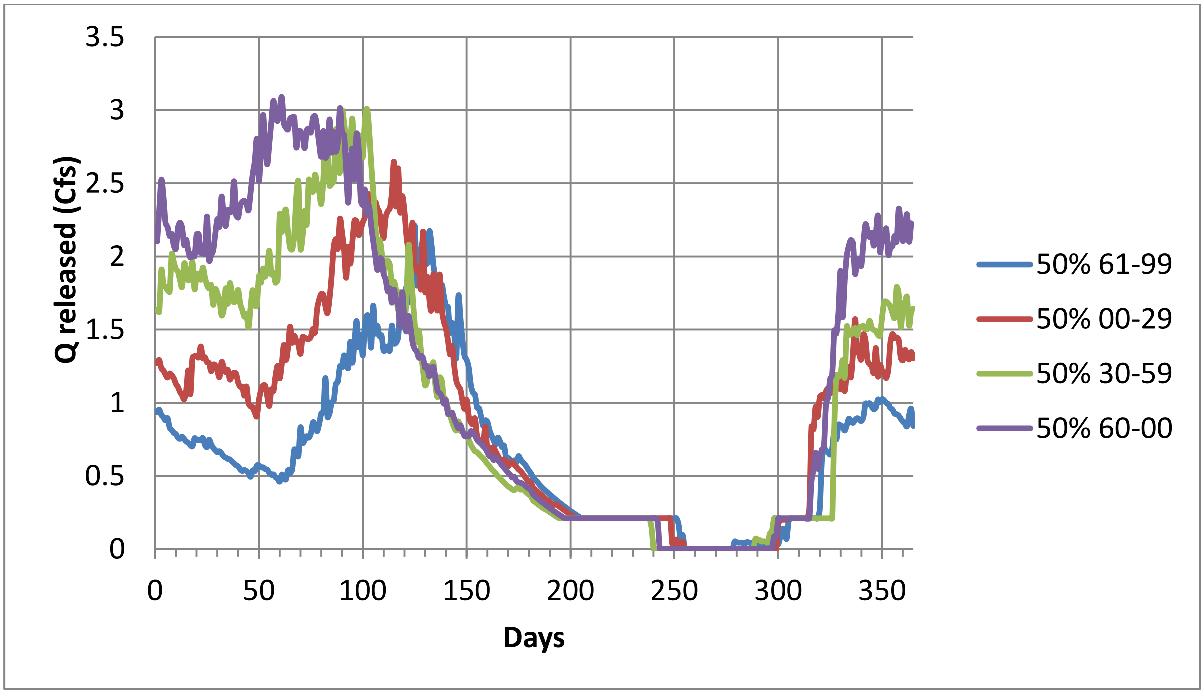


Figure 42: RCP 4.5 Daily discharge 50% percent exceedance calculated at incremental annual time steps below the reservoir under historic demand and 0.21cfs flow augmentation.

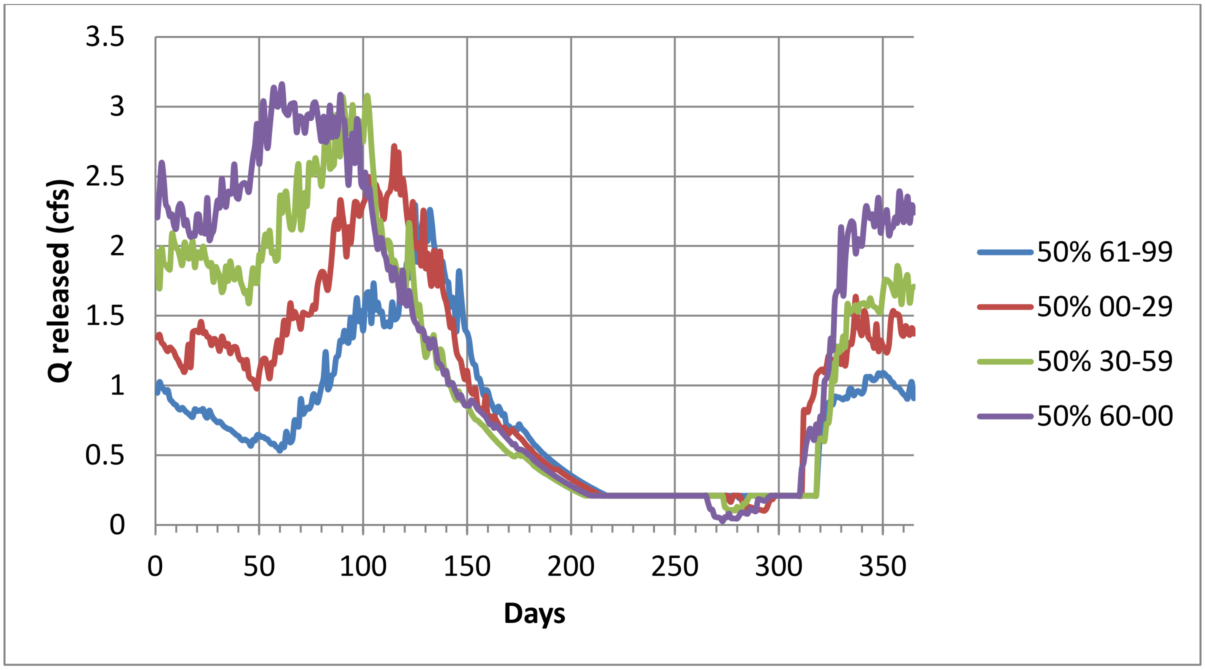


Figure 43: RCP 4.5 Daily discharge 50% percent exceedance calculated at incremental annual time steps below the reservoir under 50% less demand and 0.21cfs flow augmentation.

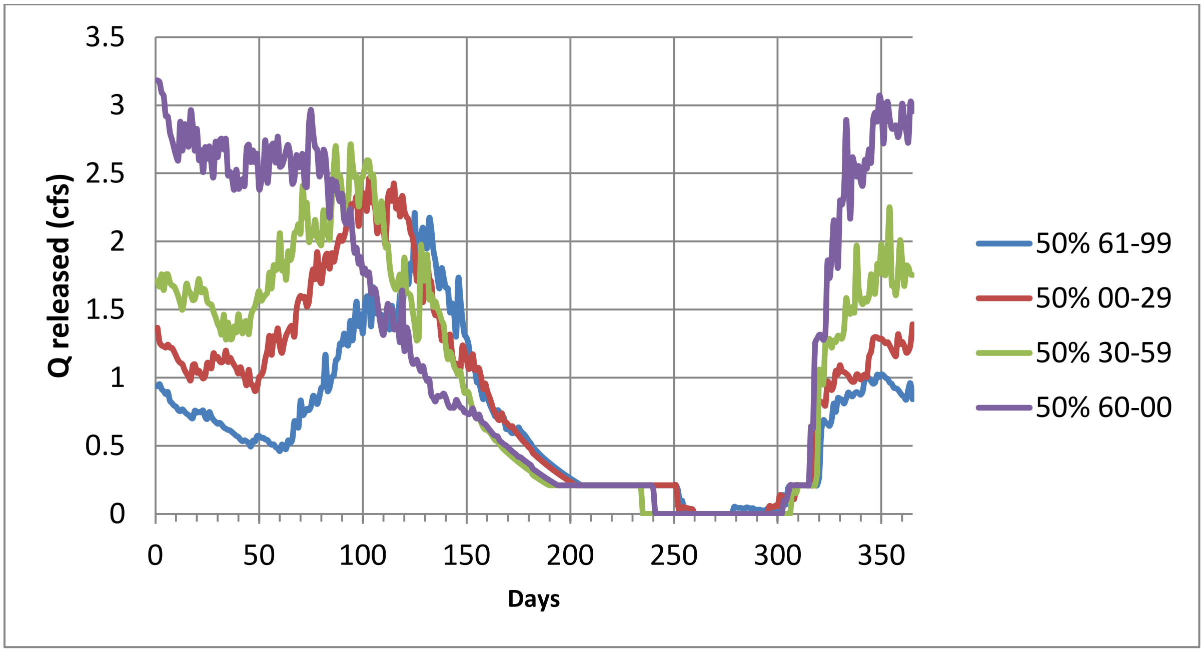


Figure 44: RCP 8.5 Daily discharge 50% percent exceedance calculated at incremental annual time steps below the reservoir under historic demand and 0.21cfs flow augmentation.

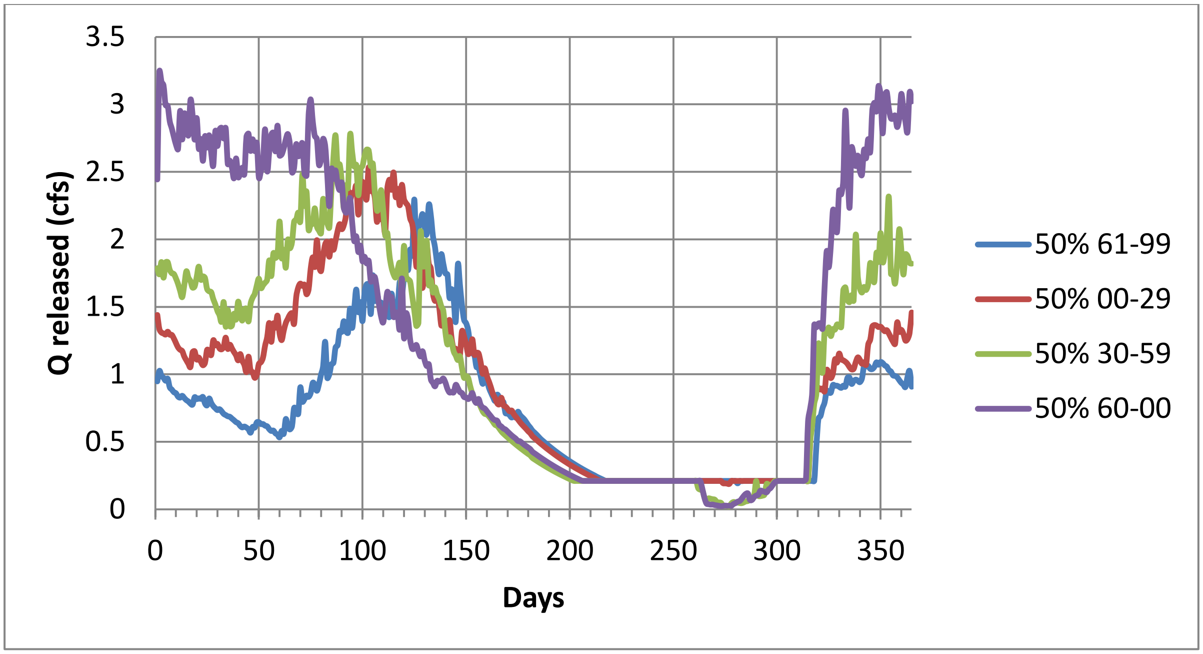


Figure 45: RCP 8.5 Daily discharge 50% percent exceedance calculated at incremental annual time steps below the reservoir under 50% less demand and 0.21cfs flow augmentation.

Table 6: The simulated number of dry creek days for RCP 4.5 and 8.5 using incremental daily exceedance flows (1961-1999, 2000-2029, 2030-2059, 2060-2100) and two demand scenarios.

Model SLR Percent Exceedance	Number of Dry Creek Days							
	Historic Consumption				50% Less Reservoir Consumption			
RCP 4.5	61-99	00-29	30-59	60-00	61-99	00-29	30-59	60-00
30%	0	32	34	27	0	0	0	0
50%	54	52	59	58	1	18	12	30
70%	76	84	89	84	38	49	52	49
90%	107	121	110	103	74	96	80	77
RCP 8.5	61-99	00-29	30-59	60-00	61-99	00-29	30-59	60-00
30%	0	25	41	49	0	0	2	3
50%	54	57	75	66	1	4	36	35
70%	76	75	102	83	38	47	69	55
90%	107	113	127	109	74	81	98	86

Adopting a reservoir management plan incorporating flow augmentation at the current demand from the reservoir, suggest the creek is 100% wetted 31% of summer days. With 50% less demand from the reservoir the percentage of 100% wetted days increases to 62% of summer days. With no baseflow augmentation the number of days with 100% wetted connectivity falls to 6% of summer days.

CHAPTER 4: CONCLUSION

As baseflows continue to decline across the Pacific Northwest, prescriptive streamflow management may provide a viable option to maintain aquatic habitat integrity. As demonstrated in this study, late summer flow augmentation from a relatively small (17.52 ac-ft) reservoir can sustain perennial flow to more than 10 km of an otherwise dry creek. A minimal release of 0.21 cfs from the Big Meadow creek reservoir sustains high quality water (i.e. meeting state water quality requirements) over the 10 km stream length. Approximately 0.16 cfs (0.21 cfs – 0.05 cfs) was lost to evaporation or deep percolation over the 10 km study reach.

Although previous studies indicated that 0.05 cfs upstream flow would ensure dissolved oxygen levels remained above the state standard of 6 mg/l downstream of the City of Troy waste water treatment plant, dissolved oxygen levels in 2013 remained well below 6 mg/l despite upstream flows as high as 0.3 cfs while dissolved oxygen levels in 2012 were mostly above 6 mg/l. The inconclusive results were likely due to differences in the management of the WWTP in 2012 than in 2013. In general flow augmentation does not appear to be a suitable management option to improve water quality conditions in effluent receiving waters when ammonia concentrations emitted from the WWTP are greater than 15 mg/l at the current capacity. Future monitoring is recommended to more fully assess the benefits of flow augmentation on downstream dissolved oxygen conditions.

The Soil Moisture Routing model performed well at predicting observed streamflow data and simulating potential streamflow responses to climate change. Model results indicate baseflow augmentation is feasible in the Big Meadow system during average water years under current climate conditions. To ensure that 100% wetted connectivity was maintained throughout the duration of baseflow periods 7 out of 10 years, would require strict adaptive management to meet the population’s water demand through sustained aquifer consumption and reduced reservoir consumption during summer months.

Water quality and habitat availability improvements were accomplished through baseflow augmentation upstream of the effluent point, therefore to improve juvenile steelhead rearing habitat, it is highly recommended flow augmentation campaigns continue in this system. There currently exist three water rights licensed from Big Meadow creek surface waters, all apportioned to the City of Troy at 1.0, 0.22 and 0.12 cfs (Water Right NO. 86-2014, 86-7012 and 86-2039, respectively). Averaged monthly total consumption values from 16 years of available data and maximum observed discharges for three wells belonging to Troy were used to determine aquifer consumption could maintain total average demand during summer months. At the current demand these wells could sustain the majority of the City's water demand in the summer which would allow a flow augmentation campaign to sustain 100% habitat connectivity the entirety of the summer 7 out of 10 years.

Considering the vast improvements in water quality upstream of the effluent, pursuing baseflow augmentation campaigns is highly encouraged throughout the region on existing and future proposed reservoirs. For example, Spring Valley Reservoir, 37 times larger than Big Meadow Reservoir, is located approximately 5 km East of Big Meadow Reservoir with soil classifications at the outlet of the Spring Valley similar to the Big Meadow creek "meadow reach." This would imply that a baseflow augmentation campaign of 0.15 cfs could maintain a minimum of 6 km suitable rearing habitat. The creek below Spring Valley Reservoir has similar dry stream conditions in summer months. In a system such as Spring Valley creek, a flow augmentation campaign could greatly improve juvenile steelhead rearing habitat. A release of 0.3 cfs from Spring Valley would drop the reservoir level by 1 foot and maintain a minimum of 16 km of habitat.

CHAPTER 5: INTERDISCIPLINARY PROPOSAL: ADOPTING NEW TECHNOLOGIES TO INCREASE WATER RESOURCES EDUCATION.

Out of general interest and in an effort to fulfill interdisciplinary requirements relevant towards the current degree and thesis, an investigation was pursued to examine the best methods for promoting water conservation. The pursuit began with local efforts to encourage summer water conservation focusing on increased awareness of water consumptive affects with regard to aquatic habitat availability and quality for an endangered anadromous species. Childhood education became the focal point of these efforts motivated by the opportunity to reach a larger audience (i.e. parents) with each contact. Collaboration with the University of Idaho College of Art and Architecture Virtual Design Program was established with the sophomore design studio to create an educational, web-based, interactive platform to accomplish water resources educational pedagogies that allowed potential outreach to span even larger audiences. This then led to the current proposal adapting interactive gaming concepts in youth education to promote water resources awareness and systems interactions.

Institution: University of Idaho and Washington State University

PI___Joe Vandal____; **Co-PIs:** Brant Miller, John Anderson, Alex Fremier, Allyson Beall

Faculty Advisors: Erin Brooks, Bio & Agr. Engineering; Kelly Anderson, College of Art and Architecture;

STEM Graduate Fellow for duration of project: 1

K-12 Classes anticipated served per year: 1000+

Number of Schools and District Partners: 5

Target Audience: Middle School

Setting: Rural and inner city

Timeline: 5 years

NSF-supported STEM disciplines and Theme: Physical, earth, social and life sciences for Water Resources

The objective of this project is to create an inquiry-based, collaborative, online platform geared towards middle school science education focusing on the interconnections between hydrology, society, economics, basic chemistry and ecology, utilizing systems dynamics modeling, immersive gaming environments and the scientific method to engage in self-regulated learning. Adopting Next Generation Science Standards (http://www.nextgenscience.org/next-generation-science-standards), the interface will require pedagogy and extensions that educators can easily adopt in their curriculum. Educators will assess student progress through lab reports, guided by a generalized discussion rubric for model parameters as an evaluation tool.

The main goal is to make complex scientific subjects accessible to middle school students by presenting broad conceptual frameworks (social and natural system interactions) through an interactive online platform using Systems Dynamics Modeling as the backbone of the platform. This knowledge base then provides the student with a foundation to motivate deeper understanding of the fundamentals of these scientific subjects and their connectedness to modern life, addressing current social issues associated with water and environmental integrity. Significant emphasis in recent years has focused on providing students with greater hands-on experience in science (Wen-jin et al. 2012). This project builds upon those beginnings and engages students directly in how science is used in real world applications. The adaptive middle school science education platform will start from the application of science principles by establishing common questions to be answered and work down to the fundamentals in order to address the question at hand.

In an effort to captivate the imagination, creativity and desire of students to participate in the curriculum, this online platform will resonate much like a video game, where the student acts as a city developer, building infrastructure to support community growth (e.g. drinking water and waste water facilities, libraries, lumber mills, agriculture, etc.), yet the student is informed that the primary challenge for the city manager is managing salmon in the stream. In this respect, the student annually harvests salmon from the stream and, based on harvest rates, the student is then instructed to play the role of a scientist to determine the cause of poor catch rates over time as a result of poor land management practices. Actively engaging in these simulations will allow the students to gain an understanding of the basics of hydrology through exploratory manipulation of the social and thus physical environments (i.e. climate and hydrology) in context to aquatic ecology.

The primary objectives of this project are to:

1. Design and develop an interactive gaming platform which builds understanding of managing salmon in complex watersheds with competing demands for water.
2. Assess the efficiency of the program to improve student understanding through exploratory use in real class room settings
3. Develop conceptual plans to adapt the tool to other ecoregions around the world.

The final deliverable for the current proposal will accomplish the design phase and production of the mountain eco-region platform and will incorporate exploratory use in local classrooms and youth educational services. Efficiency of the platform will be assessed through pre/post surveys, critical thinking and inquiry exams focusing on simple hydrologic principles, systems interactions, the scientific method, career goals and logical deduction. This proposal will also fund investigatory efforts and the initial design phase for other eco-regions of the world beginning with monsoon driven systems (i.e. India and southern Asia). Each eco-region will act as a closed system that allows the student to manage the land, water and waste water to support community growth. Concurrently, the society in which they are managing relies on an aquatic species for the livelihood of their people. Thus, using land management practices, the student can explore how hydrologic processes have associated effects on aquatic communities through a competitive/reward based approach of harvesting the aquatic species; for example, catch rates (witnessed much like a "first person" video game) will diminish with poorly managed lands, over consumption of water, or degradation of water quality. The final products from this proposal have strong potential to be used as a basis for the development of an educational video game in a commercial or broader educational setting.

INTELLECTUAL MERIT:

Water resource issues and their impacts on society, economics and ecology are increasingly complex, often requiring immediate action by entire communities as opposed to managers alone. However, much of the conversation and knowledge about these systems are restricted to trained personnel, leaving the public unaware of the issues and their role in potentially mitigating negative impacts.

This project provides a unique opportunity for scientists to improve their communication of complex concepts to non-scientists, who then participate in the process of teaching these concepts to middle school students. Scientists will communicate and collaborate with university students in graphic design and computer programming to design an online platform for teaching middle school students in an immersive world. The process of creating this adaptive middle school science platform adopts a theory of teaching that allows undergraduate students the opportunity to be involved in developing educational materials and a pedagogical strategy. Through this process, graphic designers and programmers will learn the interconnections between economics, society, hydrology and ecology and utilize their expertise in information technology to relay the material in a platform open to the general public. Much of the complexities of these systems will be simulated and validated with already collected data pertaining to water consumption, stream losses, water quality parameters, land management practices and nutrient concentrations through the utilization of Systems Dynamics Modeling (SDM). The game experience will allow middle school students to gain an in-depth understanding of individual concepts and larger system interactions related to ecosystem integrity and social mores. This project will help prepare future scientists with systems thinking, allowing for more creative and adaptive management of natural resources and allow the student to act as scientists, further encouraging students of their capacity to conduct general science principles.

BROADER IMPACTS:

The project highlights the value of teaching science with a holistic systems perspective. Middle school students will learn scientific concepts through exploring application-based inquiry. Students will control simulations of social impacts to stream health utilizing the scientific method to determine which factors contribute to the success or failure of various harvest management options of aquatic species. Through the “gaming” environment, students will become confident and comfortable with the methods to address real world issues, increasing science literacy and knowledge pertaining to the human role in natural systems. This application based approach may improve student motivation to dive into the fundamentals of scientific subjects to answer larger social questions. We anticipate this instilled confidence, along with relevant field trips where students gain hands-on experience, will increase the number of students interested in pursuing careers in science or water related fields.

Great efforts have been made to increase middle school performance in science however they have been met with varying degrees of success. The overall consensus is that traditional methods for teaching science do not motivate the majority of US primary students (Annetta 2008). Programs such as GK12 have made great strides in communicating the importance of science to primary students, allowing the students a unique perspective about whom and what a scientist is. However, the sustainability of such programs is expensive. This proposal sets out to create a sustainable educational endeavor that enables primary students to follow the scientific method in respect to social constructs by inadvertently playing the role of a scientist.

Every population around the world inhabits a watershed and as the global population increases, practically every watershed is impacted by human activities. These impacts are wide ranging and frequently reinforce the reality of the immense interconnectedness between water quantity, water quality, species richness, nutrient uptake and ecosystem functioning, inevitably reducing the ability of the system to be resilient. Climate trends and anthropogenic influences are altering many temperate waterways with adverse effects on ecological communities (Poff et al. 2006). Changes in climate patterns are predicted to have more severe hydrologic episodes and in general, an altered hydro system. Spring runoff in mountain systems are repeatedly documented to occur earlier, resulting in earlier baseflows and a reduction in available habitat for aquatic assemblages in late summer months (Hamlet et al. 2006). Consequently, waste water effluent throughout much of the western United States dominates the majority of available habitat for aquatic assemblages. Moreover, watersheds are a function of the terrestrial landscape and the management practices therein.

Hydropower, channelization and flood control are further exacerbations from the natural ebb and flow in our freshwater systems. Ecologic assemblages, specifically aquatic assemblages, have evolved and adapted to the variable seasonal fluctuations within these systems resulting in a complex series of biotic interactions as a result of the physical environment. Until recently, and even still, the majority of management and restoration practices target key, typically threatened, species, ignoring the interactions between food sources, nutrient transfer and the importance of habitat connectivity, which often results in trophic cascades and invasive species altering the original benefits of the watershed. For example, an intact wetland can filter out vast amounts of nutrient loads, that if left in the water column, create lethal condition for aquatic assemblages both in fresh and brine habitats from which the human community relies on for sustenance. Ironically, where there were once vast wetlands, now stands vast agricultural influences that contribute the high nutrient loads (Zedler and Kercher 2005).

A systems understanding of both the physical and biotic responses, including economic feedbacks (i.e. the human influence) is vital for adaptive management. One of society's most pressing concerns is drinking water quantity, quality and irrigation. As these components continue to be jeopardized by a changing climate, over allocation of water resources and poor land management practices, the effects to consumptive social water demands are only recently being felt in the United States (fracking, blue baby syndrome, the Navajo Nation to New York). However, the impacts beyond suitable drinking water such as aquatic ecological integrity and ecosystem functioning have had drastic social implications in both rural and native areas that rely on these systems for sustenance, as well as greater economic stress on industrial and agriculture limitations to waste water and water scarcity, respectively. Teaching about degraded ecosystems and associated socio-economic feedback loops in primary science education will better prepare our community and our community leaders. As both water quality and quantity continue to dwindle, conflicts that occur between the differing economic interests, environmental stewardship and the public well being, a well informed public may allow for our world's water resources to serve the greatest good. In the 1970's Government intervention, such as the development of the Clean Water Act and the Environmental Protection Agency, initiated major strides towards better environmental stewardship and public awareness of water resources issues, yet for the past forty years, economics still maintains precedence over suitable aquatic habitat and the quality of future water supplies. In response to the complex social and natural systems affecting our water resources, many immerging fields have developed such as socio-hydrology, eco-hydrology and integrated water resource management to mitigate conflicts and preserve the integrity of our water resources. Comparable to the necessity of creating new scientific fields, adaptive resilience to manage our water supplies for the greatest good is imperative. Social consciousness of water resource issues should span every discipline, in both blue and white collared fields. Baron et al. (2002) relentlessly stresses the need for policy reform and greater educational efforts with respect to ecosystem functioning and water resources.

A feasible solution for promoting water resources concerns amongst our population is more emphasis of such issues in childhood education. Furthermore, the need to develop future scientific literacy amongst our population, as well as the need to increase scientific inquiry and confidence to pursue careers in science has received continuous attention. The need to change the means in which this is accomplished has received much deliberation over the past 100 years and with the advent of recent technologies, specifically virtual realities, the means of teaching complex systems interactions can forever be changed for the better. This increased knowledge base about water resources and ecosystem functioning among our emerging future leaders may enable policy changes to preserve our water resources, the integrity of our ecological systems and the ability for humanity to be adaptively resilient. Not only will adaptive education provide encouragement for more youth to follow science as a career, but this systems interaction education will set water resources and systems thinking as a backbone to other facets of occupation and to the voting community.

Education in the US, more specifically traditional science education has had its obvious flaws with nearly forty years of sub-par test scores compared to our international counterparts. Political infrastructure and insubstantial funds aside, the methods in which science is taught is out-of-date, focuses on memorization of facts and lacks inquiry based skills required to engage youth motivation for learning the material. Based on the arguments that greater retention is attained through hands-on experiences and further understanding requires big picture concepts (Haury and Rillero 1994), this proposal sets out to justify the need for immersive systems dynamics modeling to engage middle school students in the scientific method as well as conceptual understanding in regards to the Next Generation Science Standards.

System dynamics modeling (SDM) has been used to communicate scientific information to stakeholders and attempts to incorporate the complexities associated with natural resource management. SDM allows easy and inexpensive repetitive testing of complex real world issues in a controlled environment (Winz et al. 2009). It operates under the pretenses of a known systems state and computational development of future systems states through desired time steps creating better informed management decisions. SDM provides a transparent approach to future scenario testing through conceptual diagrams that clearly indicate unknowns while taking into account qualitative stocks and flows, feedback loops and quantitative modeling (Winz et al. 2009). SDM needs to be long term in scope in order to account for lag times and delays within the system.

In the late eighties, SDM began to pick up momentum again with the construct of better computer software, leading to both complex approaches for more detailed understanding of interactions, as well as simplistic applications to provide educational understanding and problem solving requirements of water related issues to the public (Winz 2009). SDM has been used for water resource issues for the last half a century and has evolved from its beginnings of incorporating just hydrologic components of stores and flows to representing hydrologic processes as well as the social, industrial and political requirements of water regionally, nationally, and on a global scale (Winz et al. 2009). Ford (1996), used stakeholder participation to create the Snake River model accounting for the large breadth of components associated with water in the basin ranging from agriculture, politics and ecology. Using participatory model creation has recently been well applauded to allow transparency and understanding, acting as an educational experience to each of the variety of stakeholders. SDM has recently been used in the Palouse involving the uncertainty associated with groundwater supplies, population growth and demands, and potential mitigations with much success in communicating the influences of human actions on a limited resource (Beall et al. 2011).

Baron et al. (2002) described recommendations to incorporate ecological integrity in water resource management among policy makers. While not necessarily utilizing SDM, their arguments support similar thinking to system dynamics modeling such as framing national and regional water policy to freshwater ecosystem needs, localized views of watersheds in context to each individual system, increasing communication and education among disciplines, increasing restoration efforts using ecological principles as guidelines, maintaining and protecting high integrity ecological systems and recognizing the dependence of human systems on naturally functioning ecosystems.

Technology is changing the way we learn and immersion with technology at an early age sets the stage for cognitive patterns and development for the years to come. The use of technology in education has great potential allowing for infinite patience during the teaching process and iterative large scale simulations to allow for full understanding of systems interaction and the mechanisms that drive such interactions. The emersion of educational video games was seen in the late 90's, yet their production and full potential have been limited especially in scope with commercial video games. In 2003 the Foundation of American Scientists promoted educational video games, yet since then few games have been created. Successful endeavors, such as NSF founded projects, Harvard's River City (Ketelhut et al. 2010), of which the design for this study is based, as well as the University of Indiana's Quest Atlantis focuses on water quality and pathogens in order to keep a virtual civilization healthy. The students in these games act as collaborating scientists to figure out what is making people sick. Both projects instigated amazing student performances, even by the "poorest" of students (Ketelhut et al. 2010). While these narrative, storyboard games allow the student to follow the scientific method, they lack conceptual systems simulations of large scale water resource issues.

Other entities have used systems dynamics modeling as the backbone of educational gaming environments, such as MIT's Fish Banks, focusing on ocean harvest of salmonids, time lags and economics, as well as Climate-Interactive, using systems dynamics within our global community, representing the global system response to alternate human activity. Yet both of these examples lack the immersive visualizations that enable a student to become completely enveloped in the gaming, or learning process. In November of 2013 GlassLab has teamed up with SimCityEDU: Pollution Challenge™

to publically launch an educational video game about climate change and pollution which is very much in line with the current proposal.

Participatory learning allows individuals to build literacy and confidence in the material (Creative Learning Exchange 2013). Moreover, gaining hands on experience, witnessing cause and affect scenarios and collaborating with other peers to solve a problem engages individuals beyond the essentials needed to score good marks, but allows for relevance and creative thinking to captivate the learner. Systems interaction education involving water in an immersive world has direct pedagogical extensions throughout their own community and may motivate students, and subsequently their parents, to become more active in local water related practices. Lastly, presenting water related issues in an interactive approach at a young age may promote more adaptive resource managers in future generations.

THE GAME

The video game should be designed so that the virtual environment (see figure 46 and 47 for an example of immersive worlds) and the students actions through their avatar is a reflection of natural systems interactions based on systems dynamics modeling. The following paragraphs highlight potential examples of game play, however, should this proposal be pursued, Virtual Technology Design and Education students will be responsible to utilize their training towards the best design.

Figure 46: Example of immersive world (YouTube video 2013).

Figure 47: Example of immersive world (YouTube video 2013).

Game play example design:

A cohort of five students begins the game in a small village within a virtual mountain watershed. Each student has his or her representative avatar that has complete autonomy from the other players. They are shown how to operate the game (resource icons, talking to each other and other villagers as well as general movement control throughout the game). A random number generator assigns each individual a trade that is relevant for the city's economy and growth (i.e. timber harvesting, raising cattle, timber mills, agriculture and teachers) however, there are other computer based agents that have been living in the village and they inform the students that fishing the anadromous salmon is the main currency. The student has a tool bar that they can use to learn more about unknown vocabulary or concepts (i.e. a resource icon: anadromous salmon).

It is summer when they initiate the game. With the addition of these five students the current population level is already surpassing a need to secure water resources; they are directed to build a reservoir. An elder (computer based agent) enters the game to tell them to be careful where and how they build the reservoir to minimize impacting the fish migrations. (Second example of resource icon: reservoir designs).

Here is where the virtue of an immersive world is invaluable; after learning of potential reservoir designs and considerations the student can then gain aerial perspective of the watershed witnessing the best placement for a reservoir and the wooded hillsides. Additionally, this is a good time to note that the players are in game time where seasons pass each time the student enters and leaves the game.

As the students continue their trades, autumn rains raise the water levels. As winter embarks the salmon return and the pupils get to commence on their first annual harvest. This is truly a reward based approach to keep the student captivated: the game mode switches to first person while they cast and catch salmon. They are made aware that they are to cure their harvest and use them for currency and food throughout the year.

Spring brings continued work to the students' respective trades. A doctor addresses the cohort about an outbreak of E. coli in downstream village inhabitants and that a waste water treatment plant must be built (resource icon: Treatment plants and how the work).

As game play persists, harvest amounts decrease. The students are instructed to investigate why this is happening through the use of resources within the game. They will learn when the fish migrate and what juveniles require to survive as well as the basics of ecology (i.e. carrying capacity, population recruitment, etc.).

The elder has streamflow data that can be analyzed. The students will learn that summer flows are diminishing and will learn how diminished streamflow affects critical factors to ensure healthy salmon population recruitment. They are then directed to learn about what factors determine the extent of summer flows. Through this investigation they will determine that timber harvest increasing the magnitude of spring snowmelt events subsequently reducing the amount of summer rearing habitat. Additionally, they determine that cattle grazing directly in the stream increase sediments to the water column, which in turn absorb more energy from the sun and cause higher water temperatures and lower dissolved oxygen levels. Finally, they will learn that the treatment plant they built isn't completely effective at converting organic forms of nitrogen to stable forms. They will learn that this conversion instead happens in the stream itself, creating low DO levels.

The cohorts are to work together to maintain or improve current salmon populations by implementing mitigations to one another's trade, improving rearing habitat.

At the end of game play they are to write a lab report explaining what they learned including showing graphical analysis that supports their actions.

COLLEGIATE LEARNING OBJECTIVES

The University of Idaho and Washington State University has several colleges and departments whose undergraduates and graduate students could play an essential role in the creation of such an endeavor. There has been support shown from the College of Education, Art and Architecture (Virtual Technology and Design Program) Environmental Sciences, Waters of the West and Water Resources programs. Creating this platform along side with individuals learning the material will aid in the overall accessibility of the material, while simultaneously providing an education.

PLATFORM OBJECTIVES

The outline below represents an understanding of the major tasks associated with creating a study design to evaluate effectiveness of the proposed educational platform, the tasks associated with designing an immersive, virtual, educational environment that accurately express systems interactions and the ease at which middle school educators can incorporate the platform in their classroom through an iterative design process.

I. Treatment Groups
    i. Control
        1. Develop a six week non-gaming pedagogy addressing watershed interactions, as well as social and ecological limitations
        2. Extension: field trip to local water and waste water facilities
        3. Pre/post student evaluation to assess middle school student performance
    ii. Treatment
        1. Develop a six week immersive gaming pedagogy addressing watershed interactions, as well as social and ecological limitations
        2. Extension: field trip to local water and waste water facilities
        3. Pre/post student evaluation to assess middle school student performance
II. Teacher investment challenges
    i. Pedagogical Focus group
        1. Instructional Workshops
        2. Support through use
III. Create virtual immersive environment utilizing SDM
    i. Adopt Next Generation Science Standards
    ii. Watershed system coupled with social and ecological systems

   iii. Self-regulated student learning following the Scientific Method and simulation

METHODS

IV. Educational game/ SDM initial design
   i. Create SD Models for each of the following:
      1. City water consumption infrastructure model in conjunction with amount of available stream habitat
      2. Land use in conjunction with amount of available stream habitat and water quality
      3. Simplified economics model regarding resource (i.e. land use (timber, agriculture, and cattle) vs Fish and population growth).
      4. Nutrient model for non-point source WQ/ habitat quality(agriculture)
      5. Nutrient model for point source WQ/ habitat quality (waste water)
      6. Modified Tucannon Steelhead Model incorporating previously mentioned models and relating back to lag times and fish population
   ii. Connect Each SD model to create the platform for an immersive world

V. Pedagogical development –Treatment group
   i. Back ground lesson plans before use of game
   ii. Lesson plan to incorporate game play
   iii. Conversation rubrics during game play and after game play
   iv. Extensions during game play
   v. Extensions after game play
   vi. Critical thinking and inquiry exams

VI. Pedagogical development – Control group
   i. Lesson plan development for ecology (anadromous fish, migration timing, juvenile habitat quality, carrying capacity and population recruitment)
   ii. Lesson plan development for hydrology (hydrograph, baseflow, transpiration , snowmelt, and water quality)
   iii. Lesson plan development for the social-hydrologic interface
   iv. Direction to write lab report
   v. Extensions during and after the lesson series
   vi. Critical thinking and inquiry exams

VII. Creating virtual immersive world for middle school exploration

i. SD Model validation based on collected hydrological, ecological and social water consumptive data/literature in small rural town
ii. Scientists teach Undergraduate Virtual Technology and Design students hydrologic, social, ecologic systems through exploration of SDM
iii. Iterative design phase: programming SDM into an immersive world
iv. More in-depth conceptual visualization for components of SDM not directly incorporated in models (i.e. porous media, transpiration, etc.) using animation.

SUMMARY

In general, the objectives of the proposed project would allow middle school student to examine the interactions between society, hydrology ecology and chemistry (see figure 48), while concurrently promoting interdisciplinary collaboration at collegiate levels.

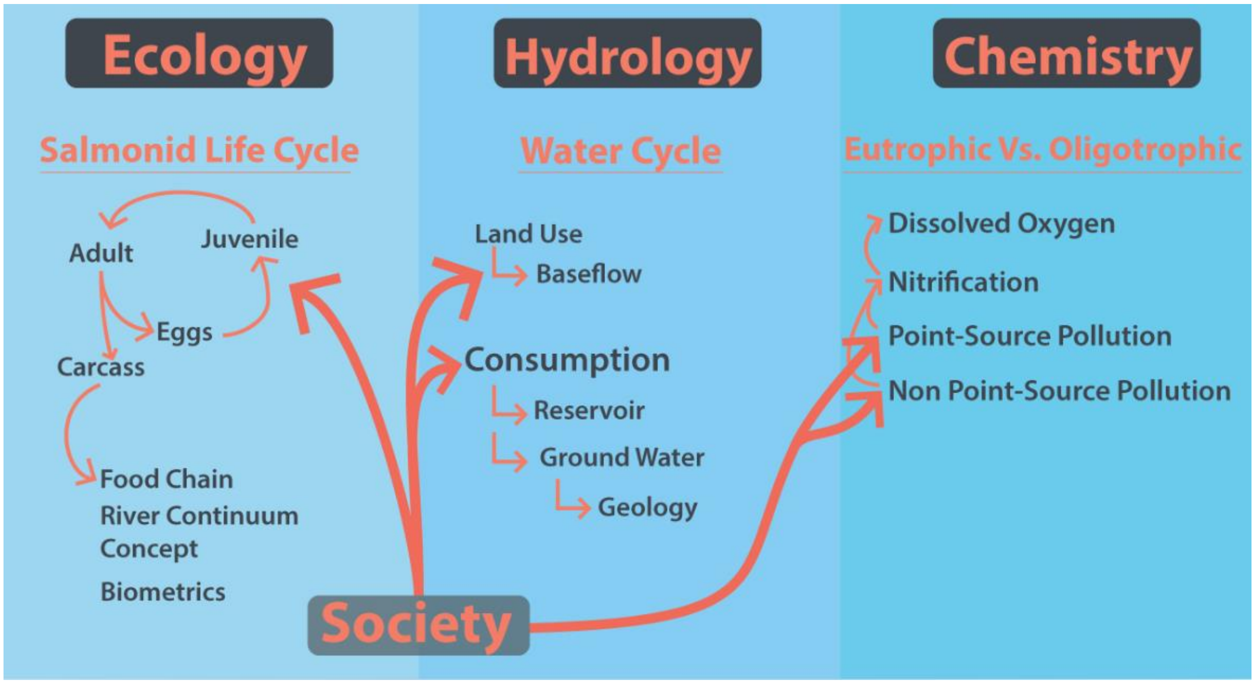


Figure 48: Conceptual diagram of systems interaction within the educational platform.

This example proposal highlights a need for such a platform and a potential ability to accomplish the objectives at the University of Idaho. The technological requirements and limitations are currently unknown by the author and would require further work and collaboration with educators and Information Technology specialists to complete the proposal, as well as validate the legitimacy and ability of completing the objectives at the University of Idaho.

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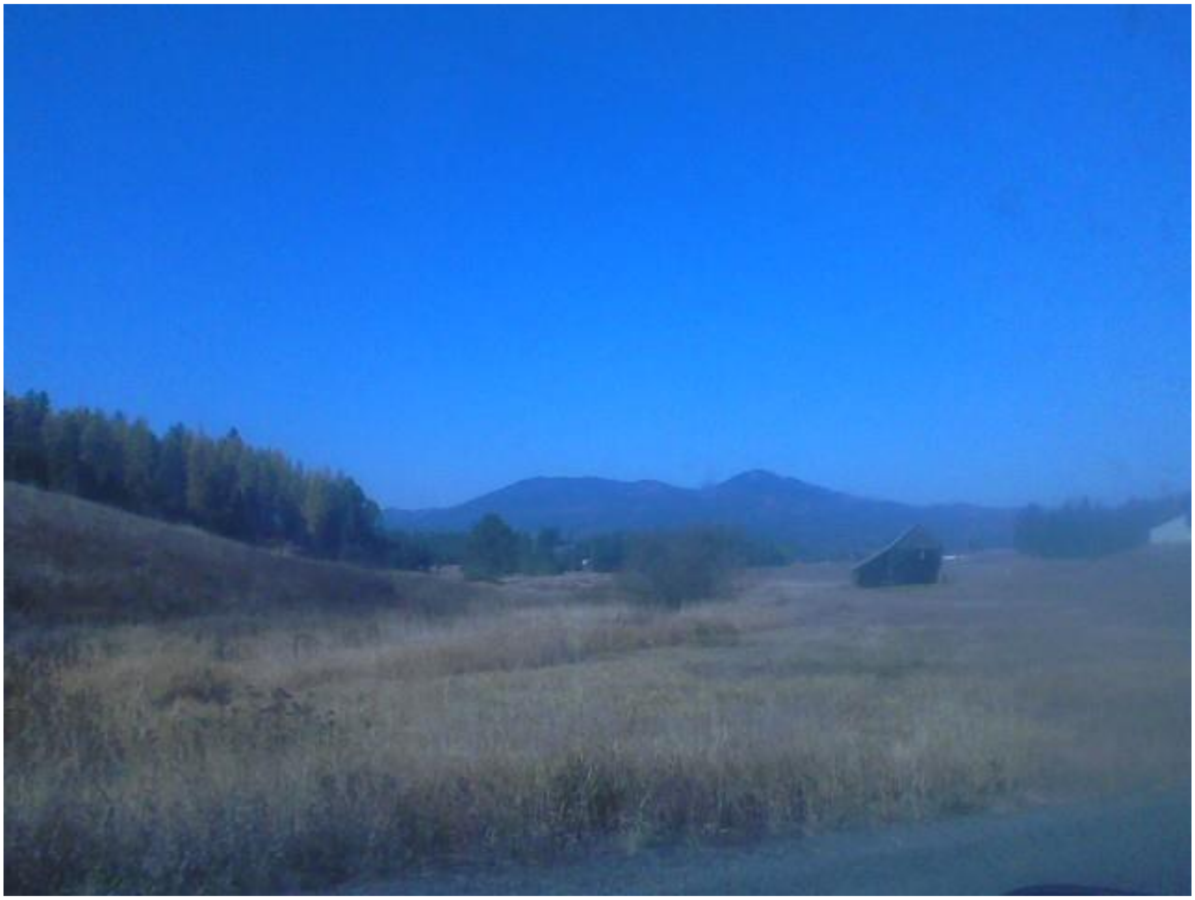
APPENDIX OF AUXILLARY MATERIALS

A 1: Mountain Reach.

A 2: Mountain Reach.

A 3: Mountain Reach.

A 4: Mountain Reach Stream channel.



A 5: Meadow Reach.

A 6: Meadow Reach.

A 7: Meadow Reach stream channel.

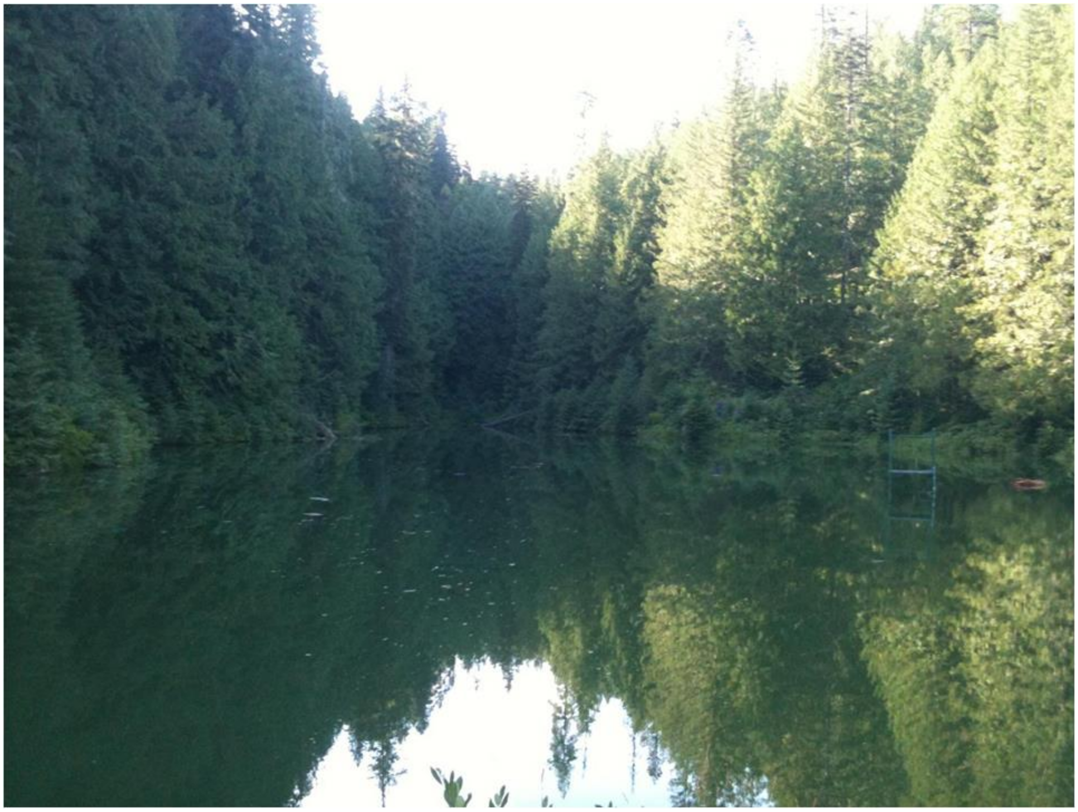
A 8: Top of Canyon Reach during flow augmentation.

A 9: Top of Canyon Reach without flow augmentation.

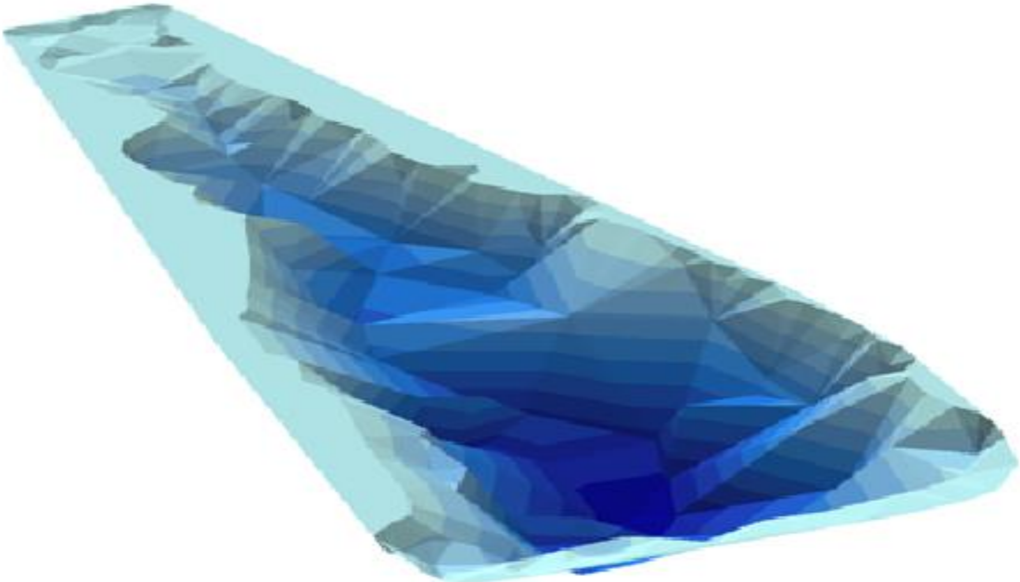
A 10: Canyon Reach.

A 11: Bottom of Canyon Reach stream channel without flow augmentation.

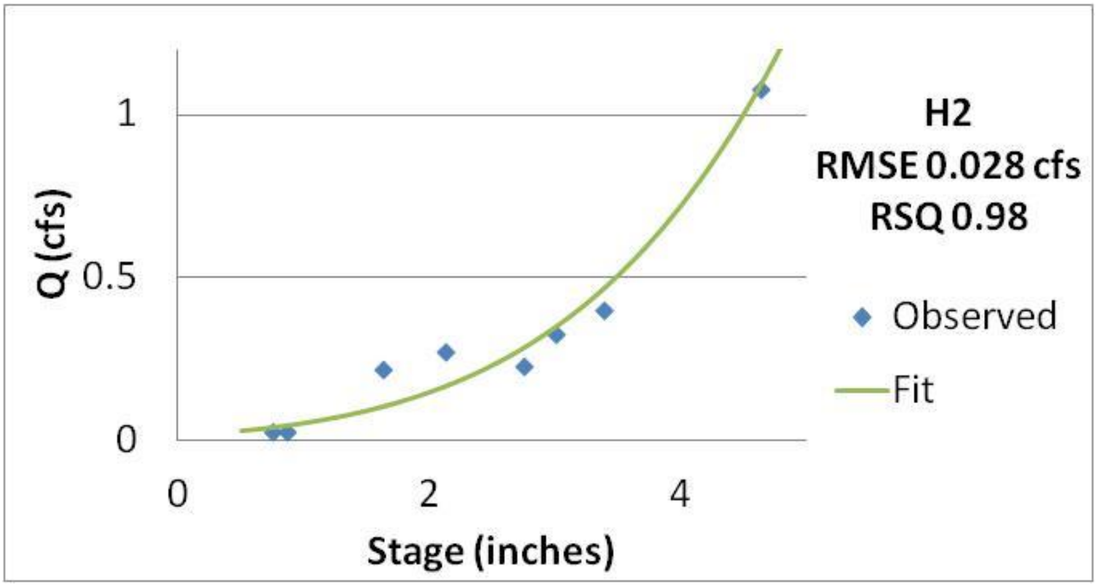
A 12: H10 pool no flow augmentation at the bottom of Canyon Reach.



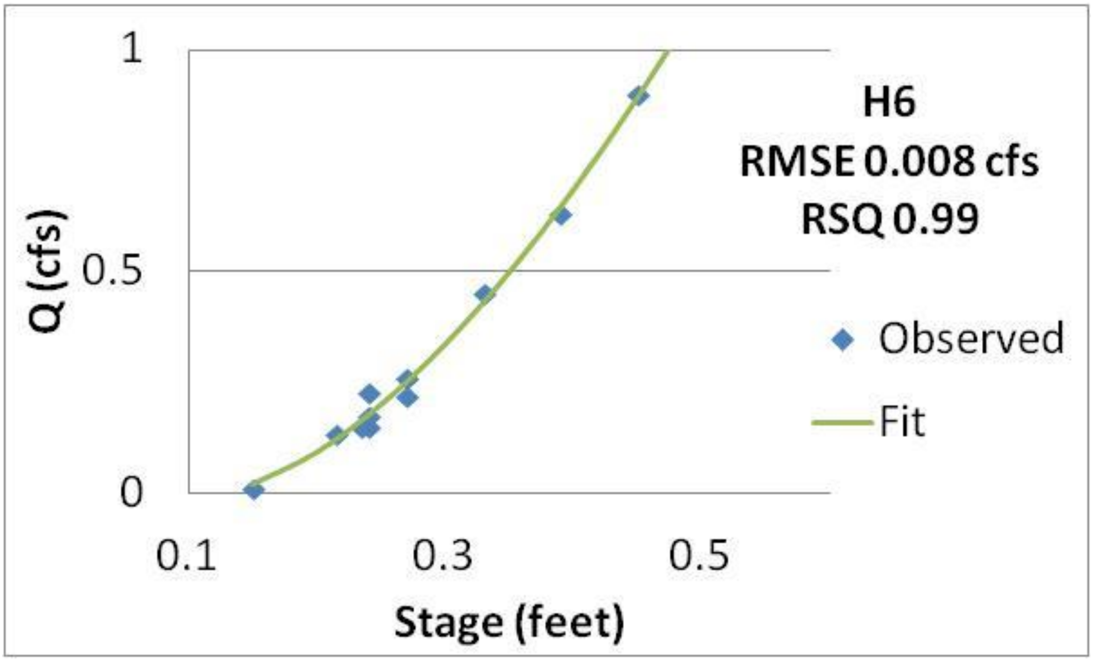
A 13: Big Meadow Reservoir.



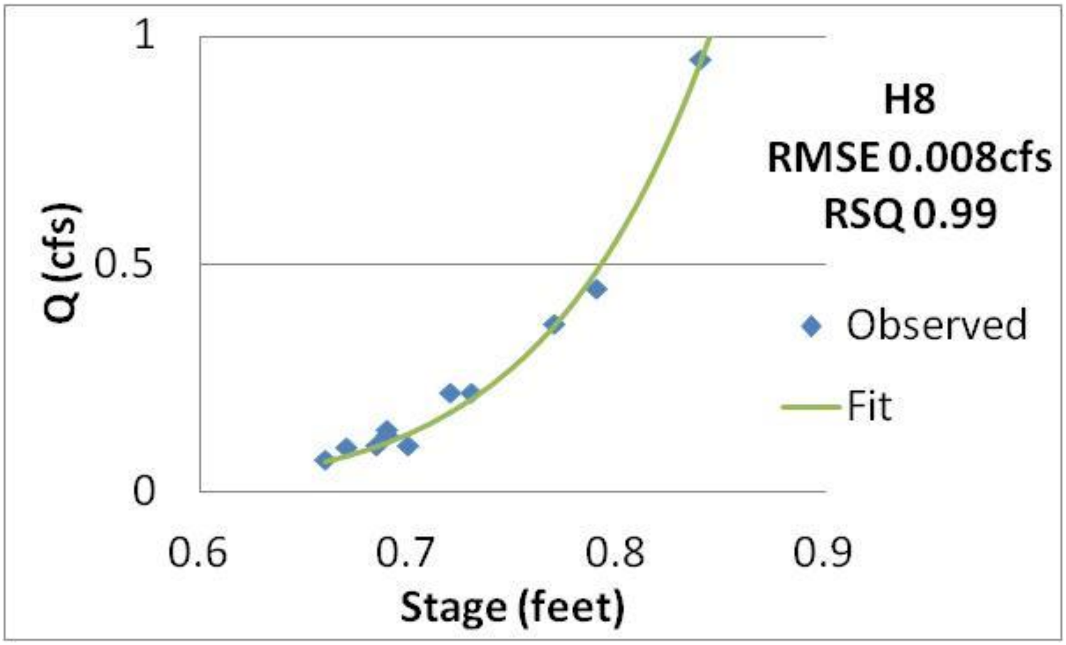
A 14: Bathometric image of Big Meadow Reservoir.



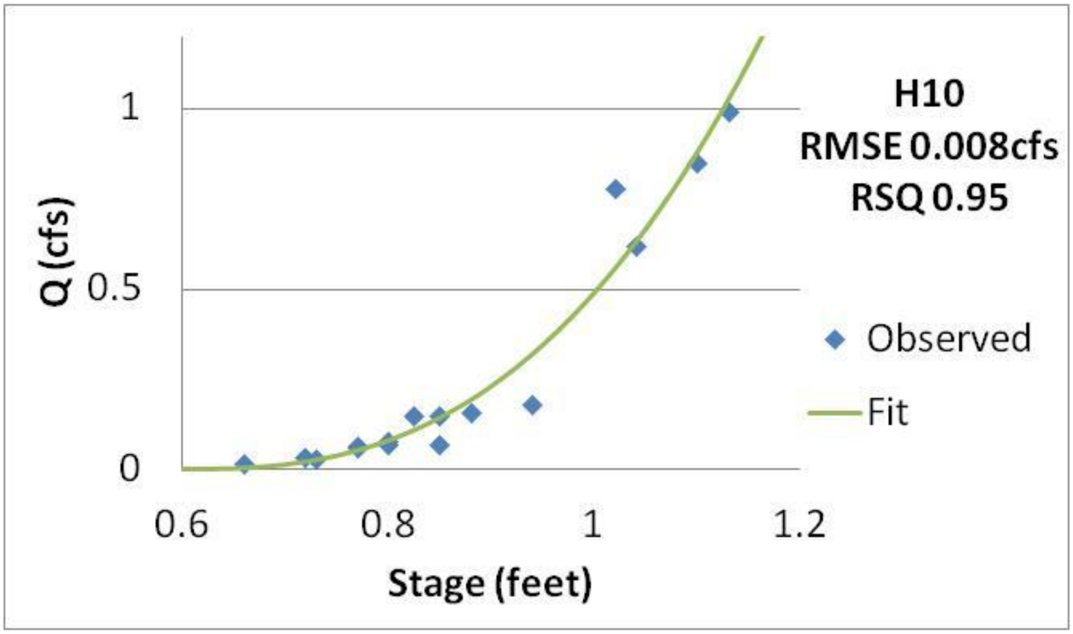
A 15: H2 rating curve showing average error of 0.028 cfs.



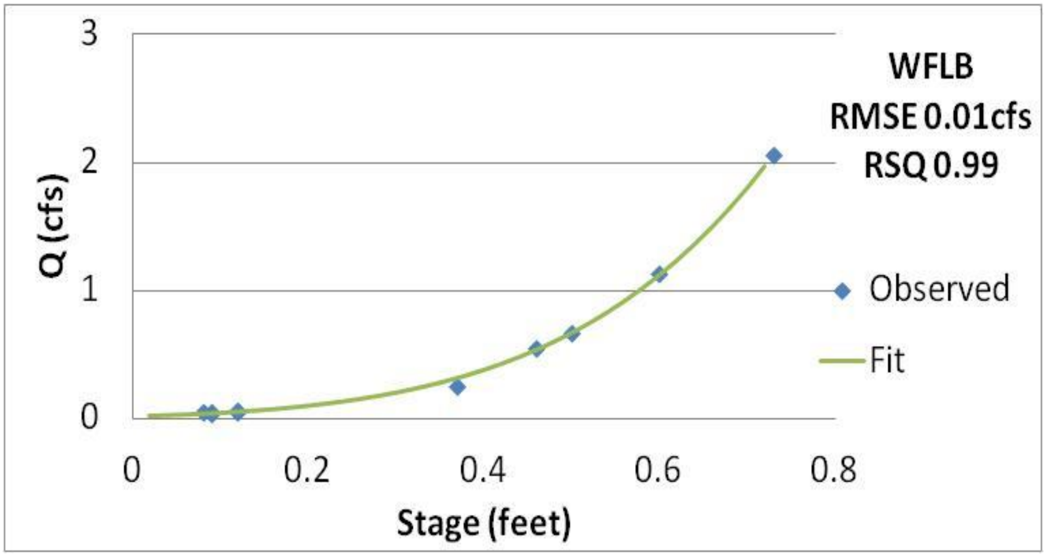
A 16: H6 rating curve showing average error of 0.008 cfs.



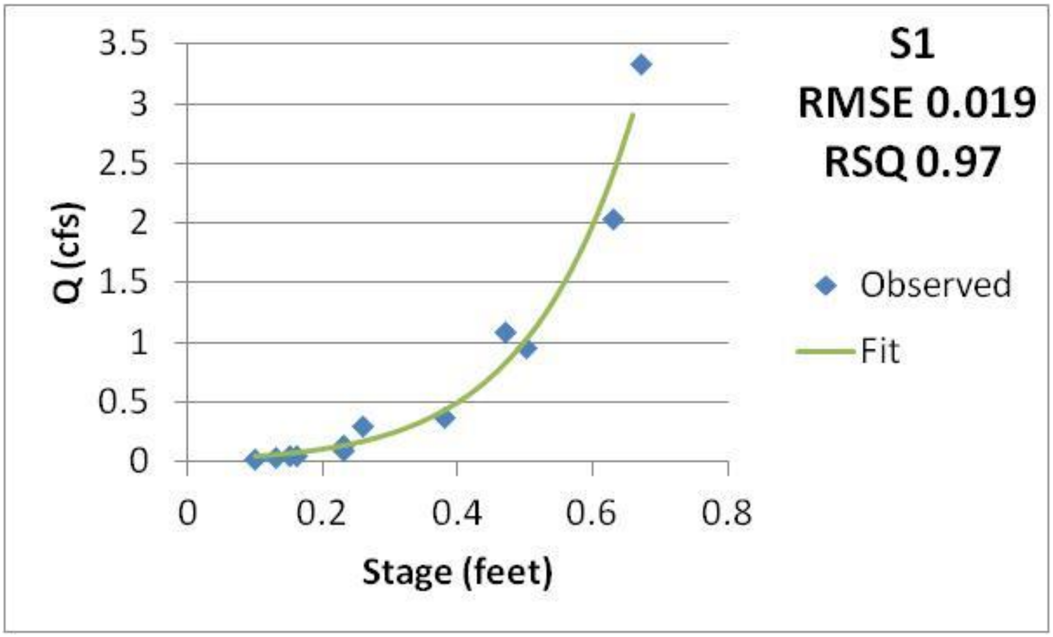
A 17: H8 rating curve showing average error of 0.008 cfs.



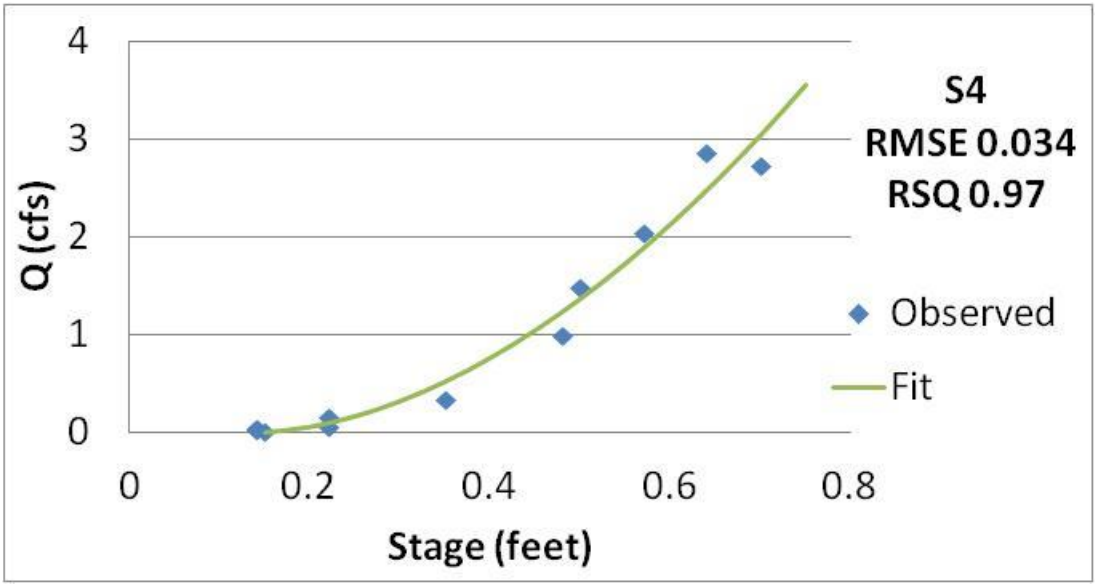
A 18: H10 Rating Curve showing average error of 0.008 cfs.



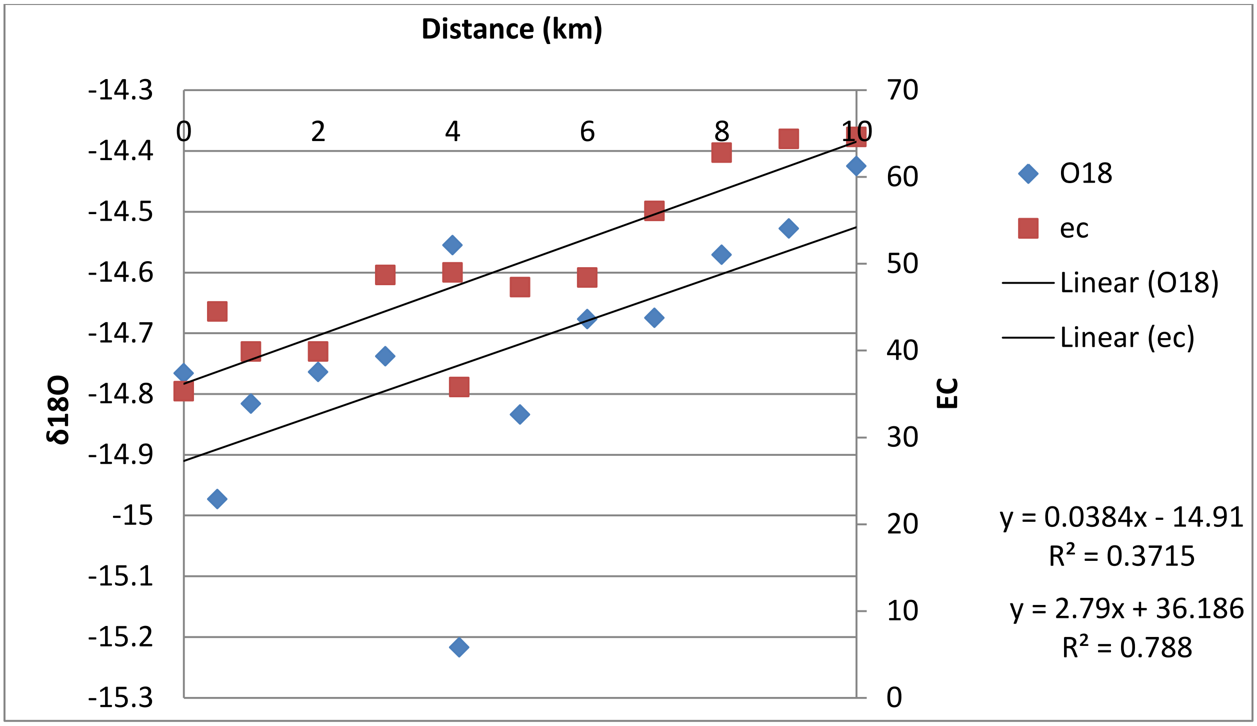
A 19: West Fork of Little Bear rating curve showing average error of 0.01 cfs.



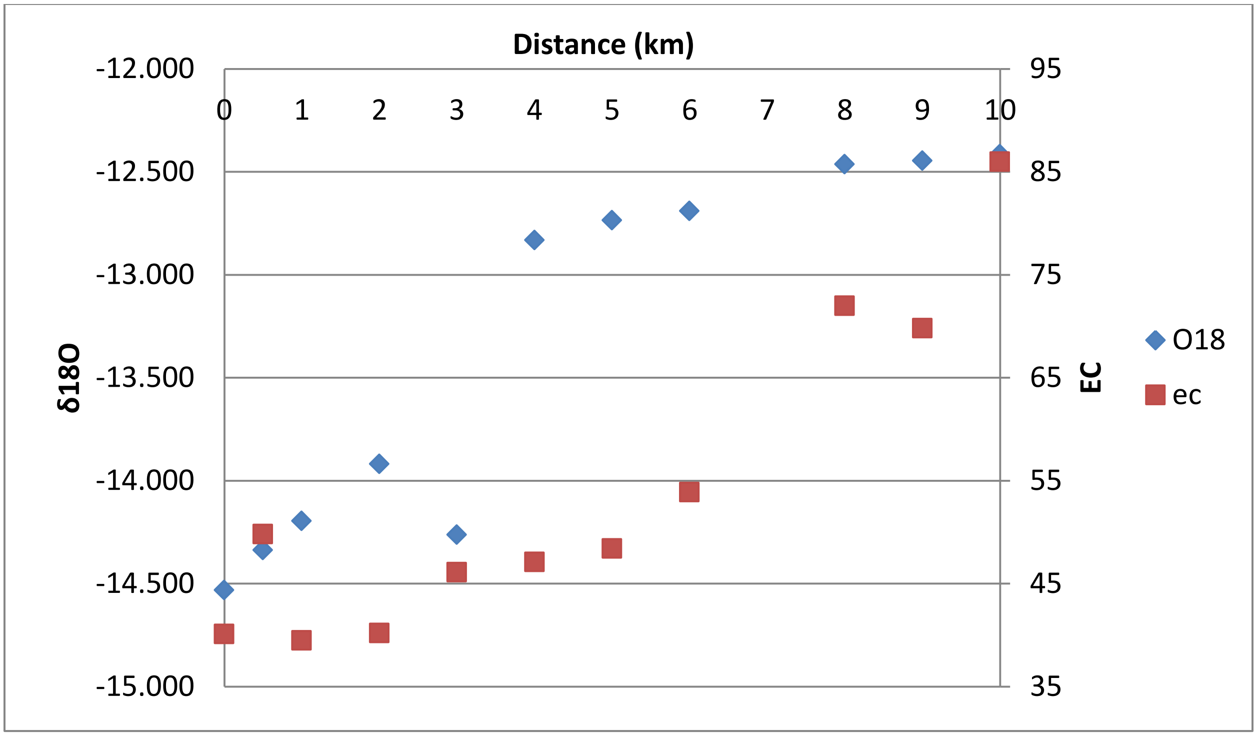
A 20: S1 rating curve showing average error of 0.019 cfs.



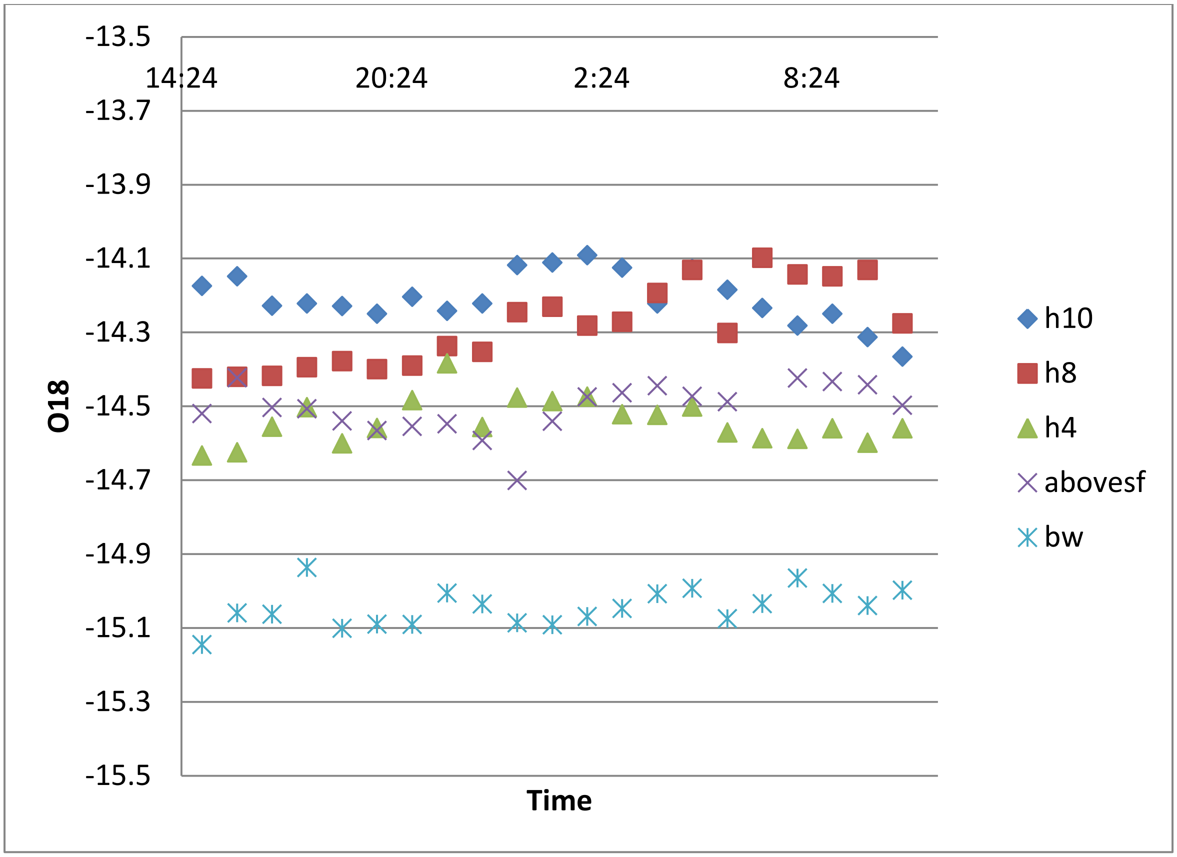
A 21: S4 rating curve showing average error of 0.034 cfs.



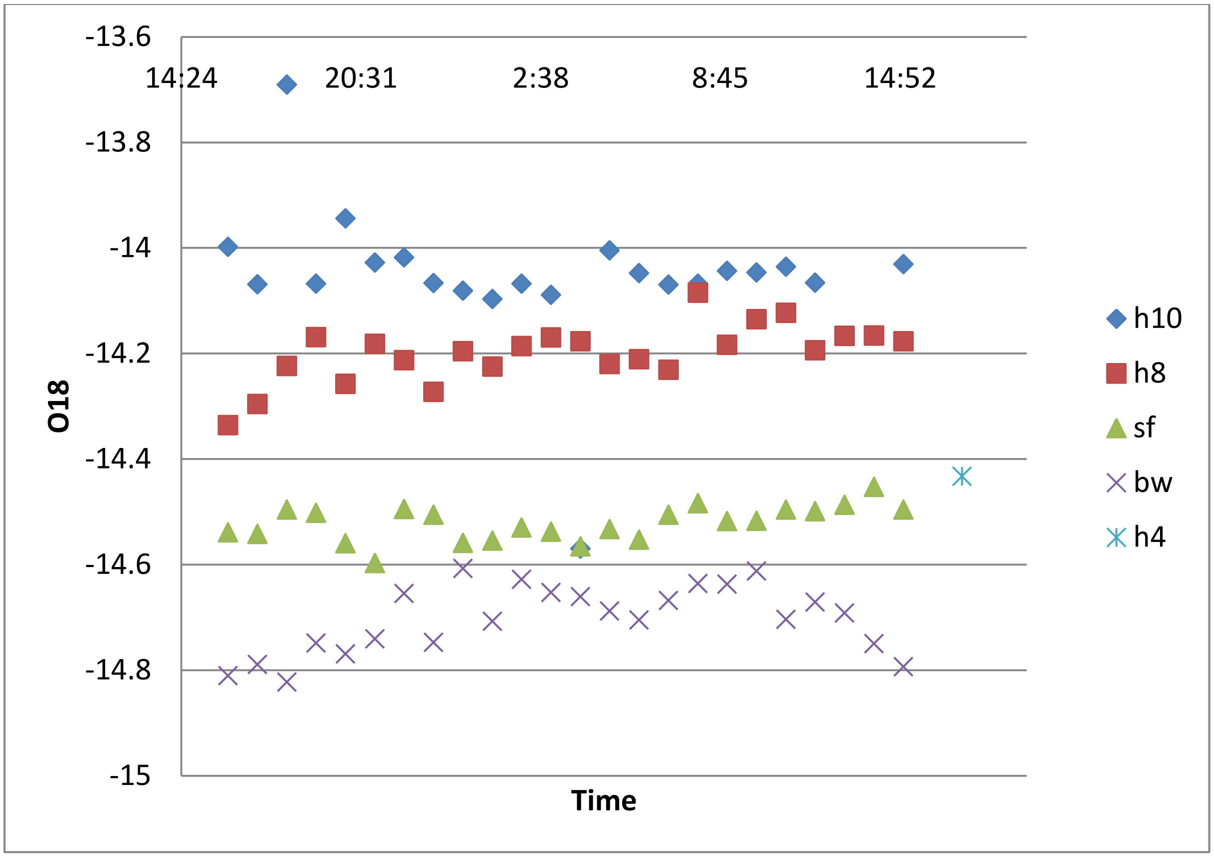
A 22: Initial isotope sampling campaign results daytime longitudinal gradient of EC and δ^{18}O enrichment before controlled release. The depleted signal at 4 km represents reservoir waters added to the system via the slow sand filter overfill.



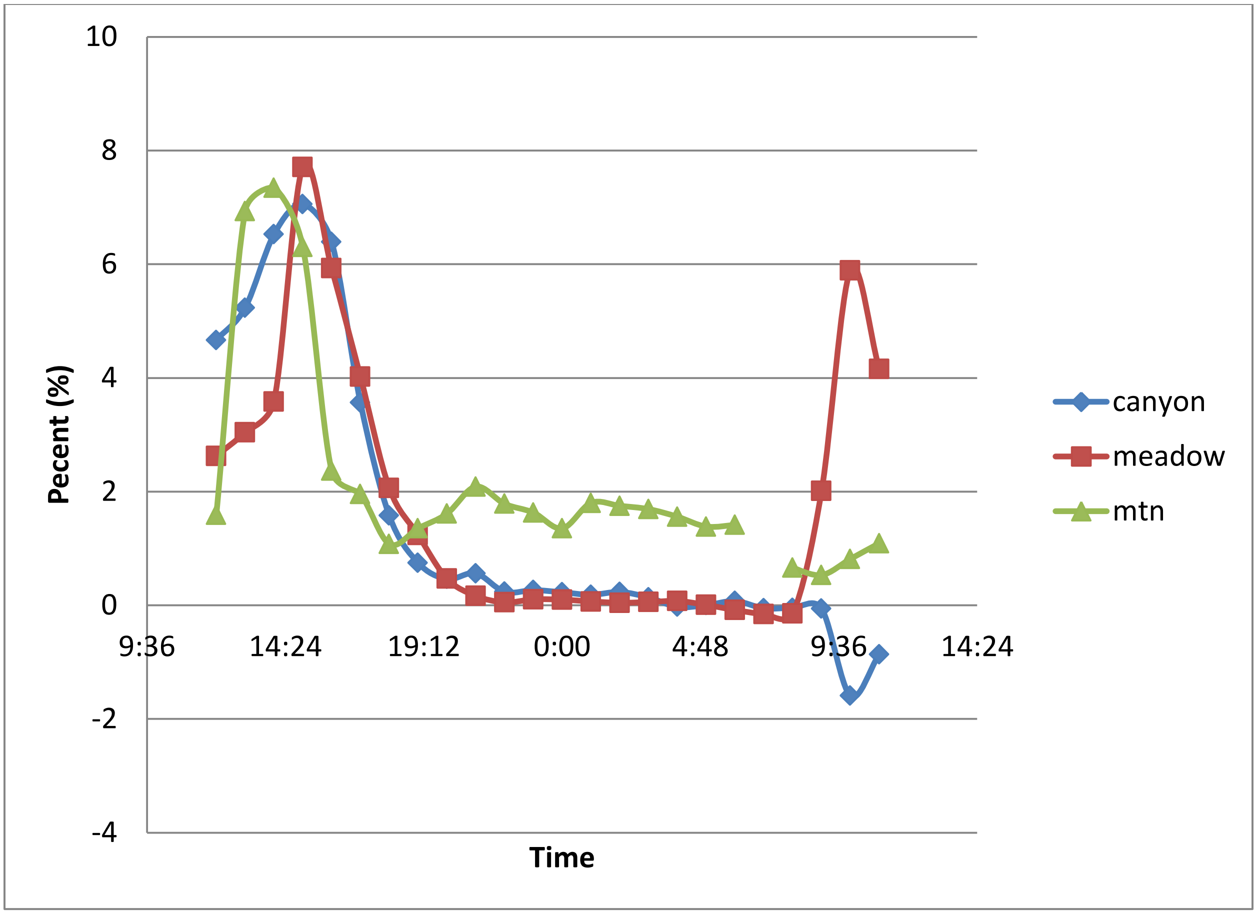
A 23: Nighttime δ18O and EC showing the distinction between the isotopic signal between Day and night as well as the associated lag time.



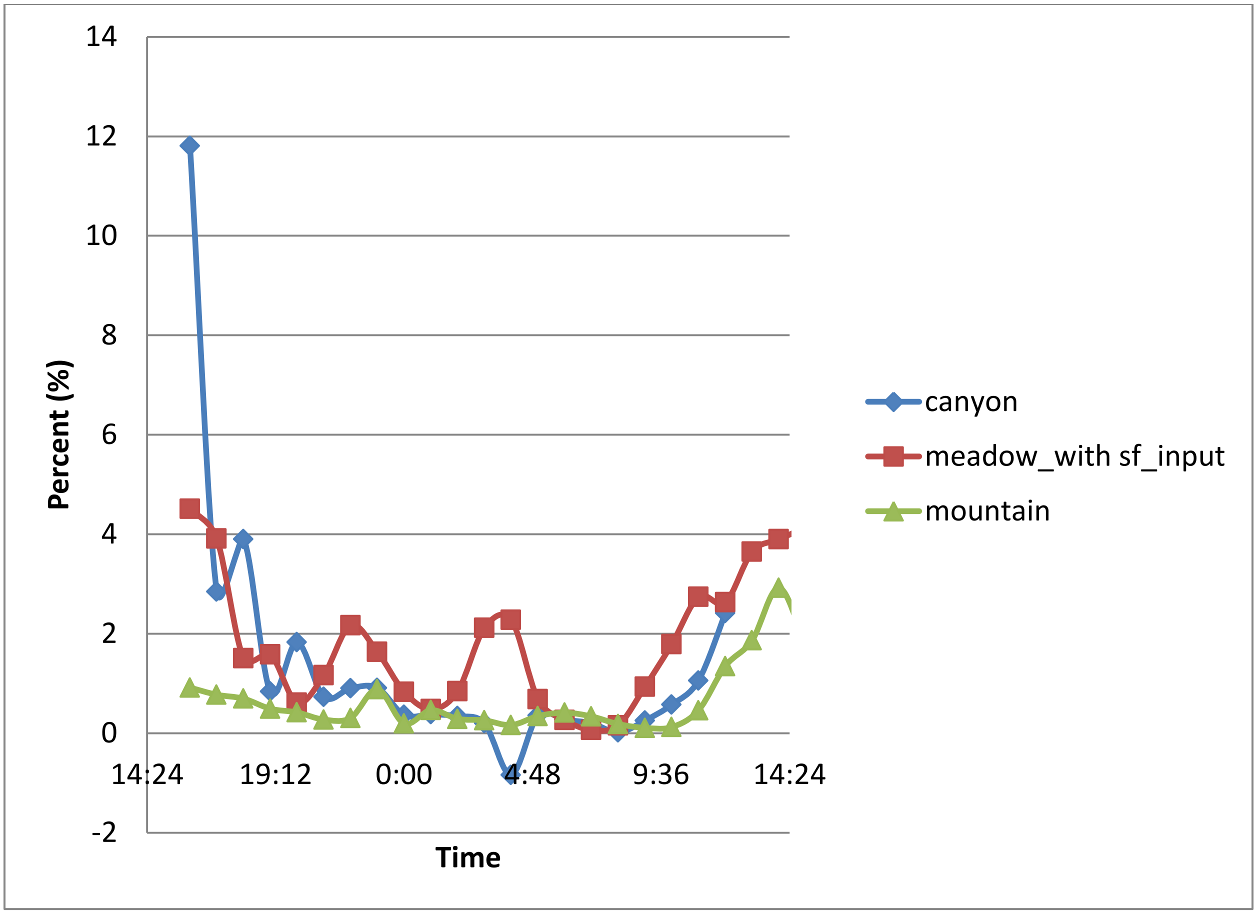
A 24: Raw δ18O values during 24 hour sampling campaign at 0.2 cfs release during 8/8-8/9/13.



A 25: Raw δ18O values at a 0.21 cfs release during 8/14-8/15/13. Note: due to an error, no samples were taken to capture the isotopic signature of Sand filter inputs at the top of the meadow reach.



A 26: Percent of flow lost to evaporation during the 8/8-8/9/13 sampling period. Negative values indicated a deviation from steady-state. In the case of the canyon reach steady state was not achieved at the beginning of the sampling campaign.



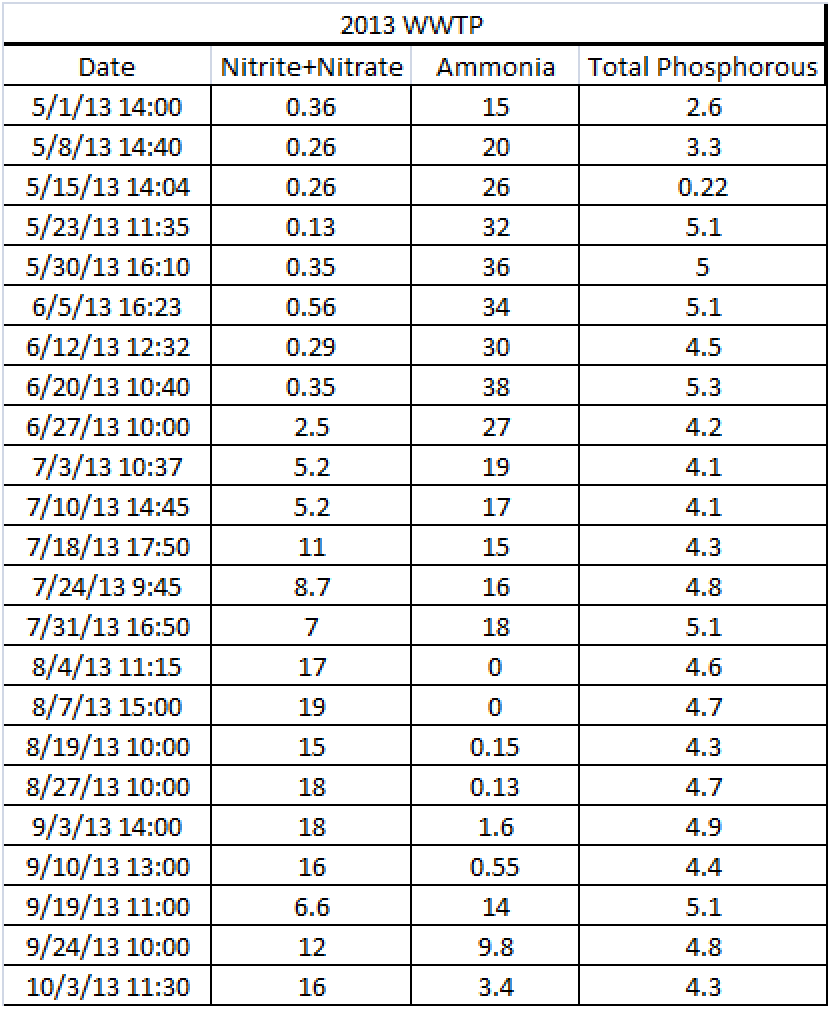
A 27: Percent of flow lost due to evaporation during 8/14-8/15/13. Due to an error samples were not taken directly below the sand filter out flow, therefore the input was directly above the sand filter and does not adequately represent true evaporation.

2012 WWTP			
Date	Nitrite+Nitrate	Ammonia	Total Phoshporous
3/6/2012	0.924	12.233	
3/15/2012	0.474	7.474	
3/24/2012	0.0438	0.605	
3/24/2012	0.438	6.05	
3/31/2012	0.2793	4.369	
4/12/2012	0.046	11.291	
4/17/2012	0.942	11.762	
4/24/2012	0.44	14.077	
5/16/2012	1.2	22.226	
5/31/2012	1.114	28.774	
6/9/2012	5.271	5.442	
6/16/2012	15.325	0.635	
6/16/2012	4.7158	0.3338	
6/20/2012	5.4	2.568	
6/26/2012	6.238	0.567	
7/12/2012	5.62	2.549	
7/16/2012	3.767	5.248	
7/17/2012	3.61	6.608	
7/20/2012	0.5519	6.63	
7/26/2012	14.4076	4.7	5.5
7/31/2012	20.489	1.14	
8/1/2012	20.6	2.5	5.1
8/7/2012	20	0.19	5.0
8/10/2012	17.6136	0.23	
8/13/2012	16.6932	0.22	
8/14/2012	18.4	0.22	4.9
8/16/2012	15.5572	0.23	
8/17/2012	16.7488	0.85	
8/20/2012	16	0.55	4.8
8/22/2012	22	0.22	
8/27/2012	11.998	0.22	
8/29/2012	15	0.50	4.9
8/31/2012	6	0.22	
9/4/2012	13.3178	0.38	4.7
9/7/2012	13.3156	0.22	
9/11/2012	13.5944	0.4368	
9/12/2012	16	0.4368	4.5
9/17/2012	10.2766	0.4364	
9/24/2012	0	9.1	4.9
10/1/2012	15.3798	< 0.10	5.4
10/11/2012	17.7702	< 0.10	4.8
10/19/2012	14.966	< 0.10	4.8
10/25/2012	0.2594	< 0.10	4.8
11/2/2012	11.625	4.4	3.8

A 28: 2012 nutrient concentrations from the WWTP.

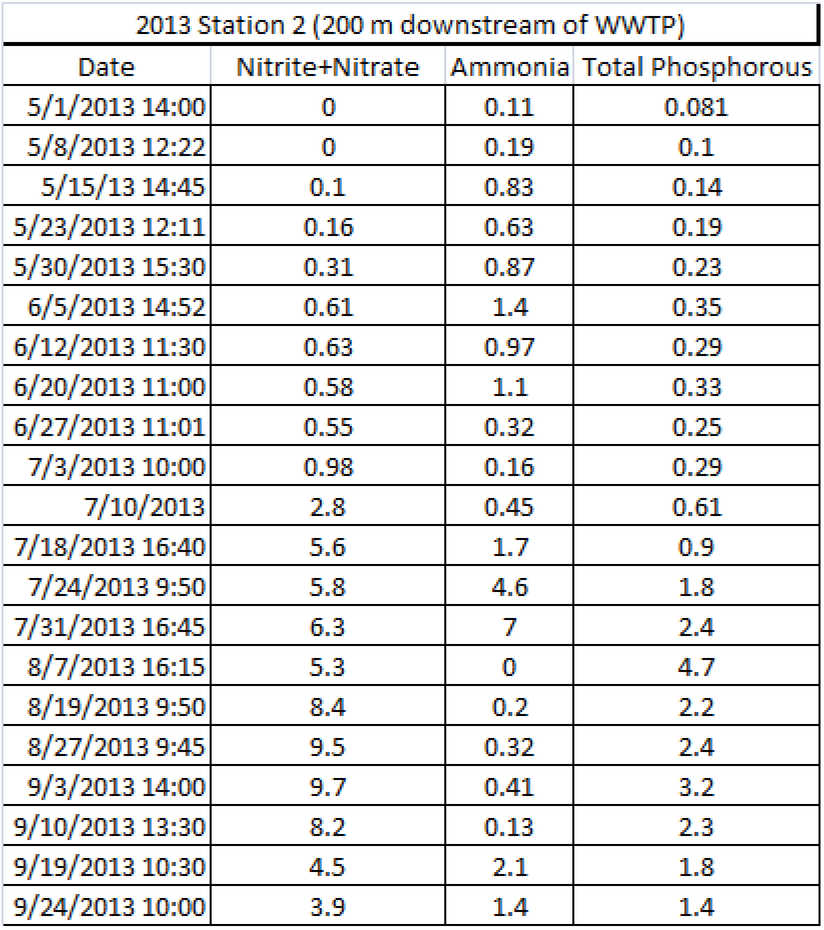
2012 Station 2 (200 m below WWTP)			
Date	Nitrite+Nitrate	Ammonia	Total Phosphorous
3/24/2012	0.08	0.04	
3/31/2012	0.36	0.33	
4/12/2012	0.13	0.09	
4/12/2012	0.10	0.05	
4/17/2012	0.09	0.04	
4/17/2012	0.14	0.11	
4/24/2012	0.12	0.09	
4/24/2012	0.08	0.04	
5/16/2012	0.09	0.06	
5/31/2012	0.11	0.07	
6/9/2012	0.08	0.04	
6/16/2012	0.09	0.06	
6/20/2012	0.40	0.20	
7/6/2012	0.15	0.12	
7/16/2012	0.10	0.06	
7/17/2012	0.25	0.22	
7/20/2012	0.23	0.20	
7/26/2012	2.47	0.22	0.78
7/31/2012	4.28	0.22	
8/1/2012	4.34	2.81	1.2
8/7/2012	5.86	3.45	1.4
8/10/2012	7.96	0.22	
8/13/2012	7.19	0.23	
8/14/2012	5.48	0.23	1.0
8/16/2012	5.63	0.22	
8/17/2012	5.44	0.22	
8/20/2012	6.78	0.23	2.2
8/22/2012	6.74	0.71	
8/27/2012	4.20	0.23	
8/29/2012	6.22	0.22	2.3
8/31/2012	6.89	0.22	
9/4/2012	6.81	0.22	2.4
9/7/2012	8.69	0.45	
9/11/2012	1.05	0.22	
9/12/2012	5.90	0.22	2.0
9/17/2012	5.10	0.45	
9/24/2012	17.00	0.00	2.4
10/1/2012	8.29	0.35	2.8
10/11/2012	9.47	< 0.10	5.4
10/19/2012	3.25	< 0.10	1
10/25/2012	0.09	< 0.10	1.1
11/2/2012	1.38	< 0.10	0.38

A 29: 2012 nutrient concentrations from S2.



2013 WWTP			
Date	Nitrite+Nitrate	Ammonia	Total Phosphorous
5/1/13 14:00	0.36	15	2.6
5/8/13 14:40	0.26	20	3.3
5/15/13 14:04	0.26	26	0.22
5/23/13 11:35	0.13	32	5.1
5/30/13 16:10	0.35	36	5
6/5/13 16:23	0.56	34	5.1
6/12/13 12:32	0.29	30	4.5
6/20/13 10:40	0.35	38	5.3
6/27/13 10:00	2.5	27	4.2
7/3/13 10:37	5.2	19	4.1
7/10/13 14:45	5.2	17	4.1
7/18/13 17:50	11	15	4.3
7/24/13 9:45	8.7	16	4.8
7/31/13 16:50	7	18	5.1
8/4/13 11:15	17	0	4.6
8/7/13 15:00	19	0	4.7
8/19/13 10:00	15	0.15	4.3
8/27/13 10:00	18	0.13	4.7
9/3/13 14:00	18	1.6	4.9
9/10/13 13:00	16	0.55	4.4
9/19/13 11:00	6.6	14	5.1
9/24/13 10:00	12	9.8	4.8
10/3/13 11:30	16	3.4	4.3

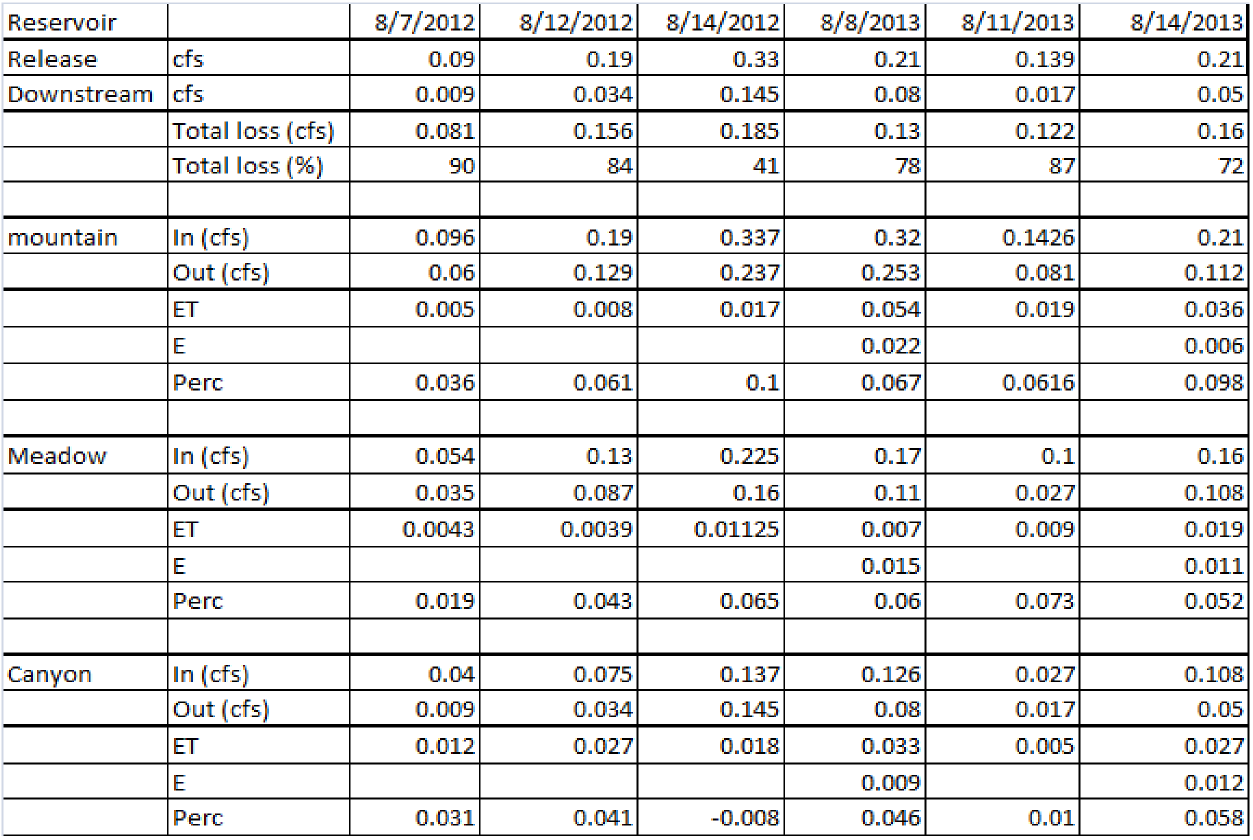
A 30: 2013 nutrient concentrations from the WWTP.



2013 Station 2 (200 m downstream of WWTP)

Date	Nitrite+Nitrate	Ammonia	Total Phosphorous
5/1/2013 14:00	0	0.11	0.081
5/8/2013 12:22	0	0.19	0.1
5/15/13 14:45	0.1	0.83	0.14
5/23/2013 12:11	0.16	0.63	0.19
5/30/2013 15:30	0.31	0.87	0.23
6/5/2013 14:52	0.61	1.4	0.35
6/12/2013 11:30	0.63	0.97	0.29
6/20/2013 11:00	0.58	1.1	0.33
6/27/2013 11:01	0.55	0.32	0.25
7/3/2013 10:00	0.98	0.16	0.29
7/10/2013	2.8	0.45	0.61
7/18/2013 16:40	5.6	1.7	0.9
7/24/2013 9:50	5.8	4.6	1.8
7/31/2013 16:45	6.3	7	2.4
8/7/2013 16:15	5.3	0	4.7
8/19/2013 9:50	8.4	0.2	2.2
8/27/2013 9:45	9.5	0.32	2.4
9/3/2013 14:00	9.7	0.41	3.2
9/10/2013 13:30	8.2	0.13	2.3
9/19/2013 10:30	4.5	2.1	1.8
9/24/2013 10:00	3.9	1.4	1.4

A 31: 2013 nutrient concentrations from S2.

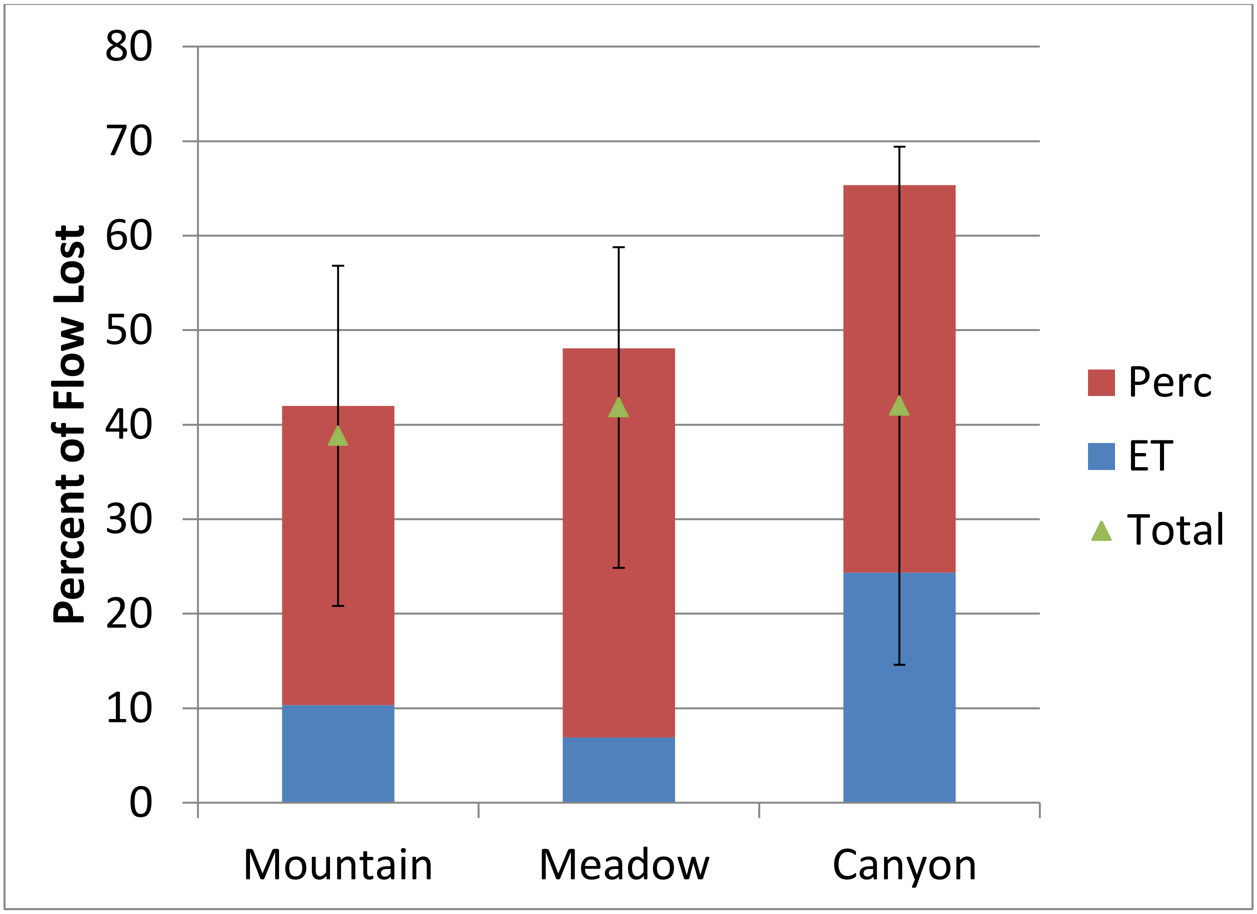


Reservoir		8/7/2012	8/12/2012	8/14/2012	8/8/2013	8/11/2013	8/14/2013
Release	cfs	0.09	0.19	0.33	0.21	0.139	0.21
Downstream	cfs	0.009	0.034	0.145	0.08	0.017	0.05
	Total loss (cfs)	0.081	0.156	0.185	0.13	0.122	0.16
	Total loss (%)	90	84	41	78	87	72
mountain	In (cfs)	0.096	0.19	0.337	0.32	0.1426	0.21
	Out (cfs)	0.06	0.129	0.237	0.253	0.081	0.112
	ET	0.005	0.008	0.017	0.054	0.019	0.036
	E				0.022		0.006
	Perc	0.036	0.061	0.1	0.067	0.0616	0.098
Meadow	In (cfs)	0.054	0.13	0.225	0.17	0.1	0.16
	Out (cfs)	0.035	0.087	0.16	0.11	0.027	0.108
	ET	0.0043	0.0039	0.01125	0.007	0.009	0.019
	E				0.015		0.011
	Perc	0.019	0.043	0.065	0.06	0.073	0.052
Canyon	In (cfs)	0.04	0.075	0.137	0.126	0.027	0.108
	Out (cfs)	0.009	0.034	0.145	0.08	0.017	0.05
	ET	0.012	0.027	0.018	0.033	0.005	0.027
	E				0.009		0.012
	Perc	0.031	0.041	-0.008	0.046	0.01	0.058

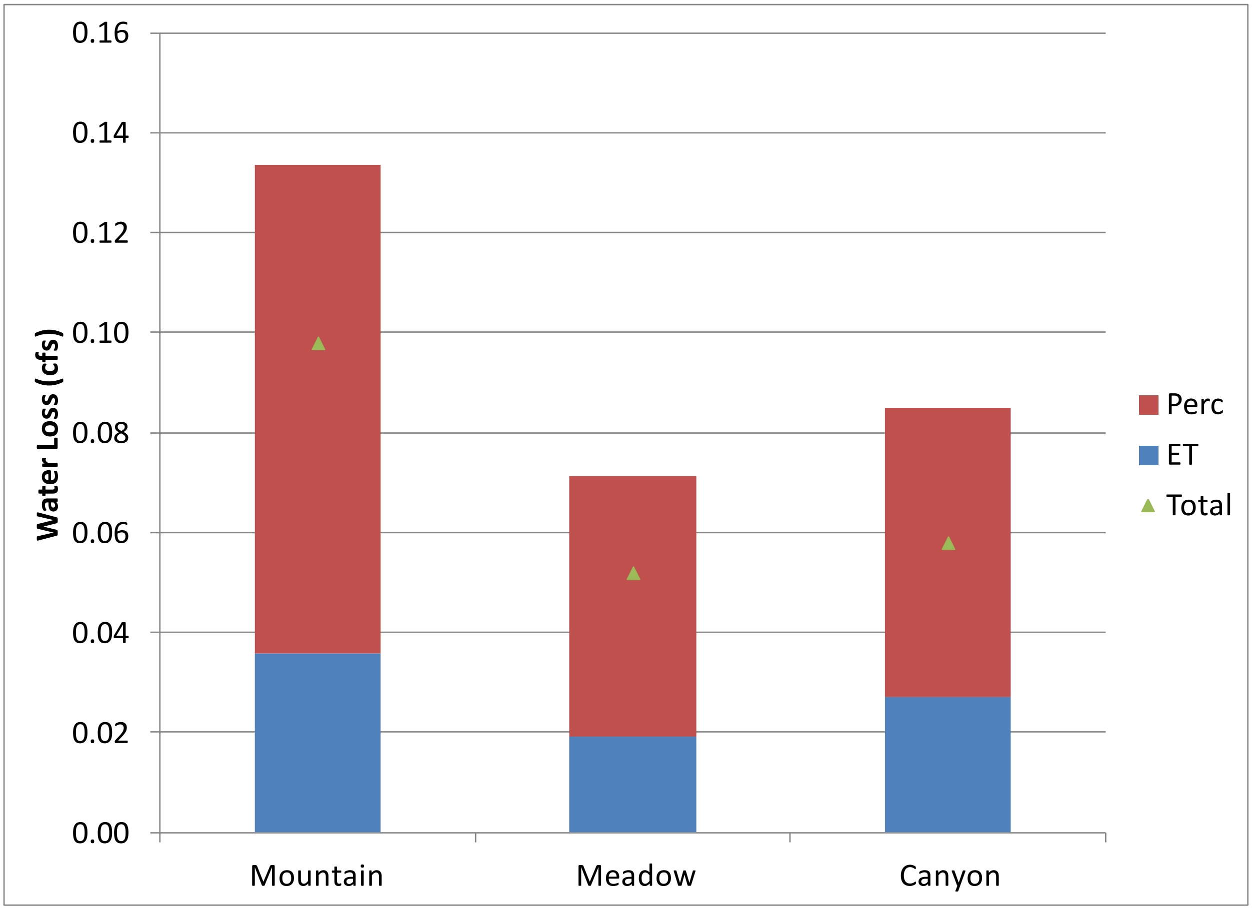
A 32: Delineated losses during controlled flow releases from the reservoir throughout the entire study reach.

SF release		9/17/2012	8/12/2012	8/14/2012	8/8/2013	8/11/2013	8/14/2013
Total	Release (cfs)	0.15	0.13	0.23	0.17	0.10	0.16
	Downstream (cfs)	0.017	0.034	0.145	0.080	0.017	0.050
	Total loss (cfs)	0.13	0.10	0.08	0.09	0.08	0.11
	total loss (%)	88	42	29	35	73	33
Meadow	In (cfs)	0.148	0.13	0.225	0.17	0.1	0.16
	Out (cfs)	0.054	0.075	0.16	0.11	0.027	0.108
	ET (%)	0.01	0.004	0.01	0.007	0.009	0.019
	E (%)				0.015		0.011
	Perc (%)	0.094	0.055	0.065	0.06	0.073	0.052
Canyon	In (cfs)	0.054	0.075	0.137	0.126	0.027	0.108
	Out (cfs)	0.017	0.034	0.145	0.08	0.017	0.05
	ET (%)	0.004	0.027	0.018	0.033	0.005	0.027
	E (%)				0.009		0.012
	Perc (%)	0.04	0.04	-0.008	0.05	0.01	0.06

A 33: Delineating losses for controlled flow releases from the sand filter, approximately located within the top half of the meadow reach.



A 34: Average percent of flow losses per habitat reach.



A 35: Delineated losses during the 8/14/13 release.