Appendix D

Hydrologic, Water Supply, and Fisheries Habitat Effects Modeling

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1.1 Overview

Appendix D, Hydrologic, Water Supply, and Fisheries Modeling provides information about the models and modeling results for the Santa Cruz Water Rights Project (Proposed Project or SCWRP).

Evaluation of long-term hydrologic variability in the City of Santa Cruz's (City) drinking water source watersheds, looking back as well as forward, is fundamental to understanding the City's effects on habitat of special-status aquatic species (specifically, Central California Coast coho salmon [coho] and Central California Coast steelhead [steelhead] which are anadromous salmonids) and options for their recovery as well as the long-term reliability of the City's water supply.[1] The City has long sponsored the United States Geological Survey (USGS) Big Trees and Santa Cruz gages on the San Lorenzo River and utilizes them to assist with seasonal supply planning and operation of the Felton Diversion, which has existing instream flow and other operational constraints dictated by the flow at the Big Trees gage. However, the City intensified its effort in 2003 during development of the Anadromous Salmonid Habitat Conservation Plan (ASHCP) with the installation of additional stream gages and initiation of related habitat evaluations. Concurrent with that, the City was also adopting the *Confluence*® water supply model to evaluate options for improving water supply reliability. Over time, the modeling of the effects of City water operations on habitat for coho and steelhead and on water supply reliability enabled the City, the California Department of Fish and Wildlife, and the National Marine Fisheries Service to develop a set of "Agreed Flows" for the ASHCP. The Agreed Flows strike a balance between water supply reliability and fisheries habitat. Consistent with the City's adopted Water Supply Augmentation Strategy, the City has evaluated its ability to meet supply reliability and fisheries conservation goals with modifications of its water rights. The modeling clearly demonstrated that the City cannot meet its water supply reliability goals without modification of its water rights and that these changes are necessary to enable long term provision of the Agreed Flows needed for the ASHCP. Therefore, the Agreed Flows and water rights modifications are included in the Proposed Project, which is described and evaluated in the Santa Cruz Water Rights Project Environmental Impact Report (EIR). The Agreed Flows are described in detail in Draft EIR Chapter 3 and Appendix C. This overview provides a summary of the three distinct models used to develop and evaluate the Proposed Project and a summary of the Baseline, Proposed Project, and alternatives for which modeling was conducted.

[1] The City owns and operates a water system that diverts and serves water both within the City limits and outside of those limits. References to the City's water system, rights and supplies therefore refer to areas both inside and outside of the City limits.

1.2 Summary of Models

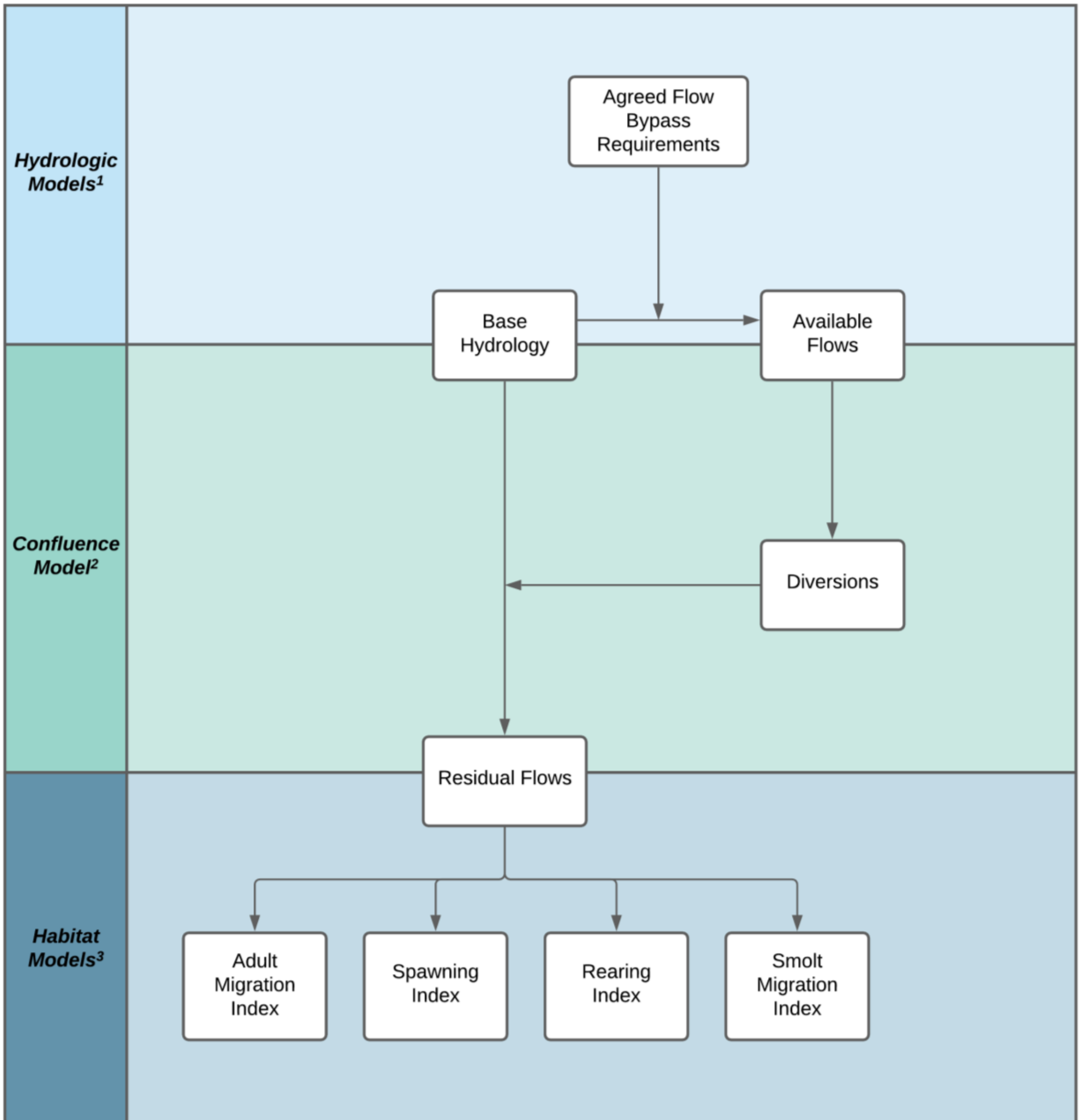
There are three distinct but interrelated models that the City has used in the effort to develop and evaluate the Proposed Project:

- **Hydrologic Model (Appendix D-1) -** A hydrologic model that develops the available daily flows in the North Coast streams (specifically Laguna, Liddell and Majors Creeks), the San Lorenzo River, and Newell Creek available for supply once the Agreed Flows are met.
- **Water Supply Model (Appendix D-2) -** The *Confluence*® water supply model, which utilizes available streamflows (generated by the Hydrologic Model) in a particular scenario (e.g., the Agreed Flows with the Proposed Project) and with many other system operating assumptions, to evaluate potential operations of the City's water system and the resulting water supply reliability and to calculate the resulting flow left instream for fish habitat.
- **Fisheries Habitat Effects Model (Appendix D-3) -** A fisheries habitat effects model that evaluates the fisheries habitat effects of the residual streamflows left instream after municipal supply demands are met in the Water Supply Model, consistent with the minimum streamflows required in a particular scenario, to develop flow-based metrics of habitat effects.

The following is a brief summary of each of these modeling components. Figure 1 provides a flow chart that illustrates how the models work together.

Hydrologic Model

As discussed in Appendix D-1, this model was developed by Balance Hydrologics, Inc. in order to better understand the long term hydrologic variability in the City's drinking water source streams to provide the foundation for fisheries conservation and supply reliability planning. Developing a long term record suitable for supply reliability and biological effects evaluation was enabled by utilizing the long term record at the USGS Big Trees gage and other stream gages, but also required installation of 10 additional stream gages to better understand effects of City operations, hydrologic dynamics as they relate to availability of anadromous salmonid habitat under different City operations scenarios, and future water supply reliability predictions. Fundamental to this effort was an evaluation of locally downscaled climatic predictions and their effects on future, changed hydrologic dynamics, and subsequently, anadromous salmonid habitat viability and water supply reliability. This model developed daily flows available for diversion and/or storage over a multi-year historical period of record and for plausible climate change conditions.



Notes:
1. The Hydrologic Models apply the Agreed Flow bypass requirements to the Base Hydrology (using historical or climate change hydrology) to determine Available Flows for diversion at each of the City's diversion points.
2. The Available Flows are used in the Confluence Model to generate simulated Diversions. The Diversions are subtracted from the Base Flows to generate the Residual Flows remaining downstream of the diversion points.
3. The Habitat Models use the Residual Flows to develop the various fish habitat indices. Residual Flows represent the amount of streamflow left in the stream after Diversions, assuming diversion is possible after the Agreed Flow bypass requirements are met. Residual Flow may be different than the Agreed Flow bypass requirements if there is more flow in the stream than needed by the Diversions or if flow is less than the Agreed Flow bypass requirements with no diversion.

Figure 1. Flow Chart of Hydrologic, Water Supply, and Fisheries Habitat Models

Water Supply Model

As discussed in Appendix D-2, this model was developed by Gary Fiske and Associates, Inc. *Confluence*® is a model designed to simulate the operation of water systems to assist water supply agencies to evaluate and compare supply and infrastructure alternatives. The model can accommodate a wide variety of water supplies, storage facilities, infrastructure and operating constraints including, but not limited to, raw water quality and instream flow needs. The model enables water suppliers to focus on the results that are most important to their decision-making or that are needed to fulfill legal or regulatory requirements, including different representations of:

- Water supply reliability
- Water demands including instream flow needs or other environmental demands
- Source-specific production
- Surface water and groundwater storage levels
- Treatment and transmission throughput

Confluence® used the available daily flows to assess the impacts on system operations and water supply reliability of different water rights and infrastructure alternatives, and produced residual streamflows after City diversions, which are input to the fisheries effects modeling.

Fisheries Habitat Effects Model

As discussed in Appendix D-3, the fisheries habitat effects model was developed by Hagar Environmental Science to evaluate habitat conditions in City drinking water source streams under a variety of instream flow conditions. Effects analysis was based on determining flow/habitat relationships in streams from which the City diverts water using several standard methods. Flow/habitat relationships were used to evaluate potential habitat effects across a wide variety of hydrologic conditions to better understand the City's past, present, and future effects on coho and steelhead. The effects analysis was primarily focused on the influence of the City's water system operations on instream flows and the related habitat effects.

The following appendices describe each of these models and modeling results in detail. All three of the models are required to evaluate the Baseline, Proposed Project, and the alternatives discussed in the EIR, which are further described below.

1.3 Proposed Project and Alternatives Modeled

The scenarios evaluated in the EIR and modeled in this appendix include the following:

- **Baseline:** Conditions at the time the City issued the Notice of Preparation (NOP) for the EIR (2018).
- **Proposed Project:** All water rights modifications, including addition of Agreed Flows as the minimum bypass flows, and water supply augmentation components of the Proposed Project.
- **Alternative 1:** Agreed Flows only without other Proposed Project components.
- **Alternative 2:** Agreed Flows with all Proposed Project components except there is no place of use expansion, which means that there are no water transfers to neighboring agencies, and that aquifer storage and recovery (ASR) is possible only within the City's area of service.
- **Alternative 3:** Agreed Flows with all Proposed Project components except ASR.

Additionally, the standard operational and construction practices identified in Draft EIR Chapter 3 would apply to Alternatives 1 through 3, where relevant to each alternative. Additional description of the Baseline, Proposed Project, and alternatives is provided below. Detailed modeling assumptions for each scenario are included in Table 1 and described in more detail in Appendix D-2.

Baseline

The Baseline represents City water rights, water supply operations, and bypass flows that were in place at the time the NOP was released (2018). The City's existing pre-1914 appropriative water rights authorize diversions from several North Coast streams and the City's post-1914 appropriative water rights allow diversions from Newell Creek and the San Lorenzo River under existing water rights licenses and permits (see EIR Chapter 3, Tables 3-1 and 3-2). Water supply operations under the Baseline consider existing infrastructure capacities, as shown in Table 1 and described in more detail in Appendix D-2. Bypass flows under the Baseline are defined by the interim bypass flow agreement between the City and the California Department of Fish and Wildlife (CDFW) which was included in the April 30, 2018 Tolling Agreement between CDFW and the City of Santa Cruz (see Appendix C for this agreement). All other conditions are based on those existing in 2018.

Proposed Project

The Proposed Project is described in detail in EIR Chapter 3, Project Description. The Proposed Project includes proposed modifications to the City's existing water rights to improve flexibility in operation of the City's water system to better use limited water resources, while enhancing stream flows for local anadromous fisheries. The Proposed Project also includes water supply augmentation components and surface water diversion improvements that could result after the water rights modifications are approved. Specifically, the Proposed Project includes the following elements:

Water Rights Modifications

- Expanding the authorized place of use of the City's pre-1914 and post-1914 appropriative water rights to include the areas of service for the City, two local groundwater basins, and the service areas of neighboring water agencies, including Soquel Creek Water District, Scotts Valley Water District, San Lorenzo Valley Water District, and Central Water District.
- Explicitly authorizing direct diversion as a method of diversion under the City's Newell Creek License (License 9847) and its water-right permits for diversions at its Felton Diversion (Permits 16123 and 16601), which is not explicitly authorized under the current license and permits. This would complement the existing stated storage rights under that license and those permits and add a new maximum direct diversion rate of 31 cubic feet per second (cfs) to the Newell Creek license.
- Adding the City's existing Beltz system as points of rediversion into and out of groundwater storage through aquifer storage and recovery (ASR) wells to the City's Tait Licenses (Licenses 1553 and 7200) and Felton Permits, and adding the Tait Diversion as a new point of diversion on the Felton Permits, which would provide the ability to divert water under the Felton Permits with or without activation of the Felton Diversion inflatable dam. This would help the City to fully utilize the 3,000 acre-foot per year (afy) appropriation authorized by the Felton permits.
- Adding an underground storage supplement to the City's Tait Licenses and Felton Permits to allow for the City's Beltz system ASR component. An underground storage supplement is required to be filed with the SWRCB for post-1914 water right permits and licenses seeking to divert surface water to groundwater aquifers to artificially recharge these aquifers for further beneficial use. The City also is similarly adding potential groundwater storage through ASR operations in the Beltz system to its pre-1914 appropriative water rights.
- Granting an extension of time of 25 years to maximize beneficial use of water under the Felton Permits.
- Modifying City water rights to include the Agreed Flows as minimum bypass flows as negotiated with state and federal resource agencies to protect fisheries.

Water Supply Augmentation Components

- Santa Cruz ASR - ASR in the Santa Cruz Mid-County Groundwater Basin inside the areas served by the City and/or in the Santa Margarita Groundwater Basin outside the areas served by the City
- Beltz System ASR - ASR within the City's existing Beltz well system
- Water transfers and exchanges and intertie improvements

Surface Water Diversion Improvements

- Felton Diversion fish passage improvements
- Tait Diversion and Coast Pump Station improvements

The modeling of the Proposed Project accounts for the proposed water rights modifications, proposed water supply augmentation and surface water diversion improvements, as applicable, as well as infrastructure improvements that have independent utility and would be implemented in the future regardless of the Proposed Project, as identified in Table 1 and described in more detail in Appendix D-2.

Alternative 1: Agreed Flows Only Without Other Proposed Project Components

Alternative 1 consists of the Agreed Flows, consistent with the Proposed Project. None of the other components of the Proposed Project, as summarized above and described in more detail in EIR Chapter 3, would be implemented under Alternative 1. All other conditions are generally based on those existing in 2018 and include existing water rights and existing infrastructure capacities, with the exception that all infrastructure improvements that have independent utility and would be implemented in the future regardless of the Proposed Project are also included in the modeling. These include improvements related to the Newell Creek Pipeline and the Graham Hill Water Treatment Plant. See Table 1 and Appendix D-2 for additional information about the modeling conditions for Alternative 1.

Alternative 2: All Proposed Project Components except Place of Use Expansion

Alternative 2 includes most components of the Proposed Project, as summarized above and described in more detail in EIR Chapter 3, except there would be no place of use expansion focused on ensuring regional water supply reliability in neighboring districts and groundwater basins. That said, the place of use for City water rights may still be refined to provide alignment amongst the City's water rights – which are currently inconsistent in their respective places of use. Alternative 2 would not include water transfers to neighboring water agencies and ASR would be possible only within the City's water system's service area. Therefore, Alternative 2 would include Beltz ASR and potentially other ASR facilities within the areas served by the City's water system. Given the limited area to implement ASR, the modeling considers a reduced injection and extraction capacity, as shown in Table 1 and described in more detail in Appendix D-2. All other modeling conditions for Alternative 2 are consistent with the Proposed Project.

Alternative 3: All Proposed Project Components except Aquifer Storage and Recovery

Alternative 3 includes most components of the Proposed Project, as summarized above and described in more detail in EIR Chapter 3, except there would be no ASR. Therefore, Alternative 3 would not include Beltz ASR or other ASR facilities within or beyond the areas served by the City. All other modeling conditions for Alternative 3 are consistent with the Proposed Project.

TABLE 1: MODELING ASSUMPTIONS FOR BASELINE, PROPOSED PROJECT AND ALTERNATIVES

MODELING COMPONENT	MODELING ASSUMPTIONS				
	Baseline	**Proposed Project**	**Alt 1**	**Alt 2**	**Alt 3**
DEMANDS					
City Service Area	3,200 mgy	3,200 mgy	3,200 mgy	3,200 mgy	3,200 mgy
North Coast Agriculture	40 mgy	40 mgy	40 mgy	40 mgy	40 mgy
HYDROLOGY					
Historical Hydrologic Record	1937-2015	1937-2015	1937-2015	1937-2015	1937-2015
Climate Change Hydrologic Record	2020-2070	2020-2070	NA	NA	NA
Climate Model	CMIP-5 MOD	CMIP-5 MOD	NA	NA	NA
Flow Rules	2018 Interim Bypass Flows	Agreed Flows	Agreed Flows	Agreed Flows	Agreed Flows
DISPATCH OF SUPPLIES IN MODELING					
Source Dispatch Order to Meet City Demand	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Beltz Wells 5. Surface water storage	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Felton 5. Beltz Wells 6. Surface water and groundwater storage operated in parallel	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Beltz Wells 5. Surface water storage	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Felton 5. Beltz Wells 6. Surface water and groundwater storage operated in parallel	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Felton 5. Beltz Wells 6. Surface water
North Coast Potential End Uses	1. Agricultural Demands 2. City Demands	1. Agricultural Demands 2. City Demands 3. GW Storage 4. Transfers	1. Agricultural Demands 2. City Demands	1. Agricultural Demands 2. City Demands 3. GW Storage	1. Agricultural Demands 2. City Demands 3. Transfers
Tait Potential End Uses	City Demands	1. City Demands 2. GW Storage 3. Transfers	City Demand	1. City Demands 2. GW Storage	1. City Demands 2. Transfers

TABLE 1: MODELING ASSUMPTIONS FOR BASELINE, PROPOSED PROJECT AND ALTERNATIVES

MODELING COMPONENT	MODELING ASSUMPTIONS				
	Baseline	**Proposed Project**	**Alt 1**	**Alt 2**	**Alt 3**
Felton Potential End Uses	Surface storage	1. City Demands 2. Surface storage 3. GW Storage 4. Transfers	Surface storage	1. City Demands 2. Surface storage 3. GW Storage	1. City Demands 2. Surface storage 3. Transfers
Beltz Wells Potential End Uses	City Demands	City Demands	City Demands	City Demands	City Demands
Loch Lomond Potential End Uses (and ASR Potential End Uses for Proposed Project and Alt 2)	City Demands	City Demands	City Demands	City Demands	City Demands
DIVERSION CAPACITIES					
Liddell	2.47 cfs	2.47 cfs	2.47 cfs	2.47 cfs	2.47 cfs
Laguna	6.27 cfs	6.27 cfs	6.27 cfs	6.27 cfs	6.27 cfs
Majors	2.09 cfs	2.09 cfs	2.09 cfs	2.09 cfs	2.09 cfs
Tait	11.52 cfs	27.85 cfs	11.52 cfs	27.85 cfs	27.85 cfs
Felton	12.40 cfs	13.70 cfs	13.70 cfs	13.70 cfs	13.70 cfs

TABLE 1: MODELING ASSUMPTIONS FOR BASELINE, PROPOSED PROJECT AND ALTERNATIVES

MODELING COMPONENT	MODELING ASSUMPTIONS				
	Baseline	**Proposed Project**	**Alt 1**	**Alt 2**	**Alt 3**
WATER RIGHTS (maximum diversion rate)					
North Coast	No limit	No limit	No limit	No limit	No limit
Felton	Jan-May; Oct-Dec 20.0 cfs Jun-Aug 0 Sep 7.8 cfs	Shared water right: Jan-May; Oct-Dec 32.2 cfs Jun-Aug 12.2 cfs Sep 20.0 cfs[2]	Jan-May; Oct-Dec 20.0 cfs Jun-Aug 0 Sep 7.8 cfs	Shared water right: Jan-May; Oct-Dec 32.2 cfs Jun-Aug 12.2 cfs Sep 20.0 cfs	Shared water right: Jan-May; Oct-Dec 32.2 cfs Jun-Aug 12.2 cfs Sep 20.0 cfs
Tait	12.2 cfs in all months		12.2 cfs in all months		
WATER TREATMENT PLANT CAPACITY (mgd)					
Graham Hill WTP	16.5 mgd	18.0 mgd	18.0 mgd	18.0 mgd	18.0 mgd
OTHER KEY OPERATING CONSTRAINTS					
North Coast	Turbidity	Turbidity	Turbidity	Turbidity	Turbidity
Felton	Turbidity, First Flush, Pump limitations, Reservoir elevations	Turbidity, First Flush	Turbidity, First Flush	Turbidity, First Flush	Turbidity, First Flush
Tait	Turbidity	Turbidity	Turbidity	Turbidity	Turbidity

[2] This manner of modeling the way that diversions at Tait and Felton would interact in the Proposed Project and Alternatives 2 and 3 reasonably replicates how the two facilities would operate with proposed changes to the City's current water rights for those facilities. The City's proposed changes to those rights, however, would not involve adding Felton as a point of diversion on the City's licenses for the Tait Diversion. The City therefore would not divert water at Felton during the period of each year when the Felton Permits do not authorize diversions. Permit 16123 only authorizes diversions at Felton from September 1 through June 1. Permit 16601 only authorizes diversions there from October 1 to June 1.

TABLE 1: MODELING ASSUMPTIONS FOR BASELINE, PROPOSED PROJECT AND ALTERNATIVES

MODELING COMPONENT	MODELING ASSUMPTIONS				
	Baseline	**Proposed Project**	**Alt 1**	**Alt 2**	**Alt 3**
WELL EXTRACTION CAPACITIES (NATIVE GROUNDWATER)					
Beltz	0.8 mgd Apr - Nov in all water years	0.8 mgd Apr - Nov in all water years	0.8 mgd Apr - Nov in all water years	0.8 mgd Apr - Nov in all water years	0.8 mgd Apr - Nov in all water years
Beltz 12	0.3 mgd May - Aug in critically dry years	0.3 mgd May - Aug in critically dry years	0.3 mgd May - Aug in critically dry years	0.3 mgd May - Aug in critically dry years	0.3 mgd May - Aug in critically dry years
Tait Wells	1.28 mgd May-Dec; 0.78 mgd Jan-Apr	1.28 mgd May-Dec; 0.78 mgd Jan-Apr	1.28 mgd May-Dec; 0.78 mgd Jan-Apr	1.28 mgd May-Dec; 0.78 mgd Jan-Apr	1.28 mgd May-Dec; 0.78 mgd Jan-Apr
LOCH LOMOND RESERVOIR					
Max/usable capacity	2,810 mg/1,740 mg	2,810 mg/1,740 mg	2,810 mg/1,740 mg	2,810 mg/1,740 mg	2,810 mg/1,740 mg
Allowable diversion months	Sept-Jun	Sept-Jun	Sept-Jun	Sept-Jun	Sept-Jun
Daily Instream Release	1.00 cfs	1.00 cfs	1.00 cfs	1.00 cfs	1.00 cfs
Annual San Lorenzo Valley Entitlement	102.1 mg	102.1 mg	102.1 mg	102.1 mg	102.1 mg
AQUIFER STORAGE & RECOVERY					
Storage Capacity	N/A	3,000 mg	N/A	2,100 mg	N/A
Aquifer Losses	N/A	20%	N/A	20%	N/A
Injection Capacity	N/A	Historic 4.5 mgd; Climate Change 5.5 mgd	N/A	2.10 mgd	N/A
Extraction Capacity	N/A	Historic 8.0 mgd; Climate Change 7.0 mgd	N/A	2.17 mgd	N/A
Injection Season	N/A	Nov-Apr	N/A	Nov-Apr	N/A
Extraction Season	N/A	May-Oct	N/A	May-Oct	N/A
Hydrologic condition restriction	N/A	No injection in Hydrologic Condition-5 months	N/A	No injection in Hydrologic Condition-5 months	N/A

TABLE 1: MODELING ASSUMPTIONS FOR BASELINE, PROPOSED PROJECT AND ALTERNATIVES

MODELING COMPONENT	MODELING ASSUMPTIONS				
	Baseline	**Proposed Project**	**Alt 1**	**Alt 2**	**Alt 3**
WATER TRANSFERS					
Maximum monthly transfer	N/A	Neighbor agency groundwater demands	N/A	N/A	Neighbor agency groundwater demands
Hydrologic condition restriction	N/A	No transfer in Hydrologic Condition-4 & Hydrologic Condition-5 months	N/A	N/A	No transfer in Hydrologic Condition-4 & Hydrologic Condition-5 months

1. Introduction and Background

This document provides a general overview of the hydrologic model used to complete historical and climate change (CC) analysis in support of the City of Santa Cruz Water Supply Planning (WSP) efforts, as well as evaluation of the Proposed Santa Cruz Water Rights Project–Proposed Project (see Chapter 3 of the Draft Environmental Impact Report for a full description of the Proposed Project). Modeling work for the WSP occurred during the time period 2008–2018, referred to as the WSP analysis period, and modeling completed in support of the Draft Environmental Impact Report occurred from 2014–2020. During the WSP analysis period, the hydrologic modeling tools and approaches evolved and were updated numerous times due to active discussions with the regulatory agencies involved in the WSP negotiations, and in order to incorporate more hydrologic observations into the model framework. We refer to the model framework as the Base Hydrology Model.

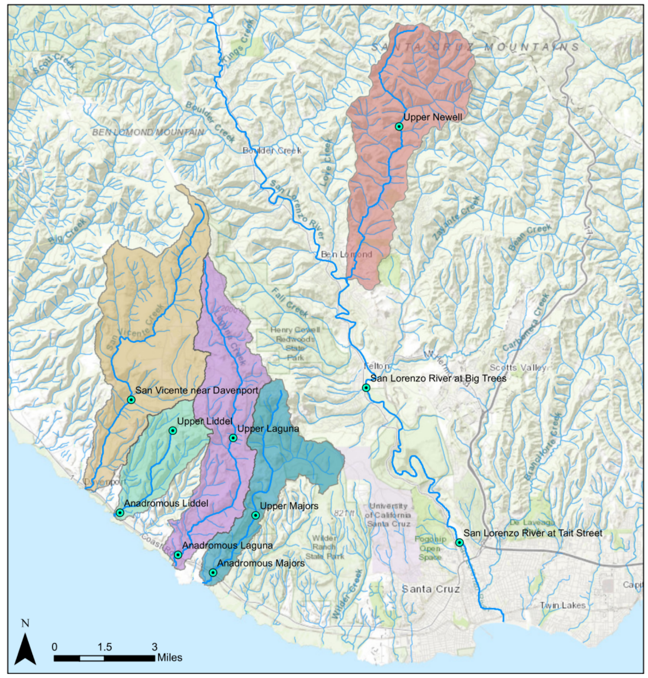


Figure 1: Source Streams and Gaging Station Locations

The Base Hydrology Model uses a combination of measured and modelled daily streamflows to represent the historical hydrology of the region. Rivers and streams represented in the model are a part of the City of Santa Cruz (City) water supply system, and provide habitat for coho salmon and steelhead trout. We refer to these streams as Source Streams (Figure 1):

a. San Lorenzo River at Big Trees Station and Tait Street Station;

b. Liddell Creek–Upper Station and Anadromous Station;

c. Majors Creek–Upper Station and Anadromous Station;

d. Laguna Creek–Upper Station and Anadromous Station; and

e. Newell Creek–Upper Station and Anadromous Station.

In the case of Laguna, Majors and Newell Creeks, the “Upper" Stations are located upstream of points of water supply diversions owned and maintained by the City. The Upper Liddell Creek station occurs downstream of the City’s diversion at Liddell Spring. In contrast, all “Anadromous" Stations are downstream of diversion points within the reaches of anadromy of coho salmon and steelhead trout (Figure 1). More specifically, Anadromous stations correspond to locations on Laguna, Majors, Liddell and Newell Creeks where upstream migration of anadromous fish is limited due to migrational barriers, or other limiting factors (Appendix D-3).

2. Overview of the Base Hydrology Model

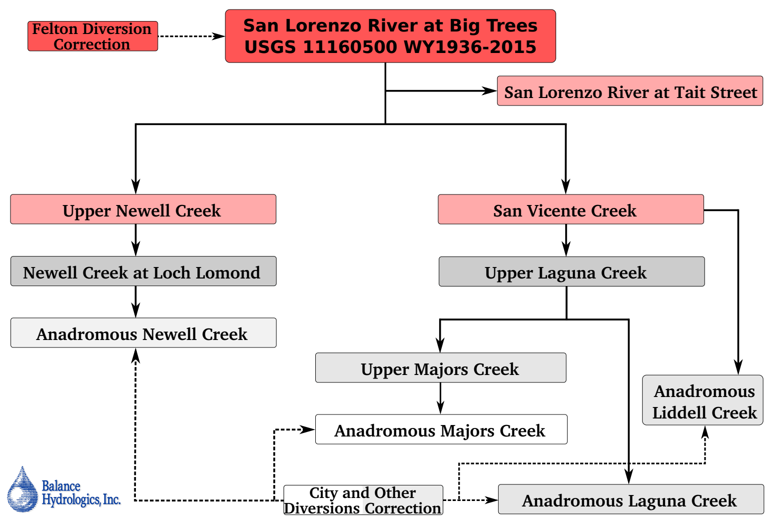


Figure 2: Work flow of the Base Hydrology Model. The diagram illustrates how the regression relationships provided within Appendix A are applied within the model. Lines between boxes indicate application of the specified set of regression relationships between the two indicated stations. All daily streamflows for the historical analysis period WY1936-2015 are derived from the USGS Big Trees published records. Dashed lines indicate that the flow corrections are estimates.

The basic purpose of the Base Hydrology Model is to partition modelled daily flow at points of diversion between water supply (Appendix D-2) and target instream flows for the various life stages of coho salmon and steelhead trout (see Appendix D-3 for a description of instream flow rule requirements, specifically referred to as the *Agreed Flows*). In general, the *Agreed Flows* vary by source stream, and according to five hydrologic categories calculated for the San Lorenzo River at Big Trees gage (Big Trees) (Table 1): critically dry, dry, average, wet and very wet (Figure 3). The five hydrologic categories are partitioned between the quintile statistics (i.e. 20%, 40%, 60% and 80%) for annual flows at Big Trees. For example, critically dry conditions correspond to total annual flows that are less than the 20^{th}–percentile flow condition for the Big Trees period of record (Figure 3). See Appendix D-3 for more information on the statistical hydrologic categories, and how they are applied within the Proposed Project instream flow rules.

Streamflow is modelled at the daily time step for multiple reasons. First, daily streamflow provides a reasonable measure of basic habitat conditions for coho salmon and steelhead trout because daily streamflow can be directly linked with field measurements of habitat suitability (Appendix D-3). Second, the water supply system model used to evaluate water supply reliability for the City of Santa Cruz operates at the daily time step since water use generally fluctuates daily (Appendix D-2). Last, we cannot reliably model streamflow at time scales smaller than daily, and the monthly time step is too coarse for analysis purposes. Next we describe the model in more detail.

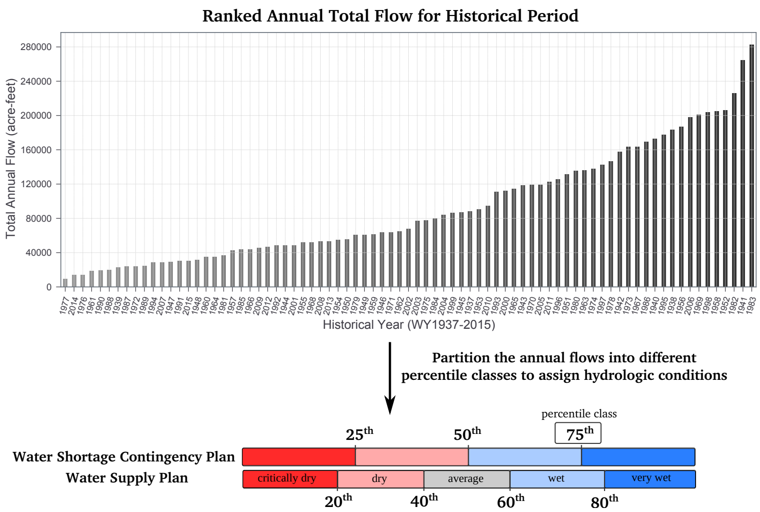


Figure 3: Graphic describing the five hydrologic categories used for the Water Supply Plan, and to evaluate the Proposed Project. The ranked annual total flow is for the Big Trees gage. The Water Shortage Contingency Plan categories were used for previous water supply planning undertaken by the City of Santa Cruz (City of Santa Cruz Water Department, 2009), and are shown for reference purposes only.

The San Lorenzo River at Big Trees (Big Trees) hydrologic record serves as the control point of the Base Hydrology Model. We selected the Big Trees record as the model control point for a few reasons. First, it is the longest running regional stream gaging station, operated by the United States Geological Survey since October 1936 and continuing to the present day. Second, the San Lorenzo River is a primary water supply source for the City of Santa Cruz. For the purposes of the WSP, the Base Hydrology Model simulates daily historical flow conditions in each source stream for the historical period October 1936–September 2015 (historical analysis period). Following standard convention, we refer to the historical analysis period as Water Years 1936-2015 (WY1936-2015). A water year runs from October 1 of one calendar year, to September 30 of the following year. For example, WY1950 begins on October 1, 1949 and ends September 30, 1950. The historical analysis period ends in September 2015 because it was necessary to stop adding data at some point in order to reach consensus on an overall conservation strategy. September 2015 was also a reasonable stopping point in the analysis data set because it followed three years of severe drought, and WY2015 is one of the driest years of local records.

Streamflow modeling occurs with regression models constructed from available gaged daily flow records. In general, daily streamflows for non-measurement periods are estimated at all source stream stations based on the Big Trees daily flow record. The specific gaging records and associated measurement periods used to develop the Base Hydrology Model and the regression relationships are provided in Table 1.

Table 1: List of Gaging Records used in the Base Hydrology Model

1. San Lorenzo River at Big Trees (USGS Gage 11160500): October 1936–September 2015;

2. San Lorenzo River at Tait Street (USGS Gage 11161000): October 1987–September 2015;

3. Laguna Creek near Davenport (USGS Gage 11161590): October 1969–September 1976;

4. Laguna Creek upstream of Laguna Dam (City and Balance Hydrologics): October 2003–present;
5. Laguna Creek at Highway 1 (City and Balance Hydrologics): October 2003–present;
6. Majors Creek near Davenport (USGS Gage 11161570): October 1969–September 1976;
7. Majors Creek upstream of Majors Dam (City and Balance Hydrologics): October 2004–present;
8. Majors Creek at Highway 1 (City and Balance Hydrologics): October 2004–present;
9. Liddell Creek near Bonny Doon (City and Balance Hydrologics): October 2003–present;
10. Liddell Creek at Highway 1 (City and Balance Hydrologics): October 2004–present;
11. San Vicente Creek near Davenport (USGS Gage 11161800): October 1969–September 1985.
12. Newell Creek upstream of Loch Lomond Dam (City and Balance Hydrologics): October 2003–present;
13. Anadromous Newell Creek (City and Balance Hydrologics): October 2003–present;

Each station in Table 1 is a modeling node in the Base Hydrology Model. We use the former USGS San Vicente Creek station daily records within the model because it provides the best basis of correlation for Laguna Creek (Figure 1). Streamflows between San Vicente and Laguna Creeks correlate because the upper watershed drainage basins include significant areas of Karst. Karst landscapes include underground drainage systems due to the dissolution of bedrock such as limestone or marble. Marble bedrock occurs in both the San Vicente and Laguna Creek basins. Note though that San Vicente Creek is not a water supply source for the City of Santa Cruz.

The regression relationships used to estimate daily flows during non-measurement periods within the Base Hydrology Model are provided in Tables A1 and A2 (Appendix A). The regression relationships were first developed in 2010, and were re-examined and revised in 2015 following three years of drought. A re-examination of the regression models resulted in changes to models for Tait Street, Liddell, Laguna and Majors Creeks (Table 1). In all cases, changes made to the regression models reflect the need to better simulate daily flows during low flow months and periods of drought. Water supply and instream habitat conditions for coho salmon and steelhead trout are most challenged during these times. The regression relationships are executed within a MathWorks MATLAB script, developed specifically for the WSP.

2.1. Calculation of Daily Flows

The Big Trees record of daily flow for the historical analysis period is read into the Base Hydrology Model. The script then computes daily flows at all other stations according to the work flow shown in Figure 2, and for the historical analysis period WY1936-2015. Color changes to the station names in Figure 2 indicate that the basis of mean flow calculation changes (Tables A1 and A2). For example, Big Trees is used to calculate the daily flow record at San Vicente Creek for the historical analysis period. Then in turn, the daily flow record for San Vicente Creek is used to calculate flows at Upper Laguna Creek over the same period (Figure 2). Although our modeling strategy may propagate errors, the results are satisfactory because the Base Hydrology Model is able to reproduce the observed hydrologic trends over the historical analysis period (discussed in more detail in the paragraphs that follow).

Table 2: Summary Information for Inter-basin Model Calibration.

	Mean daily flow for calibration period		
Stream	Obs (cfs-days)	Sim. (cfs-days)	Rel. error (%)
Laguna (11161590)	4.82	5.02	4.3
Majors (11161570)	4.24	4.30	1.5
Liddell (Upper)	4.28	4.24	1.7
Tait (11161000)	144.3	140.4	2.7

1. Calibration period varies. See Figure 4.
1. Relative error = $(Sim. - Obs.)/Obs.$

In the course of computing the daily flow records according to Figure 2, flow corrections are made to Big Trees and all anadromous stations in order to account for upstream flow diversions:

- **San Lorenzo River at Big Trees**: Record of diversion at Felton;
- **San Lorenzo River at Tait**: Record of diversion at Tait and Felton;
- **Anadromous Laguna Creek**: Record of North Coast production + 0.25 cubic feet per second ;
- **Anadromous Majors Creek**: Record of North Coast production + 0.194 cubic feet per second;
- **Anadromous Liddell Creek**: Record of diversion at Liddell Spring.

The application of flow corrections to affected gages for times when data is available means that daily flow records used in the Base Hydrology Model are assumed to represent quasi-unimpaired flow conditions. Despite the application of flow corrections, daily flows used in the model may not fully account for all upstream water extractions from source streams, tributaries and shallow ground water which directly influence instream flows. We also do not consider other watershed conditions that could influence instream flows that

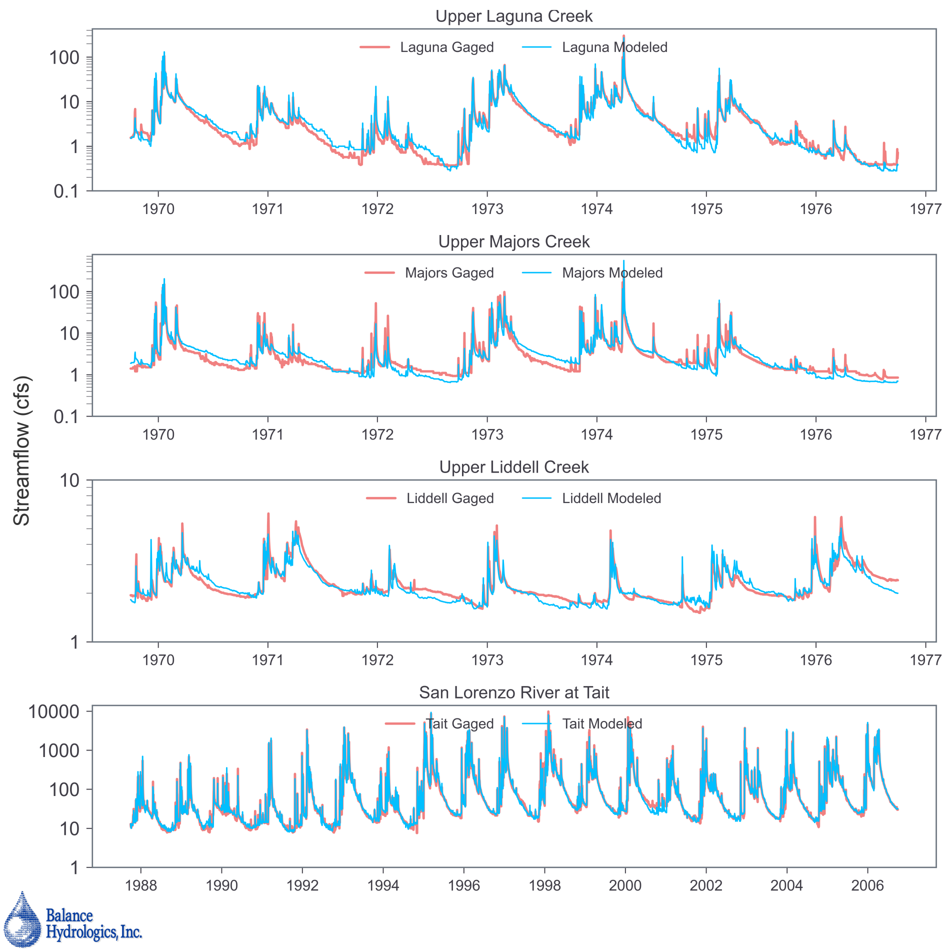


Figure 4: Comparisons between gaged and modelled daily streamflows. Modelled streamflows were calculated according to the regression relationships provided in Appendix A.

we could not possibly detect through gaging record analysis. City records of water supply production, flow release tests and gaging station records for stations located immediately downstream of City diversions on Laguna, Majors and Liddell Creeks are the basis for the corrections applied in the model. A comparison between gaged and modelled streamflows for Laguna, Majors and Liddell Creeks, as well as the San Lorenzo River at Tait Street is shown in Figure 4. The calibration period differs across the stations, and is shown as the x-axes of Figure 4.

The overall reliability of the Base Hydrology Model is reasonable for Upper Laguna, Upper Majors, Upper Liddell and Tait Street (Figure 4). Relative errors of the model for each of these four stations is < 5% when comparing mean daily streamflows over the respective calibration periods (Table 2). A suitably calibrated model is expected to have a relative error < 10% (Elsner and others, 2010).

2.2. Why a Regression Basis for the Base Hydrology Model?

The City of Santa Cruz has previously used a physically-based watershed scale hydrologic model for its Integrated Water Management Planning (IWMP) projects (City of Santa Cruz Water Department, 2009). In 2006 we evaluated output from the IWMP against gaging records for Laguna, Majors and Liddell Creeks. The comparison revealed that the IWMP-derived flows generally have a wet bias [i.e more streamflow] relative to measurements made during summertime low flow periods, periods of drought, intra-storm periods and recessional flow periods (Figure 5). A wet bias during these conditions was difficult to accept because of the challenges faced by instream habitat conditions as well as water supply availability during low flow periods. This circumstance, coupled with the City's desire to examine numerous instream flow and water supply scenarios, prompted the project team to adapt and build a hydrology model for the source streams using available gaging records as the model basis.

The simplicity of the Base Hydrology Model provides two advantages. First, we can efficiently evaluate different instream flow rules or water supply scenarios (it takes less than 1 minute to run a simulation once the input files are built), and second, the model is built using observations of streamflow (corrected with available data) within all source streams. In support of the WSP and the Draft Environmental Impact Report, the Base Hydrology Model has been used to evaluate more than 50 different scenarios.

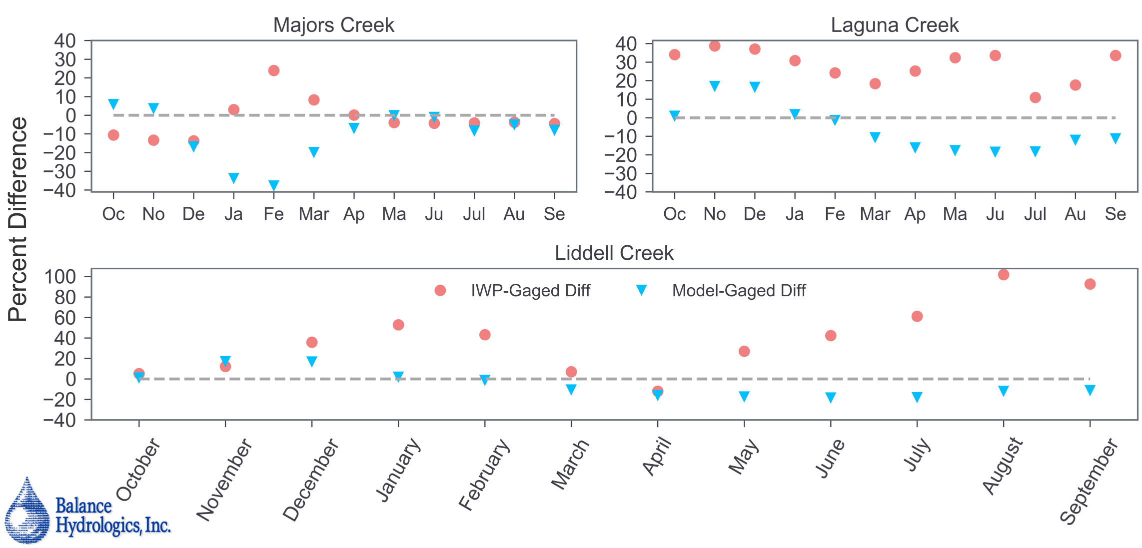


Figure 5: Percent difference between IWMP modelled flows and associated gaged flows (IWP-Gaged Diff), and regression modelled flows and associated gaged (Model-Gaged Diff) flows. Values represent monthly averages calculated over the gaging period of records (Table 1).

2.3. Limitations and Assumptions for Base Model

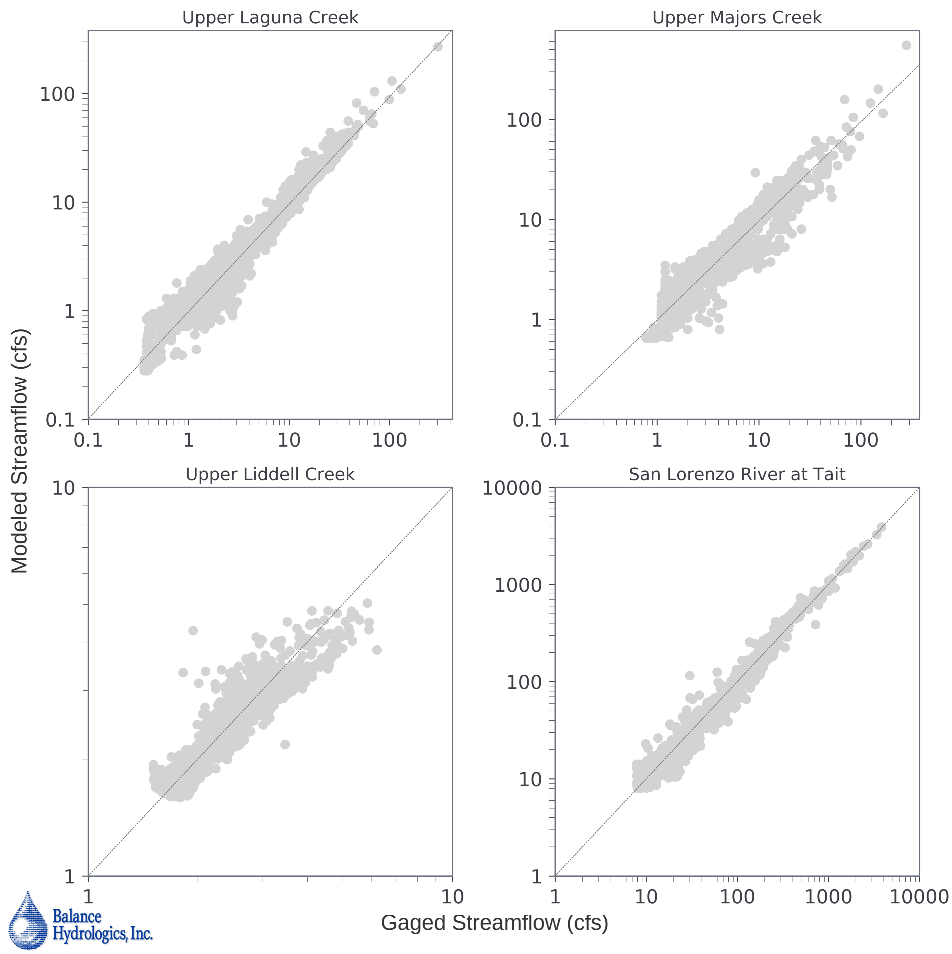


Figure 6: Comparison between gaged and modelled streamflows for Upper Laguna, Upper Majors, Upper Liddell and the San Lorenzo River at Tait Street. The data for Laguna and Majors Creek spans WY1970-76; the data for Liddell Creek spans WY2003-09, and the data for Tait spans WY1987-06. Similar results occur for Laguna and Majors Creek for the more recent period for which gaging records exist (Table 1). 1:1 lines shown for reference.

The Base Hydrology Model is constructed with regression relationships that have been identified in order to model low flow periods to a level acceptable to the City and regulatory agencies. The regression relationships can, for example, track changes in flow reported within applicable gaging records (Figure 4), and in general provide an improvement over flow records developed as a part of the IWMP (Figure 5). However, in some cases the regression relationships do not reproduce summertime flows reported, for example, at the USGS Laguna Creek near Davenport station during WY1972 (Figure 4). Model departures from summertime gaged flows in WY1972 exist because the regression relationships do not capture all of the variance present in the historical data. This is expected given our approach. Nonetheless, the model does capture the magnitude of the drought summertime flows during WY1976. This outcome reflects our general goal since we understand WY1976 was a critically dry year, and for such conditions water supply and instream habitat are most challenged.

The Base Hydrology Model is used to compile and calculate daily streamflow records for Laguna, Majors, Liddell and Newell Creeks, and for the San Lorenzo River at Tait for the period WY1936-2015. As a result, daily flow records for a majority of the water years within the historical analysis period are calculated using the regression relationships (compare historical analysis period against available gaging records in Table 1). Consequently, we assume that the inter-basin and intra-basin flow conditions captured by the years of overlapping gaging records are consistent with conditions during correlated years. We have no reasonable way to examine this assumption. However, the Big Trees record suggests that general land use practices and other activities that could affect runoff production have not changed considerably during the historical analysis period, which by extension we assume for the other basins as well. Last, based on the distribution of gaged vs. modelled flows (Figure 6) we assume that the regression relationships reflect the average, or most probable range of streamflow conditions in the source streams for any given set of precipitation, soil saturation and groundwater conditions, etc.

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3. Overview of Base Hydrology Model Application to Potential Climate Change Conditions

Climate change (CC) work for the City of Santa Cruz WSP has been ongoing since 2008. In our first step we incorporated CC into the WSP planning process. This involved a substantial literature review to gain an understanding of CC science for, in particular, California. An outgrowth of this led Balance to contact Ed Maurer at Santa Clara University to seek expert guidance on how to set-up a simplified analysis for the WSP using CC information. Guidance and suggestions resulted in the development of a water balance model (WBM), which serves as the basis for the CC modeling reported here. We run the WBM with CC data acquired through Cal–Adapt for the period WY2020–70 (CC analysis period).

At the time our CC work was getting started, the Cal–Adapt program (www.cal-adapt.org/about/) was in the early stages of implementation. The development of Cal–Adapt was in part motivated by then California Governor Schwarzenegger's November 2008 Executive Order S-13-08, which specifically asked the Natural Resources Agency to identify how state agencies can respond to CC. In essence, Cal–Adapt is a hub for climate change data relevant to adaptation planning in California. In more recent years however, Cal–Adapt has also grown to offer web-based analysis of CC data available via the Cal–Adapt website. In the remainder of this technical memorandum we review our approach to the WSP CC analysis, and the data sets we used to complete the work.

3.1. Development of Projected CC streamflows

Development of projected CC streamflows for the WSP follows three main steps, with intermediate work completed in between each step (Figure 7).

Step 1: The Water Balance Model (WBM)

The first step focuses on development of the WBM, specified as:

$$Q = P + B - Et_o - R. \tag{1}$$

The WBM is a water accounting statement which specifies that streamflow (Q) is the difference between additions and losses to the water budget. Additions in this case are the upstream contributing watershed average precipitation (P) and baseflow (B); losses are the upstream contributing watershed average potential evapotranspiration (Et_o) and groundwater recharge (R). All terms in Equation 1 are expressed in units of feet per day, and streamflow is calculated with units of cubic feet per second, summed at the monthly time step (cfs-days). The step from units of feet per day to streamflow is achieved by multiplying the water balance result over the upstream drainage basin area. Precipitation is provided directly through the CC projections, and differs depending on the projection that is used.

In contrast, baseflow is a calculated quantity, which we approximate as a backward looking function that tracks the general wetness conditions:

$$B = \left(\sum_{j=t-1}^{j=t-6} P \right) * Co_s * K_b. \quad (2)$$

Summation occurs over the prior five months average daily rainfall, Co_s is the carry-over-storage of shallow groundwater and K_b is the estimated proportion of the prior months precipitation and carry-over storage available as baseflow. K can take values between 0 and 1, and here has a value of 0.099. Testing indicates that the WBM is sensitive to K values > 0.0999, and relatively insensitive to values much less than 0.099. We calculate the carry-over-storage as a departure of recent precipitation trends from the analysis period average:

$$Co_s = \frac{\frac{1}{10} \left(\sum_{j=t}^{j=t-10} P \right)}{\overline{P}}. \quad (3)$$

The historical analysis period average precipitation $\overline{P}$ is 0.0102 feet per day.

Potential evapotranspiration is calculated according to the adjusted Blaney-Criddle equation:

$$Et_o = pr([0.75 * \overline{T}] + 0.5), \quad (4)$$

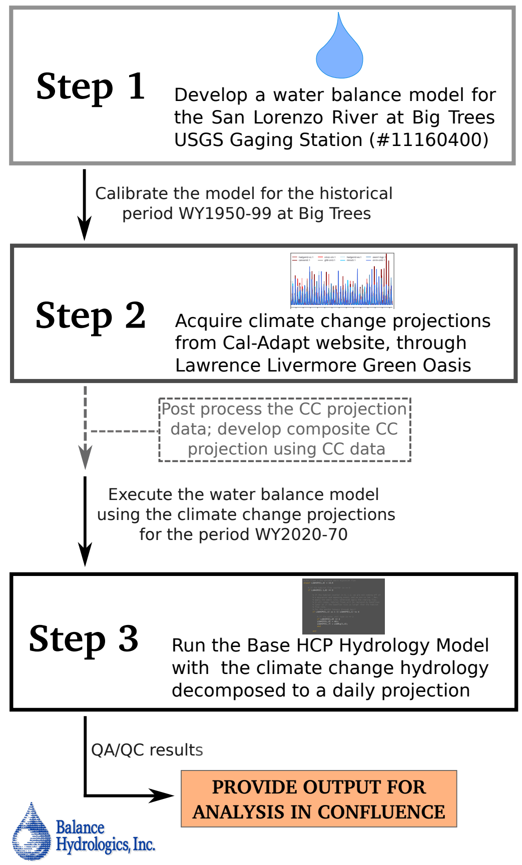

Figure 7: Steps followed to apply climate change projections to the Base Hydrology Model. The steps are discussed in the main text.

where pr is the average proportion of daylight hours for the Santa Cruz region (37.5 degrees north latitude) and $\overline{T}$ is the contributing watershed average monthly air temperature in degrees centigrade. The adjusted Blaney-Criddle equation produces an Et_o curve that rises to a maximum during the late summer months and achieves a minimum during the early winter months of December and January. See the following website for more details regarding the Blaney-Criddle equation: http://www.fao.org/3/s2022e/s2022e07.htm.

Recharge is calculated as a monthly apportioning function:

$$R = \frac{P_m}{\left(\sum_{m=1}^{m=12} P_{m,n} \right)} * K_r. \quad (5)$$

The subscript m is the present month in the present water year, and n is the present water year in the data set. The term K_r is a constant annual recharge amount that here has a value of 0.328 feet per year, based on estimates we developed using hydrologic records at Liddell Spring. Equation 5 distributes K_r based on the present month's proportion of the water year total precipitation. This approach likely underestimates recharge in wet years, and over estimates it in dry years. However, fixing K_r to a constant value yields WBM performance that is acceptable, as we will discuss further in the next section. Second, our approach to use of a fixed K_r value also avoids more sophisticated approaches that would require data that is not readily available.

Last, it is important to highlight that the WBM is primarily dependent on monthly precipitation, as well as average monthly air temperature (Equations 1–5). These dependencies provide the opportunity to apply the WBM to evaluate how future plausible climate conditions of precipitation and air temperature may affect monthly streamflow totals in the Santa Cruz region. Next we discuss how the WBM was calibrated in order to produce plausible estimates of monthly streamflow at Big Trees.

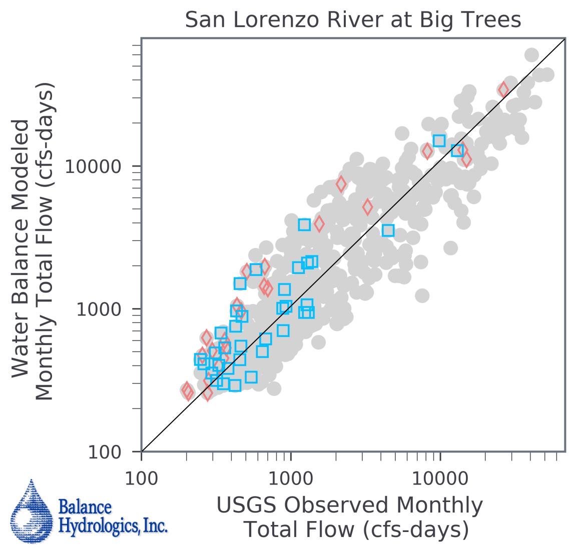

Figure 8: USGS observed monthly total streamflow vs. modelled monthly total streamflow using the Water Balance Model. The red diamonds cover the WY1976-77 drought and the blue squares cover the WY1989-91 drought. 1:1 line shown for reference.

Water Balance Model Calibration

The WBM (Equations 1–5) is calculated using local gridded climatological data (Maurer and others, 2002) available through Cal–Adapt for the period WY1950-2000. We use gridded climatological data because it is available at the same spatial resolution as the CC projection data. As a result, the WBM is constructed and used with data that are spatially consistent. The calculated WBM monthly total streamflows are then plotted against the associated observed data reported for Big Trees. Best fit lines between the two data sets provide the calibration curves for the WBM.

The goal of the calibration process is to use Equations 1–5 to predict monthly total streamflow at Big Trees as best we can given the limitations of the WBM. In particular, we seek good model performance for dry or drought years. To achieve the best approximation of drought conditions with the WBM, we treat the recharge (R) and baseflow (B) terms of Equation 1 as fitting parameters. This means we tested different ways of calculating both terms until we minimized misfit between observed and modelled, and reasonably reproduced dry and drought streamflows. Once satisfied with the WBM performance, we use the calibration curves to transform the WBM streamflows to magnitudes which occur within the observed range of streamflows at Big Trees (Figures 8 and 9).

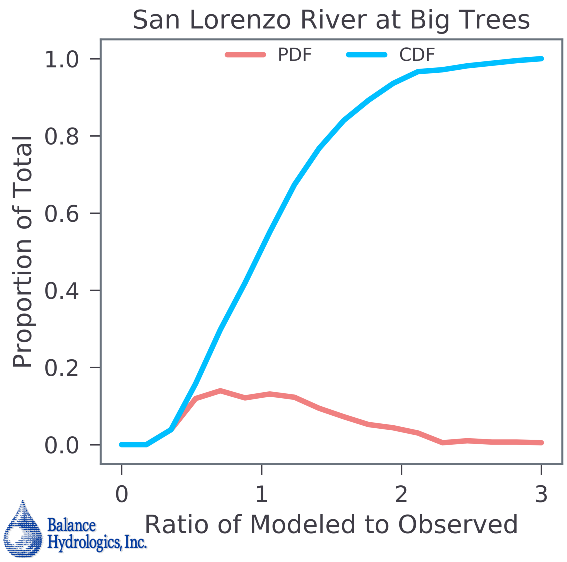

Figure 9: Probability distributions of the ratio of modelled to observed streamflows at Big Trees for the period WY1950-2000. Modelled streamflows were calculated with the Water Balance Model (Equations 1–4) and the calibration curves. PDF stands for the probability distribution function, and CDF for the cumulative distribution function.

The calibrated WBM performs as expected with respect to testing against the observed streamflow record at Big Trees, and successfully approximates flow magnitudes during the driest months on record for the period WY1950–2000 (Figures 8 and 10). Outside of the driest months, there is a clear linear correlation between observed and modelled flows, and the calibrated WBM calculates a majority of Big Trees flows within a factor 2 and less of the observed flows (Figure 9). In more detail, roughly 70% of modelled flows are within a factor 0.6–1.5 of observed flows (Figure 9). Beyond these specific results, the overall skill of the WBM is reasonable, with a relative error < 1% when comparing monthly mean streamflows over the calibration period (Table 3). As mentioned above, a suitably calibrated model is expected to have a relative error < 10% (Elsner and others, 2010). The model is capable of capturing observed year-to-year fluctuations and trends from wet to dry, and all the other climatological combinations (Figure 10). This result indicates the WBM can track how climatological conditions drive year-to-year fluctuations in streamflow, which makes intuitive sense given how the model is constructed (Equations 1–5).

Table 3: Summary Information for Water Balance Model Calibration.

San Lorenzo River	Monthly mean for calibration period		
	Obs (cfs-days)	Sim. (cfs-days)	Rel. error (%)
Big Trees (11160500)	4028.4	4026.9	0.03

1. Calibration period WY1950–2000.
1. Relative error = $(Sim. - Obs.)/Obs.$

It is important to point out that the WBM does not contain a change of storage term, which would be typical for mass balance statements. We do not include a change of storage term because we do not know how groundwater storage within the study area changes over the period WY1950–2000 (i.e. the calibration period), and consequently, we cannot constrain storage fluctuations under future plausible climates. We address the model shortcoming with respect to groundwater storage through our approaches to estimate the baseflow and recharge terms of Equation 1. Additional model limitations are presented at the end of this section.

Step 2: Acquire Climate Change Projections

All CC projections used as a part of the WSP analysis were acquired via the Cal-Adapt website (Figure 7). Projected climate data have a monthly time step and include precipitation, minimum air temperature and maximum air temperature. Values for each of these three climate parameters represent spatial averages over model grid cells which contribute runoff to the Big Trees gaging station. The spatial resolution of the different CC projections used in the WSP planning process varied, and is discussed in the following sections for each projection.

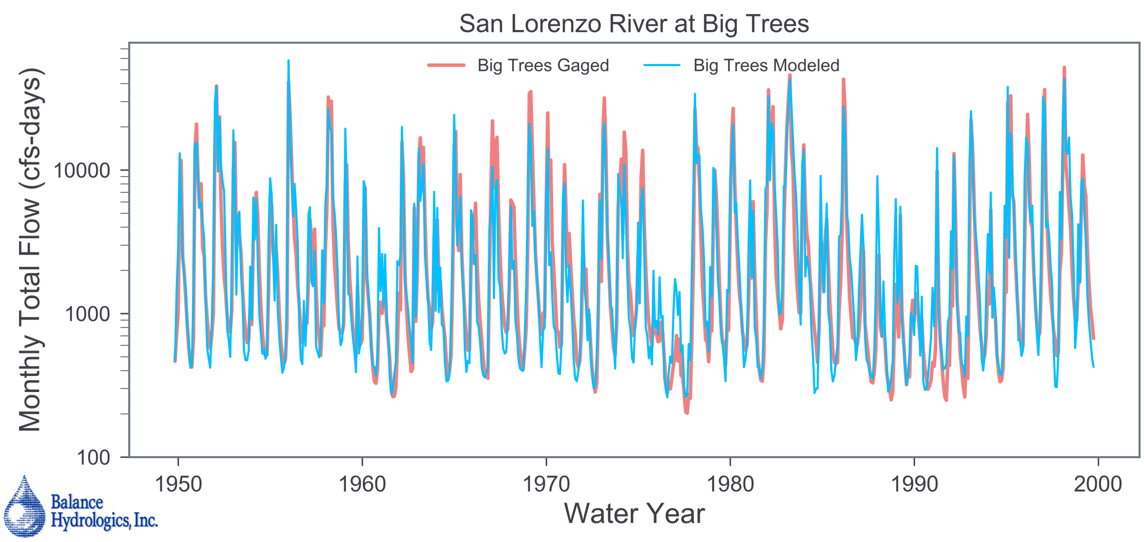

Figure 10: Comparison of observed and modelled monthly total streamflow for the Big Trees station for the period WY1950–2000. Modelled streamflows were calculated with the Water Balance Model (Equations 1–4) and the calibration curves.

CC Projection 1

The first CC projection used in the WSP planning process is the CMIP3 GFDL2.1 A2 data set (Projection 1), downscaled from Global Climate Model (GCM) simulations to grid cells with a spatial resolution of 1/8°. This resolution roughly equates to model grids that measure 7.4x7.4 square miles. Downscaling was performed by others and occurred following the Bias Correction and Spatial Disaggregation procedure (BCSD) (Wood and others, 2004). The abbreviation parts of the data set name include important information about the projection:

- **CMIP**: Stands for the *Coupled Model Intercomparison Project* (see https://pcmdi.llnl.gov/mips/ for more information about CMIP in general);
- **3**: The number 3 stands for the third phase of the collaborative effort;
- **GFDL**: The abbreviation GFDL stands for the Geophysical Fluid Dynamics Laboratory;

- **2.1**: The number 2.1 refers to the GFDL Global Climate Model (GCM) version 2.1; and
- **A2**: The abbreviation refers to the emissions scenario.

CMIP3 and all other CMIP phases are numerical experiments completed to help climate scientists carry out basic research using GCMs. CMIP3 was specifically completed in support of developing the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007). The IPCC is administered under the auspices of the World Meteorological Organization, a specialized agency of the United Nations Environment Program. We selected this particular projection from among several available at the time through Cal–Adapt because the A2 emissions scenario projected large average temperature increases in the range of 2–5.4°C (IPCC, 2007) by 2090–2099, relative to 1980–1999 temperatures. Increases of local temperatures over time reduces streamflow for any given precipitation event due to higher evapotranspirative losses (Equation 4). Consequently, this means less instream water for coho salmon and steelhead trout, and less streamflow available for water supply.

The Projection 1 precipitation data was post-processed because after initial inspection it was noted that the data set is wet, and quite wet when compared to the historical period record (Figure 11). It is known that the BCSD downscaling process may introduce a wet bias into modelled data relative to the historic calibration period record (Stratus Consulting, 2015). Therefore, an alternative approach was used to develop the projected precipitation and air temperature records. The Projection 1 data set downloaded from Cal–Adapt was adjusted according to the *Delta* method (Stratus Consulting, 2015; Hamlet and Lettenmaier, 1999), which was termed the transient record. The transient record preserves the distribution of events present in the raw projected CC data set (i.e. the variability of the raw GFDL2.1 A2 record), but scales it according to recorded monthly rainfall depths and air temperature magnitudes reported for the Santa Cruz region (NOAA and CDEC CRZ Station). The transient precipitation record is drier than the Projection 1 record, but preserves the year–to–year variability of the unadjusted data (Figure 11). The transient air temperatures are warmer than the Projection 1 record. Combined, the transient monthly precipitation, minimum air temperature and maximum air temperature records were used as the Projection 1 data set in the WSP planning analysis.

CC Projection 2

The second CC projection used in the WSP planning process represents a statistical combination of four different downscaled GCMs produced as a part of CMIP5 (Projection 2). The CMIP5 experiment is the basis of the Fifth Assessment Report (AR5) of the IPCC, which was carried out with new emissions scenarios known as Representative Concentration Pathways (RCP) (IPCC, 2014). We used projections developed with RCP8.5, which represents the radiative forcing at year 2100, with units of Watts/square meter. The emissions scenario RCP8.5 represents very high Green House Gas (GHG) emissions as understood at the time when AR5 was completed. In contrast to Projection 1, Projection 2 data were downscaled to a spatial resolution of 1/16°, or grids that measure roughly 3.8x3.8 square miles. CMIP5 data available via Cal–Adapt were downscaled two different ways, and used selected data that were specifically downscaled using the BCSD approach, consistent with Projection 1.

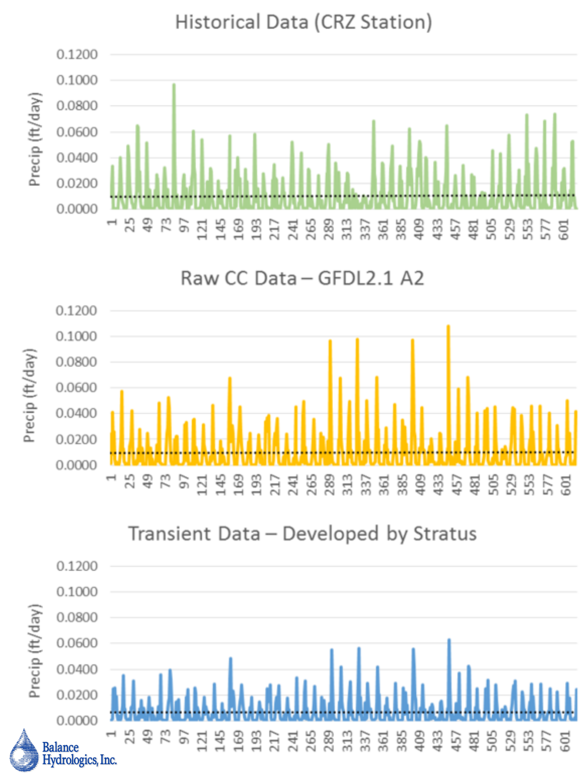

Figure 11: Precipitation data for the Santa Cruz region. Each data set covers a 50-year time span, and the x-axis of each plot is expressed in months since start of record – 1950 for historical data and 2020 for CC data. The monthly total precipitation totals were divided by the number of days in each month to yield precipitation in feet per day (y-axis). The transient data set was developed by Stratus Consulting.

Cal–Adapt and its partners made 10 different specific projections available as a part of the CMIP5 data set. After weeks of testing, four out of the ten individual projections were used as the basis for calculating the statistical CC projection (recall from Projection 1 that the abbreviation for each model cited next conveys important information about each source):

- ACCESS1-0.1.rcp85: Australian Community Climate and Earth System Simulator 1;
- CCSM4.1.rcp85: Community Climate System Model 4;
- HadGEM2-CC.1.rcp85: Hadley Global Environment Model 2 – Carbon Cycle;
- CanESM2.1.rcp85: Canadian Earth System Model 2.1;

The four chosen data sets that we used to build Projection 2 are on average moderate in terms of precipitation when compared to all ten models available for planning use (Figure 12). However, even though these four CC projections are moderate as defined by departures from the cumulative mean across all 10 models, the chosen data sets contain quite dry and wet conditions when compared to historical conditions. This point will be clear when we present the precipitation record for Projection 2 below.

At this point we have four different monthly CC projections to use for water supply planning under Projection 2. We decided that rather than chose one of the four projections, we would build upon the four and develop a statistical CC projection. We choose this approach for Projection 2 because it is not possible to *predict* future climate.

The strategy used here to develop a statistical CC projection with the four identified times series involves a stochastic modeling technique, illustrated schematically in Figure 13. The stochastic approach requires the

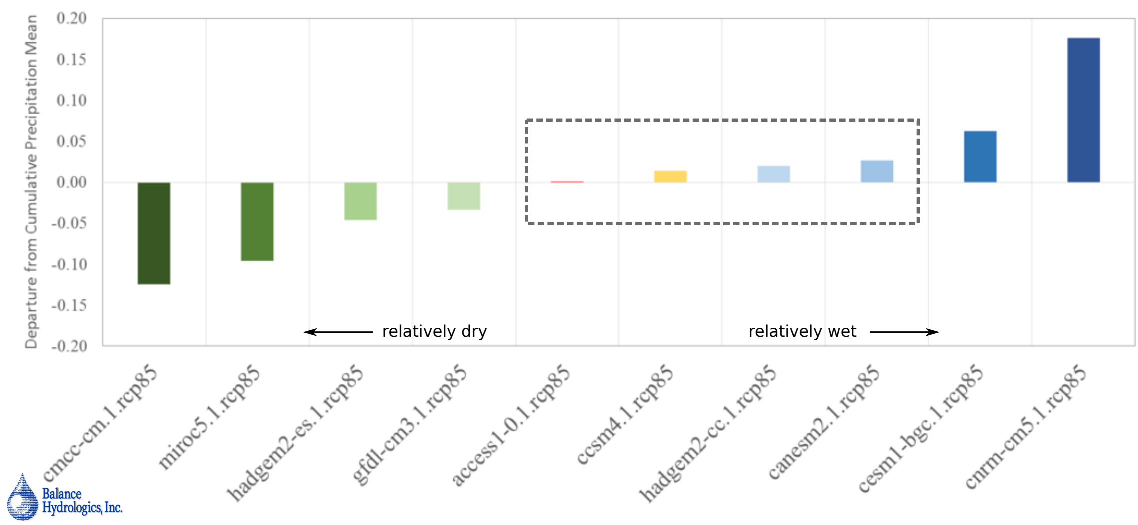

Figure 12: Model specific departure from the cumulative precipitation mean for all ten downscaled CMIP5 climate projections of precipitation over the CC analysis period. The plot provides an indication of which projected data sets are relatively dry, relatively wet and comparable to the cumulative mean across the projection data sets. The four models used to build Projection 2 are indicated by the dashed box.

assumption that the four moderate climate projections approximately capture the *expected range* of monthly and annual precipitation (and air temperature trends) totals for the CC analysis period. The *expected range* assumption permits us to numerically expand the records of monthly precipitation (and air temperature) for the four moderate models to monthly arrays that are > 4 in size. Here, we chose 100 equally incremented values within the range set by the four projection minimum and maximum values for each month of the CC analysis period. As a result, the sample size of future plausible climate conditions increases from 4 to 100 for any given month in the CC analysis period.

Expanding the projection sample size from 4 to 100 inclusive samples is analogous to assuming that a relatively large number N of GCMs would yield, after sampling, a downscaled distribution of climate projections that would approach the distribution defined by the 100 equally incremented values across all months of the CC analysis period. For relatively dry conditions, the 100 equally incremented values differ by approximately 1 millimeter/month (mm/month). This difference increases to roughly 4 mm/month for progressively wetter conditions. Although 100 future plausible climates may be a small sample size, it does serve the purpose of reducing our reliance on only 4 projections of future climate. The more critical issue, however, is how the sequence of month-to-month, or year-to-year climate might vary in the future.

Our goal is to develop a CC projection that reflects the general consensus among California climate scientists of more pronounced droughts, more severe floods and warming temperatures for the central coastal region of the State (Swain and others, 2018). We address this goal through use of percentile statistics (e.g. 10th, 20th, etc. percentiles), and add the requirement that the statistics are robust. For example, if we calcu-

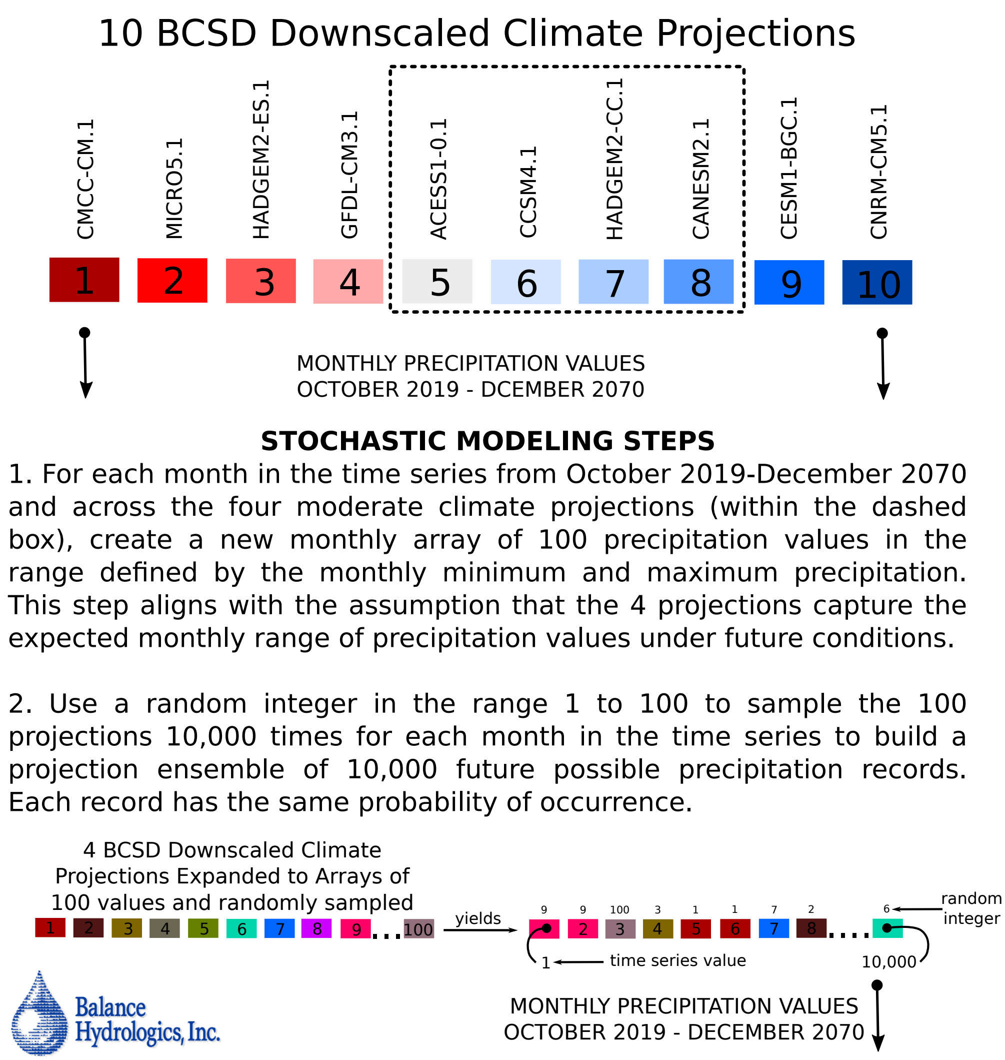

Figure 13: Schematic of the stochastic modeling workflow used to develop climate projections of precipitation and air temperature with a population of 100 samples. This population is randomly subsampled 10,000 times to develop a statistically stationary distribution of precipitation and air temperature.

late the various percentile statistics for the 4 moderate climate projections and compare these to statistics for the expanded sample of 100, it is no surprise that there are differences, some of which are substantial. This raises the issue of sample size and uncertainty. To overcome this difficulty, we randomly subsample (with replacement) the monthly arrays of 100 monthly values of precipitation and air temperature until change of the percentile statistics approaches zero. This occurs when the total number of time series > 5,000, and here, we produced 10,000 randomly constructed CC time series of precipitation and air temperature.

We calculated percentile statistics for each month of the CC analysis period using the 10,000 different monthly values for precipitation and air temperature. We also calculated percentile statistics for annual conditions. Next, we drew from the underlying annual percentile statistics in a manner which tracks overall dry, average and wet periods (Figure 14), as well as cool, average and hot conditions. After several rounds of testing, we selected the 10th percentile for dry and cool conditions, the 50th percentile for average conditions, and the 75th percentile for wet and hot conditions. Next, we needed to determine whether a future year (and the months of that year) was dry (cool), average or wet (hot).

We used the *expected range* magnitude relative to the median value to determine if any given year of the CC analysis period was likely to exhibit average vs. dry, or wet conditions. We choose three general rainfall conditions in order to keep things simple, yet adjust model calculations based on clear differences in rainfall. Recall, the *expected range* magnitude is the difference between the maximum and the minimum for the four chosen CC projections. If the *expected range* was larger than the median value for any given year, that year was deemed most likely to exhibit dry or wet conditions. On the other hand, if the *expected range* was less than the median value for any given year, that year was deemed most likely to exhibit conditions of the central tendency.

Figure 14: Heat map of population statistics for Projection 2 developed with the stochastic sampling (Figure 13). The y-axis plots how the statistics shown on the x-axis vary from month to month over the CC analysis period. Darker blue colors indicate relatively wet periods, and stronger yellow colors indicate dry periods. An example wet and dry period are indicated.

The decision to select the 10^{th} vs. 75^{th} percentile value was determined by comparing the 50^{th} percentile precipitation for each associated year vs. the 50th percentile for all years of the CC analysis period across all 10,000 samples. Years with values less than the CC analysis period 50th percentile value were considered dry, and the 10^{th} percentile was selected. Years with values greater than the projection period 50^{th} percentile value were considered wet, and the 75^{th} percentile value was selected. This manner of record construction means that years, rather than months were selected to be dry, normal or wet. We chose the annual basis to guide record construction in order to be consistent with how we develop daily hydrographs from the monthly data (discussed in the subsequent section), and because the project team has a higher confidence in annual projections of climate variables.

The Projection 2 precipitation time series contains a range of values that are generally consistent with the range of historical observations (Figure 15). However, the Projection 2 record qualitatively displays increased year to year variability relative to historical conditions, as well as consecutive years of relatively large and small precipitation totals. For example, WY2020–22 are as dry as the WY76-77 drought, but contain a third relatively dry year. On the other hand, WY2061–64 are as wet, and slightly wetter, compared to WY1956, but contain four relatively wet years in a sequence as opposed to one single wet year. This means that Projection 2 is generally consistent with previous work that suggests the central coast of California will have drier dry periods, wetter wet periods, and increased year-to-year variability that reflects abrupt switches between dry and wet conditions, and vice versa (Swain and others, 2018).

The Projection 2 precipitation time series also reflects the dry and wet trends of the overall statistics drawn from the sample of 10,000 plausible climate conditions (cf. Figures 14 and 15), which is a function of the four CC projections we choose to use. The Projection 2 maximum air temperature shows a steady increasing trend over the CC analysis period, as expected (Figure 16). However, the magnitude of temperature increase is low relative to most estimates. This result means that projected streamflow could attain lower values under Projection 2 (Equation 4) if we sampled to produce a warmer air temperature trend. We choose not to pursue this path, however, because Projection 3 was developed to reflect more severe climate conditions through much warmer air temperatures (discussed in the next section).

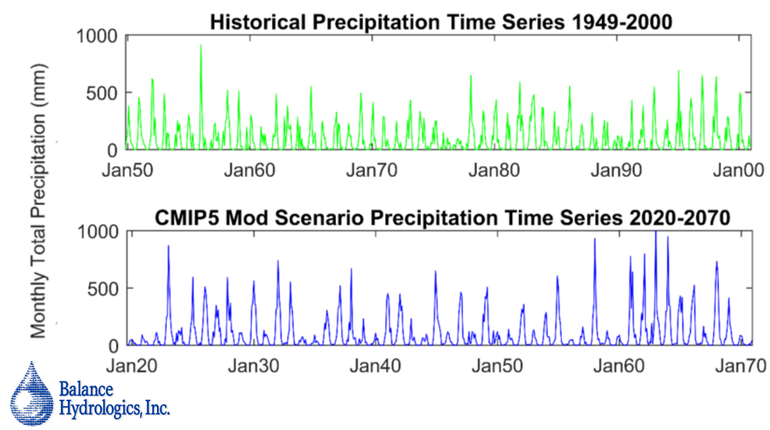

Figure 15: Comparison of an historical period observed precipitation for Santa Cruz vs. the Projection 2 precipitation developed using the stochastic modeling approach.

CC Projection 3

The Projection 3 CC data set was developed as part of the Mid–County Groundwater Basin Sustainability Plan (King and Tana, 2016). The Projection 3 approach makes use of the historical climatology for the period WY1977–2016 as a *catalog* which is sampled to develop a random sequence of annual conditions weighted by air temperature. The catalog approach has been used elsewhere in the Santa Cruz region and in other parts of California (Metropolitan Water District of Southern California, 2016; Young, 2016). Air temperature weighting was specifically used in order to produce a future climate condition which has a warming air temperature trend consistent with regional expectations from CC research (Swain and others, 2018).

The original climate catalog was used to develop a record for the period WY2016–69. However, we removed data for the period WY2016–19, and added one year of data at the end of the time series in order to line the time series up with the CC analysis period. The raw climate catalog is a just sequence of years (e.g. 1977, 2015, 1998...) of observed climate conditions. As a result, we used the historical climatology associated with the specific climate catalog sequence to construct the monthly precipitation and air temperature records of Projection 3 that are run through the WBM. See (King and Tana, 2016) for more details.

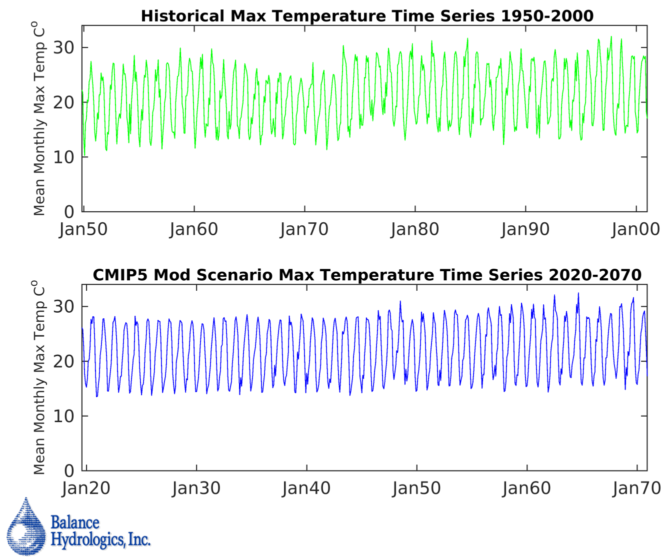

Figure 16: Comparison of an historical period observed maximum air temperature for Santa Cruz vs. the Projection 2 maximum air temperature developed using the stochastic modeling approach.

Comparison of Projections 1–3 and Historical Gridded Climate Conditions

We compare and contrast historical and projected climate conditions by plotting departures of monthly total precipitation and average air temperature, relative to historical averages for the period 1950–2000 (Figure 17). Furthermore, we focus the comparison on the winter months of December–March because that is when most precipitation falls. Monthly climate conditions can fall within one of fours quadrants relative to historical averages: dry and cool, wet and cool, dry and warm, and wet and warm (top plot of Figure 17). Use of this type of quadrant plot makes comparison across climate conditions straightforward.

The Gridded Historical precipitation distribution (Maurer and others, 2002) is left skewed, with a greater proportion of months that have less rainfall than the average. Consequently, there were fewer gridded years that were wet relative to the average, but wet years departed more strongly from the average, as shown by probability density contours that extend beyond a value of 2. Dry and wet months were both cool and warm, relative to average gridded conditions. Furthermore, monthly air temperature departures approach a normal distribution, in contrast to precipitation.

The winter month conditions of CC Projections 1–3 differ from the historical distributions of precipitation and air temperature (lower right–hand 3 plots of Figure 17). Projection 1 is in general drier and warmer than historical average conditions, which was mentioned earlier in this section (Figure 11). In contrast to Historical Gridded and Projections 2 and 3, the distributions of precipitation and air temperature of Projection 1 approach normal distributions over the CC analysis period. This highlights that Projection 1 lacks the increased rainfall variability that climate scientists expect for Central California, but reflects the rise of average air temperature (Swain and others, 2018). As a result, water supply planning with Projection 1 is understood to reflect dry and warm conditions.

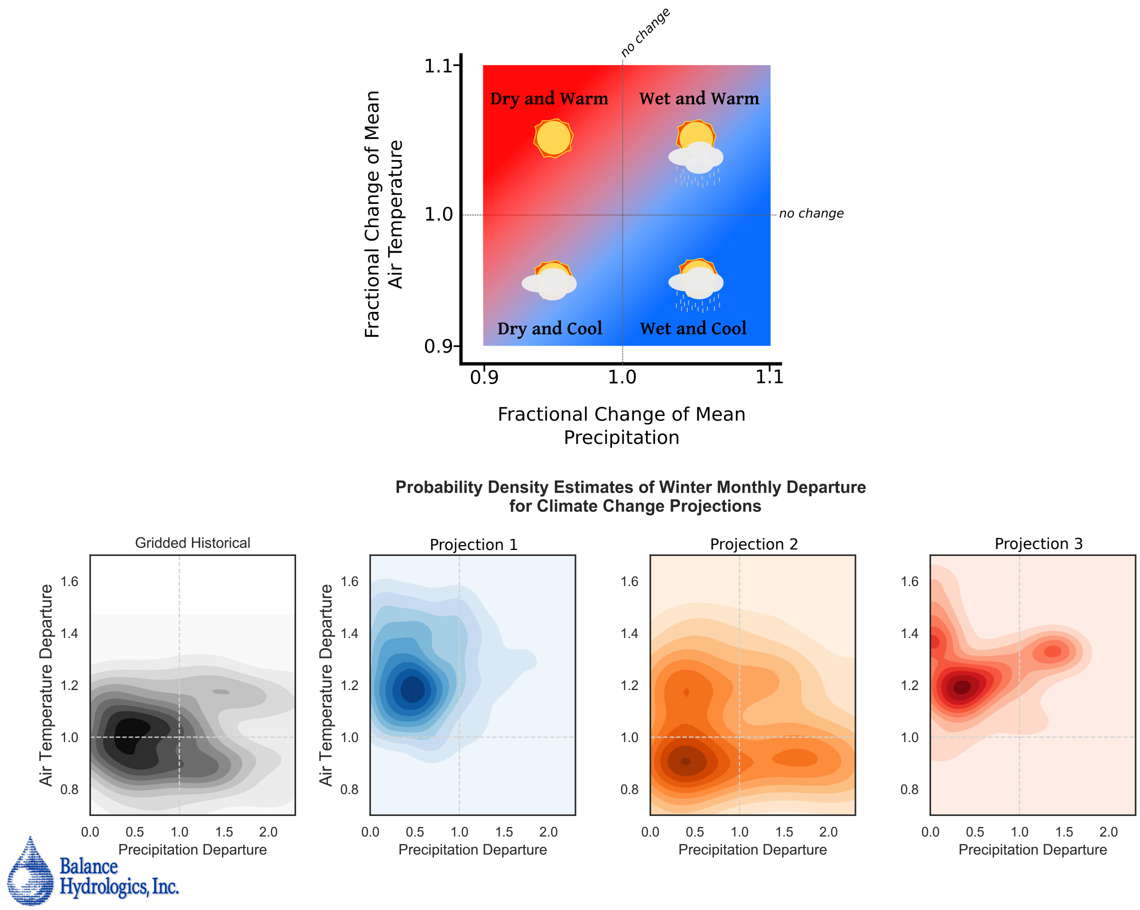

Figure 17: Summary of winter months climate conditions for the three CC projections used in WSP planning analysis. The top plot is a conceptual map that shows how different climate conditions can be understood relative to the historical gridded average annual precipitation and air temperature (coordinates of [1,1] in the plot). The bottom four plots show probability density estimates for the distributions of monthly total precipitation and monthly average air temperature over the months December–March for the historical analysis period and the three CC projection data sets. The probability density estimates provide a quick way to visually understand differences between the four data sets. Density estimates calculated using the SciPy python library.

Projection 2 exhibits a more variable future climate in terms of precipitation and air temperature, compared to Gridded Historical and Projections 1 and 3 (Figure 17). As discussed earlier, this was the intent of Projection 2. There are a concentration of winter months with cool and dry conditions, warm and dry, and cool and wet. However, there are fewer months that are warm and wet. The cooler underlying temperature trend of Projection 2 is evident in the distribution of temperatures relative to the historical average gridded condition. Nonetheless, Projection 2 does contain winter months that are warmer than historical average gridded conditions, consistent with expectations (Figure 17). Water supply planning with Projection 2 is understood to reflect more variable conditions in terms of precipitation, but air temperatures are generally cool.

Projection 3 is similar to Projection 1, but with a greater proportion of winter months that are wet and warm. Projection 3 also contains winter months that are the driest and warmest of any CC projection used for WSP (Figure 17). Compared to Projection 2, however, precipitation has less overall variability. Consequently, water supply planning with Projection 3 is understood to reflect somewhat severe dry and warm climate conditions. Overall, CC Projections 1–3 provide a wide range of future conditions relative to the historical gridded climate. Most importantly, this wide range of conditions yields a strong basis to test how projected instream flow conditions perform relative to historical conditions (Appendices 1b and 1c).

Step 3: Run the Base Hydrology Model

Develop Daily Streamflow records

We developed daily streamflow projections at Big Trees in two different ways using the monthly streamflows of Projections 1–3. In the first method we averaged daily streamflow across all months of the historical analysis period at Big Trees. This step yielded an average daily streamflow hydrograph for each of the 12 months in a water year. We then summed the average daily streamflow for each month, and used the sums to calculate the proportion of flow for each day of each month of the water year calendar. These daily flow proportions were then used to distribute the Projection 1 total monthly streamflows at Big Trees, resulting in a projected daily streamflow hydrograph for the CC analysis period.

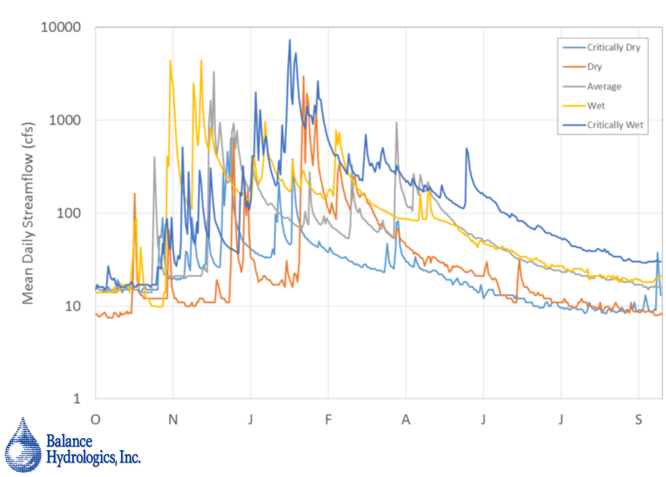

Figure 18: Characteristic annual hydrographs for critically dry, dry, average, wet and very wet total annual flow conditions at Big Trees.

The daily streamflow hydrograph for Projection 1 was post-processed to smooth abrupt and unreasonable changes in flow that occurred between days within the CC analysis period, at month-to-month transitions, and at the end of each water year (i.e. September 30^{th}). Where applied, smoothing of the daily flow record was done with a zero-order forward and reverse digital filter. This means that the location of any given peak in time is not affected, but its amplitude is adjusted based on the nature of flows forward and backward in time from any particular position, based on a specified filtering length and computed flow differences. This particular filter has the advantage of matching initial conditions well. The smoothing filter length was chosen to minimize the sum of differences between the corrected and the filtered record (< 0.1% difference in total flow). It is important to point out that even though Projection 1 data were smoothed, the operation did not result in the loss of peak flow events, etc. that result from precipitation events. The first approach yielded reasonable daily flow hydrographs for each year. However, it has the disadvantage of using a single hydrograph shape for each future year, and it requires data filtering to produce a smoothly varying flow condition at monthly and water year transitions.

For Projections 2 and 3 we applied a second and improved method to develop projected daily streamflows, after additional work carried out over the span of about a year indicated improvements to the daily records was possible. We borrowed from the climate catalog approach (King and Tana, 2016; Young, 2016) and identified characteristic annual hydrographs for the five different hydrologic categories calculated for the Big Trees gage (presented within Section 1 above, and discussed in Appendix D-3 in relation to instream flow rules): critically dry, dry, average, wet and very wet (Figure 18). We applied each characteristic hydrograph to the projections based on the annual hydrologic characteristic of each future year in Projections 2 and 3. For example, if WY2042 was a very wet year, we decomposed the projected monthly flow at Big Trees into an annual hydrograph by scaling the total 2042 annual flow over the very wet characteristic hydrograph. In order to compare model results between the historical and CC analysis periods, the 5-category hydrologic conditions were calculated for the historical analysis period, and then used as the hydrologic basis for the CC period. This is equivalent to using the historical conditions as the reference through which to understand how CC may affect hydrologic conditions at the annual time scale.

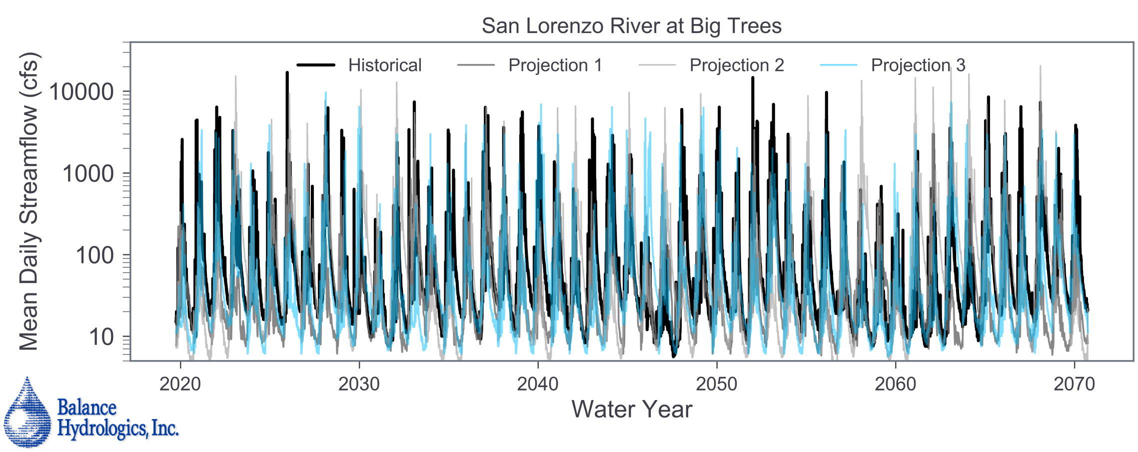

Figure 19: Summary of the daily streamflow hydrographs at Big Trees for the historical period WY1950-2000 observed streamflows, and the Projections 1–3 for the CC analysis period. Note that in this case the historical record does not correspond to gridded climate conditions (Maurer and others, 2002).

The second approach, namely the one that we used for Projections 2 and 3, has the advantage of using multiple hydrograph shapes that are classified according to dryness and wetness conditions (City of Santa Cruz Water Department, 2009), and the resulting time series only require filtering at the water year transitions to produce smoothly varying flows. In both cases nonetheless, we have no way to assess the skill of the decomposition approach because we are using CC projections made at the monthly time step. As a result, the daily hydrographs represent one outcome out of a very large possible number of future outcomes. The daily hydrographs for Projections 1–3 for the CC analysis period are shown in Figure 19. The historical observed hydrograph at Big Trees for WY1950–2000 is shown for reference.

Run the Base Hydrology Model

The daily streamflow records for Projections 1–3 at Big Trees are loaded into the Base Hydrology Model to develop CC hydrology for all source streams of the City. Daily flows for all source streams are then evaluated against instream flow rules (Appendix D-3), and remaining flows are apportioned to water supply availability (Appendix D-2).

3.2. Limitations and Assumptions for CC Analysis

Many assumptions were made to apply the Base Hydrology Model to CC analysis. Here we review some important ones. First and foremost, the analysis we have completed is intended as a means to evaluate changes in streamflow under future conditions, and primarily in terms of drought conditions and baseflows. We chose this focus because it is during these times that water supply and instream habitat conditions are most challenged. Furthermore, the collective approaches taken to yield projections of future daily streamflows was done in order to make useful comparisons to observed historical conditions, and between differing CC projections. As a result, our projections of daily streamflow for the three CC conditions should not be interpreted as *predictions* of future streamflows.

Second, we assume that the CC conditions represented by Projections 1–3 offer plausible future conditions for the Santa Cruz region. Specifically, Projections 1–3 provide a reasonable basis for testing how the instream flow rules might affect habitat conditions and water supply availability under a changed future climate. This assumption is based on the range of future conditions represented by Projections 1–3 (Figure 17).

An additional and important assumption of our work is that hydrograph shapes and day-to-day distributions of flows observed in the past are reasonable bases to project daily flows in the future. We could have used daily flows produced in the process of downscaling climate models to the local scale. However, these flows were shown to over-estimate summertime and drought streamflows. Because of the sensitivity of coho salmon and steelhead trout under these conditions, this option was not pursued in favor of the WBM (Chartrand, 2018).

Third, we assume that the WBM as set-up for climate change analysis in support of the WSP and the Draft Environmental Impact Report will apply to CC conditions in the future. This assumption may turn out to be inaccurate if, for example, stands of redwoods within the source stream watersheds transition to a drier climate forest composition, because forest composition affects the watershed water budget. Last, we did not have a reasonable way to constrain instream conditions for the CC analysis period due to potential future operations of the Felton diversion, or the present water right required bypass flow on the San Lorenzo River. We note these two points because San Lorenzo River flow diversions due to the Felton diversion and the Pre-existing legal bypass are added to gaged streamflows within the historical analysis period to develop the associated estimates of unimpaired streamflows, which is the basis of the Base Hydrology Model. As a result and based on the best available information, we set the Felton diversion [see Appendix D-2 for details] to zero for the CC analysis period, and applied the Pre-existing legal bypass based on the historical data.

References

Chartrand, S.M., 2018. Review of CMIP5 climate change hydrology projections for the City of Santa Cruz Habitat Conservation Plan. Consulting technical memorandum prepared for the City of Santa Cruz Water Department by Balance Hydrologics. 26 pp.

City of Santa Cruz Water Department, 2009, Water shortage contingency plan, www.cityofsantacruz.com/government/city-departments/water/conservation,114 p.

Elsner, M., Cuo, L., Voisin, N., Deems, J., Hamlet, A., Vano, J. and Lettenmaier, D., 2010. Implications of 21st century climate change for the hydrology of Washington State. An Interdisciplinary, International Journal Devoted to the Description, Causes and Implications of Climatic Change, 102(1–2), 225–260. https://doi.org/10.1007/s10584-010-9855.

Hamlet AF and Lettenmaier DP, 1999. Effects of climate change on hydrology and water resources of the Columbia River basin. J Am Water Resour Assoc 35:1597–1624.

IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

King, G. and Tana, C., 2016. Santa Cruz Mid-County Basin Groundwater Flow Model: Future climate for model simulations. Consulting technical memorandum prepared for the Mid-County Groundwater Agency Executive Staff by HydroMetrics. 24 pp.

Maurer, E.P., Wood, A.W., Adam, J.C., Lettenmaier, D.P. and Nijssen, B., 2002, A long-term hydrologically–based data set of land surface fluxes and states for the Conterminous United States, J. Climate 15(22), 3237-3251

Metropolitan Water District of Southern California, 2016. Integrated water resources plan, 2015 update. Report No. 1518.

Stratus Consulting, 2015. Background information on climate change effects on local hydrology. Consulting Technical Memorandum prepared for the City of Santa Cruz Water Supply Advisory Committee by Stratus Consulting in association with Balance Hydrologics, Inc. and Gary Fiske and Assocoiates. 23 pp.

Swain, D.L., Langenbrunner, B., Neelin, J.D. and Hall, A., 2018. Increasing precipitation volatility in twenty-first-century California. Nature Clim Change 8, 427–433. https://doi.org/10.1038/s41558-018-0140-y.

Wood, A. W., Leung, L. R., Sridhar, V. and Lettenmaier, D. P., 2004. Hydrologic Implications of Dynamical and Statistical Approaches to Downscaling Climate Model Outputs. Climatic Change. 62 (1–3): 189–216. doi:10.1023/B:CLIM.0000013685.99609.9e. ISSN 0165–0009.

Young, K. 2016. A high-resolution, regional-scale analysis of stormwater runoff in the San Lorenzo river basin for managed aquifer recharge decision making. Masters of Science Thesis, University of California, Santa Cruz. June.

Appendix A: Regression Models Used in Base Hydrology Model

In the tables that follow, a number of abbreviations are used: H.C.-hydrologic condition; CD-critically dry; D-dry; A-average; W-wet; VW-very wet; BT-San Lorenzo River at Big Trees USGS 11160500.

Table A1: Regression Relationships used in Base Hydrology Model for Upper Stations

Station		Regression Relationships
	Months	**All Flows**
San Vicente SV [11]	Nov.-Apr.	$SV = 0.1025 * BT^{0.9161} + 0.65$
	May-Oct.	$SV = 1.0^{-7} * BT^3 - 2.056^{-4} * BT^2 + 0.1382 * BT - 0.750$
Upper Laguna LG [4]	**H.C.**	**SV flows < 1 cfs**
	CD and D	$LG = 0.4043 * SV^{0.1109}$
	A	$LG = 0.5796 * SV^{0.0957}$
	W	$LG = 0.7551 * SV^{0.088}$
	VW	$LG = 1.0225 * SV^{0.0528}$
	H.C.	**SV flows >= 1 and < 20 cfs**
	CD and D	$LG = 0.3987 * SV^{1.1047}$
	A	$LG = 0.5452 * SV$
	W	$LG = 0.748 * SV^{0.8944}$
	VW	$LG = 1.019 * SV^{0.7931}$
	H.C.	**SV flows >= 20 cfs**
	All	$LG = 0.5452 * SV$
Upper Majors MJ [4]	**H.C.**	**LG flows < 1 cfs**
	CD and D	$MJ = 0.4455 * LG + 0.5257$
	A	$MJ = 0.5574 * LG + 0.6361$
	W	$MJ = 0.6148 * LG + 8721$
	VW	$MJ = 0.6148 * LG + 8721$
	H.C.	**MJ flows >= 1 and < 10 cfs**
	CD and D	$MJ = 0.9577 * LG^{0.7601}$
	A	$MJ = 1.1947 * LG^{6766}$
	W	$MJ = 1.4873 * LG^{0.581}$
	VW	$MJ = 1.4873 * LG^{0.581}$
	H.C.	**LG flows >= 10 cfs**
	All	$MJ = 0.2225 * LG^{1.3962}$
Upper Liddell LD [9]	**H.C.**	**LG flows < 4 cfs**
	-	$LD = 1.8414 * LG^{0.1325}$
	H.C.	**LG flows >= 4 cfs**
	-	$LD = 1.5252 * LG^{0.2727}$
	Months	**All Flows**
Upper Newell NL [12]	Oct.-Sept.	$NL = 0.00906 * BT^{1.2484}$

1. Number in [] refers to the stations listed in Table 1.

3. Flows at Loch Lomond Dam calculated as: LLD=NL*(8.25/4.81)

Table A2: Regression Relationships used in Base Hydrology Model for Anadromous Stations

Station	Months	Regression Relationships
		WY1936-69 and WY1986-15
	Months	**LG flows <= 30 cfs**
	Oct.-Mar.	$ALG = -0.02370 * LG^2 + 1.72551 * LG + 0.16774$
	-	**LG flows > 30 cfs**
	Oct.-Mar.	$ALG = (LG - 15) * 2$
Anadromous Laguna ALG [5]	**-**	**All Flows**
	Apr.-June	$ALG = -0.00498 * LG^2 + 1.3233 * LG - 0.0730$
	-	**All Flows**
	July-Sept.	$ALG = -0.0063 * LG^2 + 1.2436 * LG - 0.0906$
		WY1970-85
	Months	**All Flows**
	Oct.-Mar.	$ALG = 0.3247 * LG^{1.4939}$
	-	**LG Flows <= 30 cfs**
	Apr.-June.	$ALG = -0.002 * LG^3 + 0.1046 * LG^2 - 0.1339 * LG$
Anadromous Laguna ALG [5]	**-**	**LG Flows > 30 cfs**
	Apr.-June.	$ALG = 0.3247 * LG^1.4939$
	-	**All Flows**
	July-Sept.	$ALG = 0.0415 * LG^{2.1328}$
		WY1936-69 and WY1986-15
	Months	**All Flows**
Anadromous Majors AMJ [8]	Oct.-Sept..	$AMJ = 0.9248 * MJ^{1.0961}$
		WY1970-85
	Months	**All Flows**
Anadromous Majors AMJ [8]	Oct.-Sept.	$AMJ = 1.1863 * MJ - 1.1052$
	Months	**All Flows**
Anadromous Liddell ALD [10]	Oct.-Sept.	$ALD = 0.44 * SV + LD$
	Months	**All Flows**
Anadromous Newell ANL [13]	Oct.-Sept.	$ANL = 1.147 * LLD$
	All Months	**BT flows < 30 cfs**
	-	$Tait = 0.94378 * BT^{1.0558}$
San Lorenzo Tait Street [9]	**All Months**	**LG flows > 30 cfs**
	-	$Tait = 1.1689 * BT^{0.9928}$

1. Number in [] refers to the stations listed in Table 1

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THE CONFLUENCE MODEL

Confluence® is a model designed to simulate the operation of water supply systems to assist water supply agencies in evaluating and comparing water supply and infrastructure alternatives. The model allows simulations using a daily or monthly time step and can accommodate a wide variety of surface water and groundwater supplies, storage facilities, infrastructure, operating constraints, and flow regimes. The model produces a wide variety of outputs in both graphical and tabular form to enable water suppliers to focus on the results that are most important to their decision-making or that are needed to fulfill legal or regulatory requirements, including different representations of:

- Water supply reliability
- Water demands
- Source-specific production
- Surface water and groundwater storage levels
- Treatment and transmission throughput
- Fixed and variable costs

The data underlying all model outputs is easily exported to Microsoft Excel to further customize needed calculations and presentations.

A key driver of the simulations is the daily streamflows available for diversion, which constrain the potential diversion volumes for each day of the hydrologic period of record. The model can simulate system operations over the entire record or any subset of that record. Modeling runs can include single or multiple simulations depending on the questions being addressed.

Model inputs for system components are entered through an interactive schematic of the water supply system. A simple system schematic for the City of Santa Cruz (City) water system[1] is shown in Figure 1. For each source, storage facility, or treatment plant, the operating and infrastructure constraints associated with that system component (including the relevant set of available flows) can be edited from the "live" schematic by the modeler. In addition, the capacities, line losses, pumping costs, and other parameters associated with each portion of the transmission system are specified, which impose other constraints on system operations.

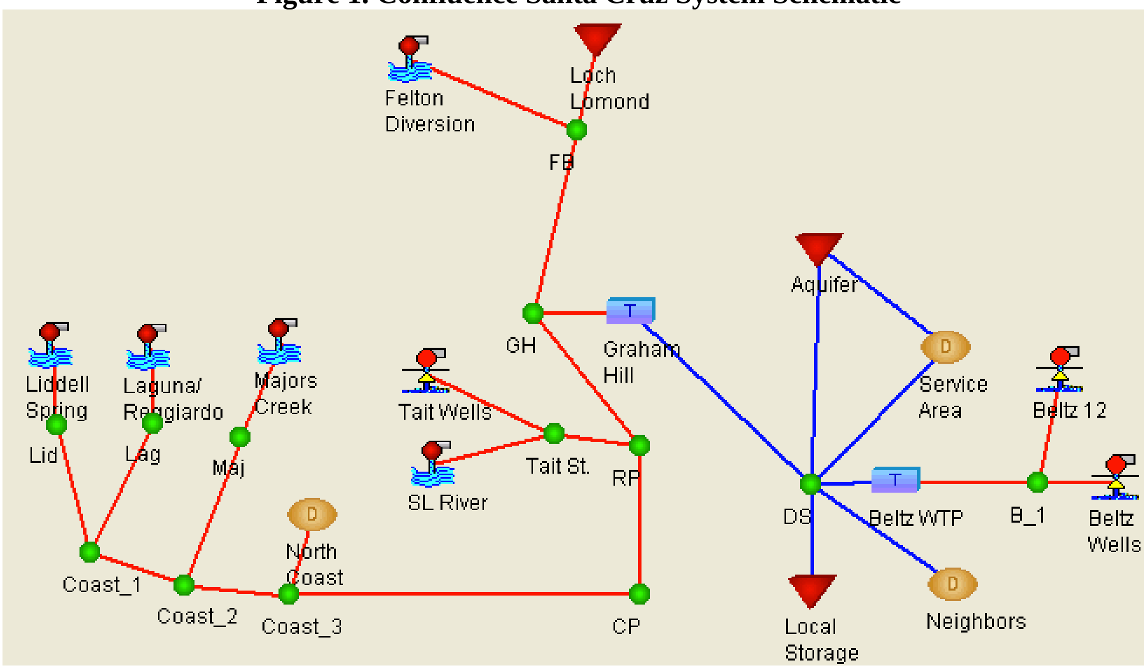
For each time step, the way the system is dispatched is determined by shadow prices assigned by the user to each supply source and each zone of surface water or groundwater storage. The simulation dispatches the system in increasing order of cost, as determined by these shadow prices and any other variable operating costs (e.g. pumping or treatment costs) associated with using each supply source. The supply source with the lowest combined cost is dispatched first, followed by the next highest cost, etc. The shadow prices assigned to storage zones are used to regulate the drawdown of surface water and groundwater storage.

[1] The City owns and operates a water system that diverts and serves water both within the City limits and outside of those limits. References to the City's water system, rights and supplies therefore refer to areas both inside and outside of the City limits.

Other model inputs include:

- The specification of the simulation parameters, including the flow years that are to be sampled and the operating years for which the simulation is to be run.
- The forecast of annual and monthly system demands.
- The specific outputs that are desired.

Figure 1. Confluence Santa Cruz System Schematic



Legend:

Demand node

Connection node

Surface water diversion

Groundwater extraction wells

Storage

Water treatment plant

USE OF CONFLUENCE IN SANTA CRUZ

History

Beginning with the City's Integrated Water Plan (IWP),[2] which was initially completed in 2003, the City has used Confluence to guide many key water resource planning efforts, including

[2] Gary Fiske & Associates. 2003. *City of Santa Cruz Integrated Water Plan, Draft Final Report*. June 2003

analyses of the potential impacts of climate change, assessments of potential water transfers to neighboring agencies, support for the City's 2015 Urban Water Management Plan,[3] and numerous evaluations of the impacts of potential supply, infrastructure and/or operational changes. In recent years, Confluence supported the City's Water Supply Advisory Committee (WSAC), as it engaged in an extended evaluation of many potential future water supply and infrastructure alternatives. Since 2008, Confluence has provided modeling support to evaluate and refine the numerous options considered by the City, the California Department of Fish and Wildlife (CDFW), the National Oceanic and Atmospheric Administration (NOAA), and the National Marine Fisheries Services (NMFS), to develop an Anadromous Salmonid Habitat Conservation Plan (ASHCP). This effort resulted in the development of minimum bypass flow requirements (Agreed Flows) to balance the habitat needs of anadromous species and the reliability of water supplied to City customers.

Application of Confluence to the Santa Cruz Water Rights Project

Modeling Approach

Confluence was used to model scenarios reflecting the Baseline, Proposed Project, and each of the Project Alternatives, all of which are described in the Appendix D Overview and in the body of the Draft EIR. In all cases, the goal of the model simulation is to maximize water supply reliability for City customers consistent with the relevant assumptions for each scenario. For example, for the Proposed Project, those assumptions include implementation of the Agreed Flows. Specifically, the objective is to minimize peak-season water shortages during the worst multi-year drought in the hydrologic record.

For all model runs, the first constraint on system operations is the daily available flows. As described in Appendix D-3, available flows for City diversions reflect the agreements reached in the City's ASHCP. The projected available flows can reflect historical conditions or projected conditions of climate change.

While the modeling approaches for the Baseline, Proposed Project, and Project Alternatives have much in common, the approach for those scenarios that include groundwater storage differs somewhat from those that do not.

Modeling Logic without Groundwater Storage (Baseline and Alternatives 1 and 3)

The lack of groundwater storage for the Baseline and Alternatives 1 and 3 results in an inability to eliminate the worst-drought shortage. Loch Lomond Reservoir is operated to minimize the magnitude of this shortage. Following are the key modeling steps, which are identical to those used in prior SCWD Confluence modeling.

[3] City of Santa Cruz. 2016. *City of Santa Cruz 2015 Urban Water Management Plan.* Prepared by the City of Santa Cruz, Water Department. August 2016.

1. Iteratively simulate the operation of the system for the worst multi-year drought and the three years of the hydrologic record prior to that drought.[4] Beginning the simulation 3 years prior to the beginning of the drought enables the drought to begin with a Loch Lomond Reservoir storage volume reflecting the prior wetter years.

2. Each iteration will adjust Loch Lomond Reservoir's rule curves and the number and costs of blocks of remaining demand that the reservoir must attempt to serve. The goal of these iterations is to regulate the reservoir drawdown so that the usable storage volume is exhausted at the end of the final month (October) of the drought, but no sooner. This will minimize the remaining water supply shortage.

3. With these rule curves and demand blocks, simulate the system over the entire hydrologic record.

Modeling Logic with Groundwater Storage (Proposed Project and Alternative 2)

The Proposed Project and Alternative 2 include ASR injection to and extraction from underground storage. The surface water and groundwater storage volumes are operated conjunctively[5] to minimize the ASR infrastructure required to achieve the reliability goal, to eliminate the worst-drought shortage. The modeling steps are as follows:

1. Iteratively simulate the operation of the system for the worst multi-year drought and the three years of the hydrologic record prior to that drought. In addition to enabling Loch Lomond Reservoir to start the drought with a storage volume reflecting the prior wetter years, this also reflects the assumption of a 3-year pre-drought fill period for groundwater storage. The storage zones and rule curves for Loch Lomond Reservoir and the underground storage are set to jointly fill and draw down both storage facilities.

2. Each iteration will adjust the ASR injection and extraction capacities to ultimately find the minimum infrastructure needed to eliminate the worst-drought shortage. The proper groundwater injection and extraction capacities are the minimum levels that will draw down the usable storage volumes of both Loch Lomond Reservoir's surface storage and the underground storage to zero at the end of the multi-year drought.

3. With these ASR injection and extraction capacities, simulate the system operation over the entire hydrologic record.

At the conclusion of the simulations of the Baseline, Proposed Project and each Alternative, the resulting daily diversions and Loch Lomond Reservoir fill and drawdown volumes are combined with the natural flows (prior to ASHCP bypass requirements) and any tributary inflows downstream of the diversions to calculate the daily anadromous-reach flows across the hydrologic

[4] For the CMIP5 climate change projection, described in Appendix D-1, the worst drought occurs in the first 3 years of the hydrologic record. The 3 prior years were set at the average available flows over the record.

[5] Conjunctive use refers to a range of actions and projects that provide for the coordinated management of surface water and groundwater supplies to increase total supplies and enhance water supply reliability.

record in each stream. These results are provided as input to the fisheries effects modeling, described in Appendix D-3.

Key Assumptions

As discussed, the use of Confluence to support the development and evaluation of the Proposed Project and Alternatives presented in the Appendix D Overview and the Draft EIR builds upon the many years of application of Confluence to the City's system. Over those years, model capabilities were continuously updated and assumptions refined to better represent the actual operation of the system. Tables 1 through 5 lay out the key assumptions that underlie the model runs for the Baseline, Proposed Project, and the three Project Alternatives discussed in the Appendix D Overview and the body of the Draft EIR.

Baseline Assumptions

Table 1. Key Modeling Assumptions for the Baseline

CATEGORY	COMPONENT	ASSUMPTION
DEMANDS	**City Service Area**	3,200 mgy
	North Coast Agriculture	40 mgy
HYDROLOGY	**Historical Hydrologic Record**	1937-2015
	Climate Change Hydrologic Record	2020-2070
	Climate Model	CMIP-5 MOD
	Flow Rules	interim bypass requirements effective in 2018
DISPATCH OF SUPPLIES	**Source Dispatch Order to Meet SCWD Demand**	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Beltz Wells 5. Surface water storage
	North Coast Potential End Uses	1. Agricultural Demands 2. City Demands
	Tait Potential End Uses	City Demands
	Felton Potential End Uses	Surface storage at Loch Lomond Reservoir
	Beltz Wells Potential End Uses	City Demands

CATEGORY	COMPONENT	ASSUMPTION
	Loch Lomond Potential End Uses	City Demands
DIVERSION CAPACITIES	**Liddell**	2.47 cfs
	Laguna	6.27 cfs
	Majors	2.09 cfs
	Tait	11.52 cfs
	Felton	12.40 cfs
WATER RIGHTS (maximum diversion rate)	**North Coast**	No Limit when minimum flows are met
	Felton	Jan-May; Oct-Dec 20.0 cfs Jun-Aug 0 Sep 7.8 cfs
	Tait	12.2 cfs in all months
WATER TREATMENT PLANT CAPACITY (mgd)	**Graham Hill WTP**	16.5 mgd
OTHER KEY OPERATING CONSTRAINTS	**North Coast**	Turbidity
	Felton	Turbidity, First Flush, Pump limitations, Reservoir elevations
	Tait	Turbidity
WELL EXTRACTION CAPACITIES (Native Groundwater)	**Beltz Live Oak**	0.8 mgd Apr - Nov in all water years
	Beltz 12	0.3 mgd May - Aug in critically dry years
	Tait Wells	1.28 mgd May-Dec; 0.78 mgd Jan-Apr
LOCH LOMOND	**Max/usable capacity**	2,810 mg/1,740 mg
	Allowable diversion months	Sept-Jun
	Daily Instream Release	1.00 cfs

CATEGORY	COMPONENT	ASSUMPTION
	Annual San Lorenzo Valley Entitlement	102.1 mg
AQUIFER STORAGE & RECOVERY	**Storage Capacity**	N/A
	Aquifer Losses	N/A
	Injection Capacity	N/A
	Extraction Capacity	N/A
	Injection Season	N/A
	Extraction Season	N/A
	Hydrologic condition restriction	N/A
WATER TRANSFERS	**Maximum monthly transfer**	N/A
	Hydrologic condition restriction	N/A

Following are brief discussions of the Baseline assumptions laid out in Table 1.

- Demands. The assumptions represent the City's best estimates of the magnitudes of long-term unconstrained annual demands. "Unconstrained demands" are those that would be expected to be realized in the absence of voluntary or mandatory drought-related curtailments as described in the City's 2009 Water Shortage Contingency Plan [City of Santa Cruz 2009). These annual demands are allocated across calendar months based on customer demand patterns. These assumptions are identical to those used in recent SCWD system modeling, including the WSAC process, and the ASHCP.

- Hydrology. The 79-year historical and the 51-year climate change periods of record are again consistent with recent modeling efforts. The CMIP-5 MOD climate change projection is described above in Appendix D-1 and was used in the ASHCP process. The available flows in the Baseline are per the interim bypass requirements effective in 2018, described in Appendix D-3.

- Dispatch of Supplies. In each daily time step, the simulation dispatches the supply sources in this order to meet that day's demands. The North Coast sources are assigned the lowest shadow prices and are thus dispatched first. The available North Coast supply first serves North Coast agricultural demands, and the remaining available North Coast supply goes to the Graham Hill Water Treatment Plant (GHWTP) to serve SCWD demands. Available supplies from the Tait Diversion and the Tait wells are then dispatched to the GHWTP to serve SCWD demands. If there remains unserved demand, the available Beltz Well supplies are dispatched. The final source to be dispatched to the GHWTP to serve SCWD demands, which is only used if the other sources are unable to serve that day's demand, is the Loch Lomond Reservoir.

  For the Baseline, the places of use for all the supplies are consistent with existing water rights.

- Diversion and Treatment Constraints. In any daily time step of the simulation, actual diversions are constrained by many factors. The first of these is the physical diversion capacities, which are displayed in the Table 1. (The capacity shown for Felton is the assumed capacity of the Felton Booster Pump Station, which is somewhat less than the 13.7 cfs physical capacity of the diversion itself.) In addition, diversions may be constrained by water rights, the current magnitudes of which are also displayed in Table 1. Other operating constraints include:

    - Excess turbidity. If the water at the relevant diversion facility is determined to be too turbid on any day to either be treated at GHWTP or, in the case of Felton, to be stored in Loch Lomond Reservoir that diversion is shut off for that day. Confluence turbidity constraints are a function of the precipitation on the current day and recent past days. The constraints are designed to approximate the current treatment capabilities at GHWTP or the current turbidity limits for water placed into Loch Lomond Reservoir for storage.

    - Additional Felton Diversion constraints. Diversions from Felton are also limited by several other factors:

        - First flush. The City currently does not divert from Felton Diversion in the fall until after there have been sufficient flows to “flush” solids and other contaminants that have accumulated in the San Lorenzo River over the dry season. The specific modeled constraint is that diversions cannot begin until there have been two days of flow at the Big Trees gage that are at least 100 cfs.

        - Pumping limitations. The current configuration of the Felton Diversion pumps allows diversions only at several discrete levels up to and including the maximum 13.7 cfs. These discrete pumping levels are reflected in the model assumptions, and further constrain diversions at Felton Diversion.

        - Loch Lomond Reservoir elevations. The current transmission from Felton Diversion to Loch Lomond Reservoir is hydraulically constrained, so that the rate at which water can be moved decreases as the reservoir’s elevation increases. Of course, if Loch Lomond Reservoir is spilling, no water can be diverted from Felton Diversion to the reservoir.

- Water Treatment Plant. The GHWTP capacity is assumed to be 16.5 mgd.

- Well Extraction Capacities. Table 1 displays the assumed well extraction capacities for the Beltz wells as well as the Tait wells.

- Loch Lomond Reservoir. The assumed maximum storage capacity of the reservoir is 2,810 mg. Of this, 70 mg is assumed to be inaccessible for drawdown. In addition, 1,000 mg is assumed to be reserved to insure against a possible future drought, which is longer and/or more severe than what has been experienced in the past. This leaves 1,740 mg usable storage volume. This usable storage capacity is filled and drawn down as described above. Other key Loch Lomond Reservoir operating constraints are also displayed in Table 1.

It is worth repeating that all assumptions have been refined over the years to ensure that the model simulates as closely as possible the manner in which City currently operates its water system.

Proposed Project Assumptions

Table 2. Key Modeling Assumptions for the Proposed Project

CATEGORY	COMPONENT	ASSUMPTION
DEMANDS	**City Service Area**	3,200 mgy
	North Coast Agriculture	40 mgy
HYDROLOGY	**Historical Hydrologic Record**	1937-2015
	Climate Change Hydrologic Record	2020-2070
	Climate Model	CMIP-5 MOD
	Flow Rules	Agreed Flows
DISPATCH OF SUPPLIES	**Source Dispatch Order to Meet City Demand**	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Felton 5. Beltz Wells 6. Surface water and groundwater storage operated in parallel
	North Coast End Uses	1. Agricultural Demands 2. City Demands 3. GW Storage 4. Transfers
	Tait Potential End Uses	1. City Demands 2. GW Storage 3. Transfers
	Felton Potential End Uses	1. City Demands 2. Surface storage 3. GW Storage 4. Transfers

CATEGORY	COMPONENT	ASSUMPTION
	Beltz Wells End Uses	City Demands
	Loch Lomond & ASR End Uses	City Demands[6]
DIVERSION CAPACITIES	**Liddell**	2.47 cfs
	Laguna	6.27 cfs
	Majors	2.09 cfs
	Tait	27.85 cfs
	Felton	13.70 cfs
WATER RIGHTS (maximum diversion rate)	**North Coast**	No Limit when Agreed Flows are met
	Felton & Tait	Shared water right: Jan-May; Oct-Dec 32.2 cfs Jun-Aug 12.2 cfs Sep 20.0 cfs
WATER TREATMENT PLANT CAPACITY (mgd)	**Graham Hill WTP**	18 mgd
OTHER KEY OPERATING CONSTRAINTS	**North Coast**	Turbidity
	Felton	Turbidity, First Flush
	Tait	Turbidity
WELL EXTRACTION CAPACITIES (Native Groundwater)	**Beltz Live Oak**	0.8 mgd Apr - Nov in all water years
	Beltz 12	0.3 mgd May - Aug in critically dry years
	Tait Wells	1.28 mgd May-Dec; 0.78 mgd Jan-Apr

[6] The Proposed Project includes the expansion of the Newell Creek/Loch Lomond water-right license's (License 9847) place of use to include neighboring agencies and the full boundaries of local groundwater basins. Transfers under that license into that expanded area are likely to be rare and are addressed qualitatively in the Draft EIR.

CATEGORY	COMPONENT	ASSUMPTION
LOCH LOMOND	**Max/usable capacity**	2,810 mg/1,740 mg
	Allowable diversion months	Sept-Jun
	Daily Instream Release	1.00 cfs
	Annual San Lorenzo Valley Entitlement	102.1 mg
AQUIFER STORAGE & RECOVERY	**Storage Capacity**	3,000 mg
	Aquifer Losses	20%
	Injection Capacity	Hist 4.5 mgd; Clim Chg 5.5 mgd
	Extraction Capacity	Hist 8.0 mgd; Clim Chg 7.0 mgd
	Injection Season	Nov-Apr
	Extraction Season	May-Oct
	Hydrologic condition restriction	No injection in Hydrologic Condition-5 months
WATER TRANSFERS	**Maximum monthly transfer**	Neighbor agency groundwater demands
	Hydrologic condition restriction	No transfer in Hydrologic Condition-4 & Hydrologic Condition-5 months

Following are brief discussions of the key differences between the modeling assumptions for the Proposed Project, as laid out in Table 2 and those for the Baseline.

- Hydrology. The available flows for diversions in the Proposed Project are determined by the Agreed Flow rules.

- Dispatch of Supplies. The final step of the dispatch includes the joint drawdown of the surface water from Loch Lomond Reservoir storage and ASR groundwater storage. In addition, the water rights changes included in the Proposed Project, discussed below, expand the potential destinations for the supplies from particular sources. Table 2 shows the order of destinations to which each source is dispatched.

- Diversion Constraints. The Tait Diversion capacity is assumed to be upgraded to match the upgraded treatment plant capacity. The current Felton Booster Pump Station constraints are assumed to be removed, so the capacity shown for the Felton Diversion is the physical capacity of the diversion itself. Other operating constraints that differ from the Baseline include:

    - Excess turbidity. Because of the assumed improvements at GHWTP, the number of days of turbidity shutoffs are assumed to be halved for the Felton and Tait Diversions.

- Additional Felton Diversion constraints. Assumed improvements to the Felton pumps eliminate the discrete pumping limitations of the Baseline. Likewise, improvements to the Felton Booster Pump Station and transmission to Loch Lomond Reservoir are assumed to remove the hydraulic constraints so the capacity to move water to the reservoir no longer depends on the reservoir elevation.

- Water Rights. The Proposed Project shares the current water rights at Felton and Tait, and the places of use for those diversions are expanded so that either can divert water to the SCWD service area, to ASR injection, and to neighboring agencies. Likewise, the Proposed Project expands the allowed places of use for the North Coast diversions.

- Water Treatment Plant. The GHWTP is assumed to be upgraded to a capacity of 18 mgd. The upgrades are also assumed to enable more turbid water to be treated.

- Well Extraction Capacities. The Beltz and Tait well capacities to extract native groundwater are supplemented by the assumed ASR well extraction capacities discussed below.

- ASR. Based on preliminary groundwater modeling, the groundwater storage capacity is assumed to be 3 billion gallons. A 20% loss factor is also assumed, so that for each 100 gallons injected, only 80 gallons are available for extraction. The volumes in groundwater storage are assumed to drawn down jointly with Loch Lomond Reservoir. Table 2 shows the assumed injection and extraction capacities. Injections are constrained in the modeling to the months of November-April; extractions are modeled to occur in May-October. Finally, no injection is permitted in months for which the Big Trees flow falls in the lowest quintile (Hydrologic Condition 5). See Appendix D-3 for a description of the Hydrologic Conditions.)

- Water Transfers. Transfers only occur when available streamflows on any day exceed the volumes that can be delivered to all other points of use. Transfers are limited by the combined estimated groundwater demands of Soquel Creek Water District, Scotts Valley Water District, and San Lorenzo Valley Water District. Central Water District demands are assumed to be within these other districts demands because Central is relatively small. Transfers cannot occur in months for which the Big Trees flow falls in the lowest two quintiles (Hydrologic Conditions 4 and 5).

Assumptions for Project Alternatives

The three Project Alternatives are described in detail in the Appendix D Overview and in the body of the Draft EIR. Their key differences in modeling assumptions are summarized as follows:

- Alternative 1. Flows available for diversion are determined by the Agreed Flows, consistent with the Proposed Project. This alternative also includes all infrastructure changes that have independent utility (see Appendix D Overview). Water rights are unchanged from current water rights, consistent with the Baseline.

- Alternative 2. Assumptions regarding available flows, infrastructure improvements, and shared water rights are consistent with the Proposed Project. However, there is no place of use expansion focused on ensuring regional water supply reliability in neighboring districts and groundwater basins. Alternative 2 would not include water transfers to neighboring agencies and ASR would be possible only within the City's service area.

- Alternative 3. Assumptions regarding available flows, infrastructure improvements, water rights, and water transfers are consistent with the Proposed Project. However, there is no ASR infrastructure for groundwater storage and extraction.

Table 3. Key Modeling Assumptions for Alternative 1

CATEGORY	COMPONENT	ASSUMPTION
DEMANDS	**City Service Area**	3,200 mgy
	North Coast Agriculture	40 mgy
HYDROLOGY	**Historical Hydrologic Record**	1937-2015
	Flow Rules	Agreed Flows
DISPATCH OF SUPPLIES	**Source Dispatch Order to Meet City Demand**	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Beltz Wells 5. Surface water storage
	North Coast End Uses	1. Agricultural Demands 2. City Demands
	Tait Potential End Uses	City Demands
	Felton Potential End Uses	Surface storage
	Beltz Wells End Uses	City Demands

CATEGORY	COMPONENT	ASSUMPTION
	Loch Lomond End Uses	City Demands
DIVERSION CAPACITIES	**Liddell**	2.47 cfs
	Laguna	6.27 cfs
	Majors	2.09 cfs
	Tait	11.52 cfs
	Felton	13.70 cfs
WATER RIGHTS (maximum diversion rate)	**North Coast**	No limit when Agreed Flows are met
	Felton	Jan-May; Oct-Dec 20.0 cfs Jun-Aug 0 Sep 7.8 cfs
	Tait	12.2 cfs in all months
WATER TREATMENT PLANT CAPACITY (mgd)	**Graham Hill WTP**	18 mgd
OTHER KEY OPERATING CONSTRAINTS	**North Coast**	Turbidity
	Felton	Turbidity, First Flush
	Tait	Turbidity
WELL EXTRACTION CAPACITIES (Native Groundwater)	**Beltz Live Oak**	0.8 mgd Apr - Nov in all water years
	Beltz 12	0.3 mgd May - Aug in critically dry years
	Tait Wells	1.28 mgd May-Dec; 0.78 mgd Jan-Apr
LOCH LOMOND	**Max/usable capacity**	2,810 mg/1,740 mg
	Allowable diversion months	Sept-Jun
	Daily Instream Release	1.00 cfs
	Annual San Lorenzo Valley Entitlement	102.1 mg

CATEGORY	COMPONENT	ASSUMPTION
AQUIFER STORAGE & RECOVERY	**Storage Capacity**	N/A
	Aquifer Losses	N/A
	Injection Capacity	N/A
	Extraction Capacity	N/A
	Injection Season	N/A
	Extraction Season	N/A
	Hydrologic condition restriction	N/A
WATER TRANSFERS	**Maximum monthly transfer**	N/A
	Hydrologic condition restriction	N/A

Table 4. Key Modeling Assumptions for Alternative 2

CATEGORY	COMPONENT	ASSUMPTION
DEMANDS	**City Service Area**	3,200 mgy
	North Coast Agriculture	40 mgy
HYDROLOGY	**Historical Hydrologic Record**	1937-2015
	Flow Rules	Agreed Flows
DISPATCH OF SUPPLIES IN MODELING	**Source Dispatch Order to Meet City Demand**	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Felton 5. Beltz Wells 6. Surface water and groundwater storage operated in parallel
	North Coast End Uses	1. Agricultural Demands 2. City Demands 3. GW Storage
	Tait Potential End Uses	1. City Demands 2. GW Storage

CATEGORY	COMPONENT	ASSUMPTION
	Felton Potential End Uses	1. City Demands 2. Surface storage 3. GW Storage
	Beltz Wells Potential Destination	City Demands
	Loch Lomond & ASR End Uses	City Demands
DIVERSION CAPACITIES	**Liddell**	2.47 cfs
	Laguna	6.27 cfs
	Majors	2.09 cfs
	Tait Street	27.85 cfs
	Felton	13.70 cfs
WATER RIGHTS (maximum diversion rate)	**North Coast**	No limit when Agreed Flows are met
	Felton & Tait	Shared water right: Jan-May; Oct-Dec 32.2 cfs Jun-Aug 12.2 cfs Sep 20.0 cfs
WATER TREATMENT PLANT CAPACITY (mgd)	**Graham Hill WTP**	18 mgd
OTHER KEY OPERATING CONSTRAINTS	**North Coast**	Turbidity
	Felton	Turbidity, First Flush
	Tait	Turbidity
WELL EXTRACTION CAPACITIES (Native Groundwater)	**Beltz Live Oak**	0.8 mgd Apr - Nov in all water years
	Beltz 12	0.3 mgd May - Aug in critically dry years
	Tait Wells	1.28 mgd May-Dec; 0.78 mgd Jan-Apr

CATEGORY	COMPONENT	ASSUMPTION
LOCH LOMOND	**Max/usable capacity**	2,810 mg/1,740 mg
	Allowable diversion months	Sept-Jun
	Daily Instream Release	1.00 cfs
	Annual San Lorenzo Valley Entitlement	102.1 mg
AQUIFER STORAGE & RECOVERY	**Storage Capacity**	2,100 mg
	Aquifer Losses	20%
	Injection Capacity	2.10 mgd
	Extraction Capacity	2.17 mgd
	Injection Season	Nov-Apr
	Extraction Season	May-Oct
	Hydrologic condition restriction	No injection in Hydrologic Condition-5 months
WATER TRANSFERS	**Maximum monthly transfer**	N/A
	Hydrologic condition restriction	N/A

Table 5. Key Modeling Assumptions for Alternative 3

CATEGORY	COMPONENT	ASSUMPTION
DEMANDS	**City Service Area**	3,200 mgy
	North Coast Agriculture	40 mgy
HYDROLOGY	**Historical Hydrologic Record**	1937-2015
	Flow Rules	Agreed Flows
DISPATCH OF SUPPLIES	**Source Dispatch Order to Meet City Demand**	1. North Coast 2. Tait Diversion 3. Tait Wells 4. Felton 5. Beltz Wells 6. Surface water
	North Coast End Uses	1. Agricultural Demands 2. City Demands

CATEGORY	COMPONENT	ASSUMPTION
		3. Transfers
	Tait Potential End Uses	1. City Demands 2. Transfers
	Felton Potential End Uses	1. City Demands 2. Surface storage 3. Transfers
	Beltz Wells End Uses	City Demands
	Loch Lomond & Aquifer Potential End Uses	City Demands
DIVERSION CAPACITIES	**Liddell**	2.47 cfs
	Laguna	6.27 cfs
	Majors	2.09 cfs
	Tait	27.85 cfs
	Felton	13.70 cfs
WATER RIGHTS (maximum diversion rate)	**North Coast**	No limit when Agreed Flows are met
	Felton & Tait	Shared water right: Jan-May; Oct-Dec 32.2 cfs Jun-Aug 12.2 cfs Sep 20.0 cfs
WATER TREATMENT PLANT CAPACITY (mgd)	**Graham Hill WTP**	18 mgd
OTHER KEY OPERATING CONSTRAINTS	**North Coast**	Turbidity
	Felton	Turbidity, First Flush
	Tait	Turbidity

CATEGORY	COMPONENT	ASSUMPTION
WELL EXTRACTION CAPACITIES (Native Groundwater)	**Beltz Live Oak**	0.8 mgd Apr - Nov in all water years
	Beltz 12	0.3 mgd May - Aug in critically dry years
	Tait Wells	1.28 mgd May-Dec; 0.78 mgd Jan-Apr
LOCH LOMOND	**Max/usable capacity**	2,810 mg/1,740 mg
	Allowable diversion months	Sept-Jun
	Daily Instream Release	1.00 cfs
	Annual San Lorenzo Valley Entitlement	102.1 mg
AQUIFER STORAGE & RECOVERY	**Storage Capacity**	N/A
	Aquifer Losses	N/A
	Injection Capacity	N/A
	Extraction Capacity	N/A
	Injection Season	N/A
	Extraction Season	N/A
	Hydrologic condition restriction	N/A
WATER TRANSFERS	**Maximum monthly transfer**	Neighbor agency groundwater demands
	Hydrologic condition restriction	No transfer in Hydrologic Condition-4 &Hydrologic Condition-5 months

Key Model Outputs

As discussed above, there is a large array of potential model outputs. Following are charts that illustrate a subset of those outputs that provide key comparisons among the Baseline, Proposed Project, and Alternatives 1 through 3. Results will first be shown for historical flows and then for climate change.

Historical Flows

For historical flows, the ASR injection and extraction capacities needed to achieve the water supply reliability goal (zero worst-drought peak-season shortage) for the Proposed Project are 4.5 mgd and 8.0 mgd, respectively. With these capacities, Figures 2 and 3 compare the total annual diversions from the San Lorenzo River.

Figure 2. Annual Felton Diversions: Historical Flows

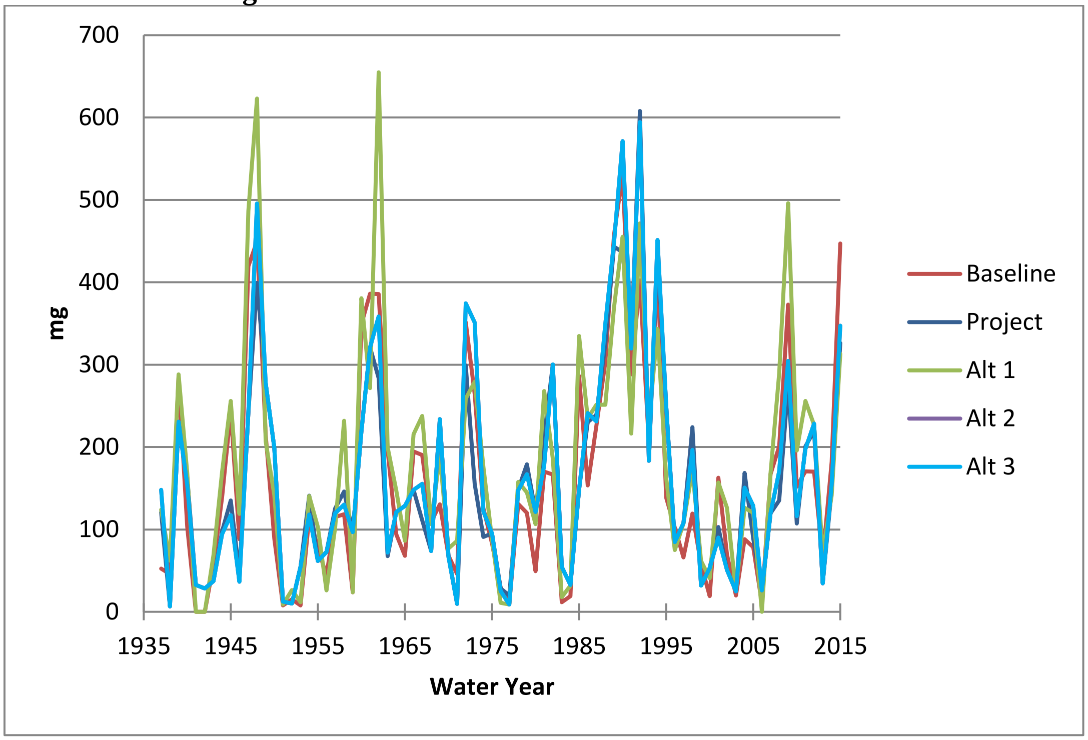


Figure 3. Annual Tait Diversions: Historical Flows

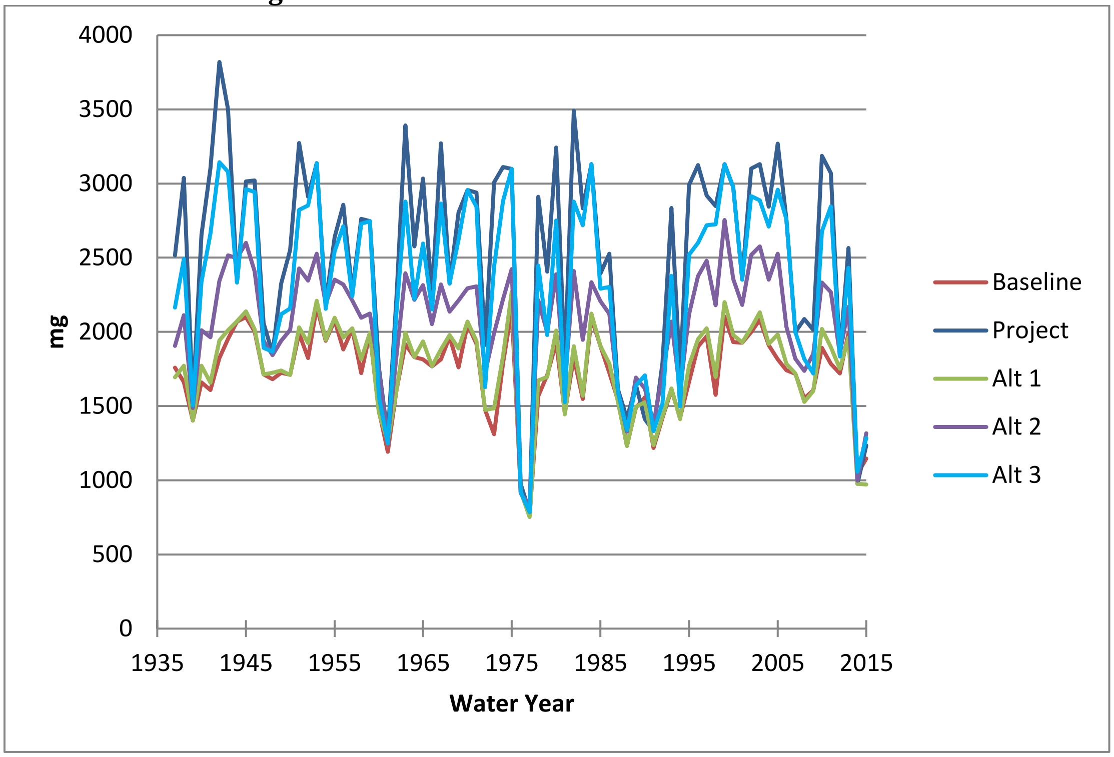


Figure 4 compares North Coast annual diversions. The slight variations are due to the small differences between the interim bypass flows effective in 2018 and the Agreed Flows.

Figure 4. Annual Diversions from the North Coast: Historical Flows

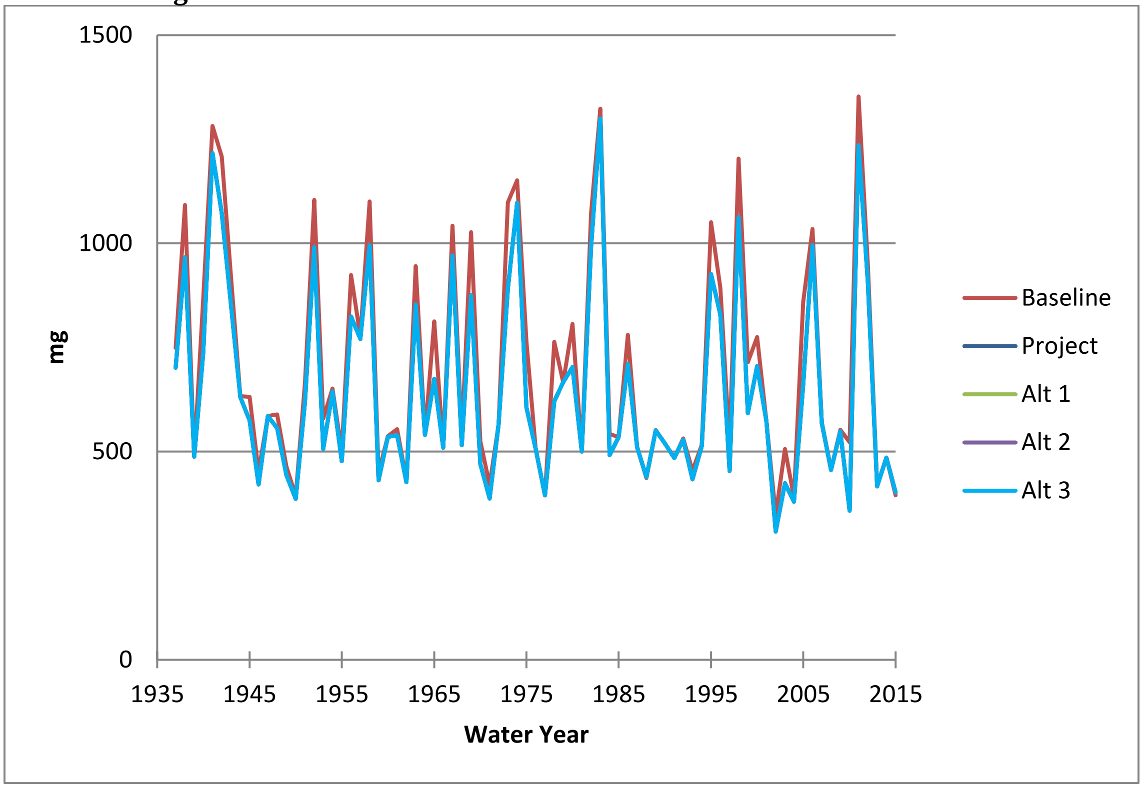


Figure 5 compares the annual ASR injection and extraction volumes for the Proposed Project and Alternative 2. (Recall that the extraction volumes reflect the assumed 20% aquifer losses.)

Figure 5. Annual ASR Injection and Extraction Volumes: Historical Flows

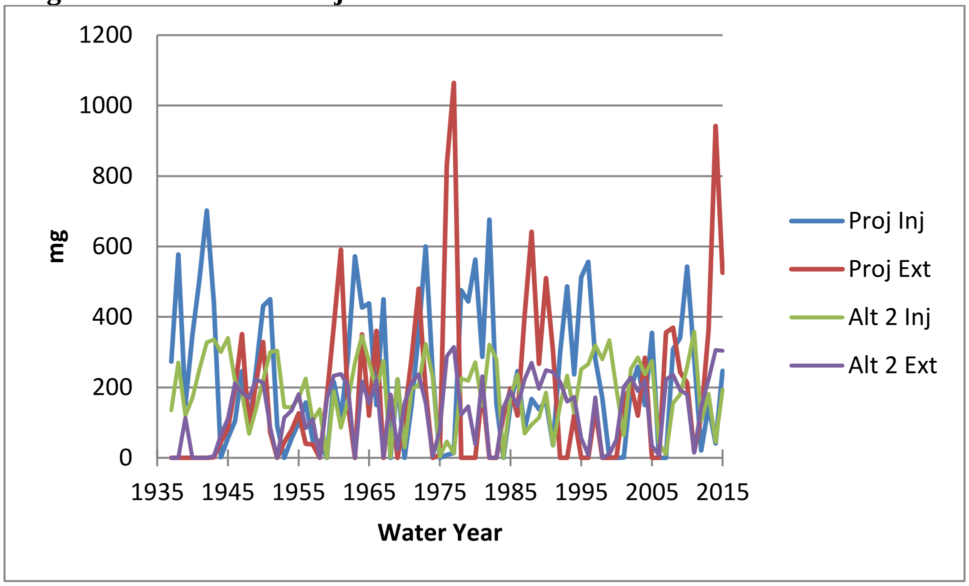


Figure 6 compares the resulting peak-season shortages across the hydrologic record. The large shortage during the worst (1976-77) drought in the Baseline is apparent. Consistent with the water supply reliability goal, that shortage is eliminated by the Proposed Project's ASR infrastructure. The Proposed Project also eliminates lesser shortages in other dry periods.

Figure 6. Peak-Season Shortages: Historical Flows

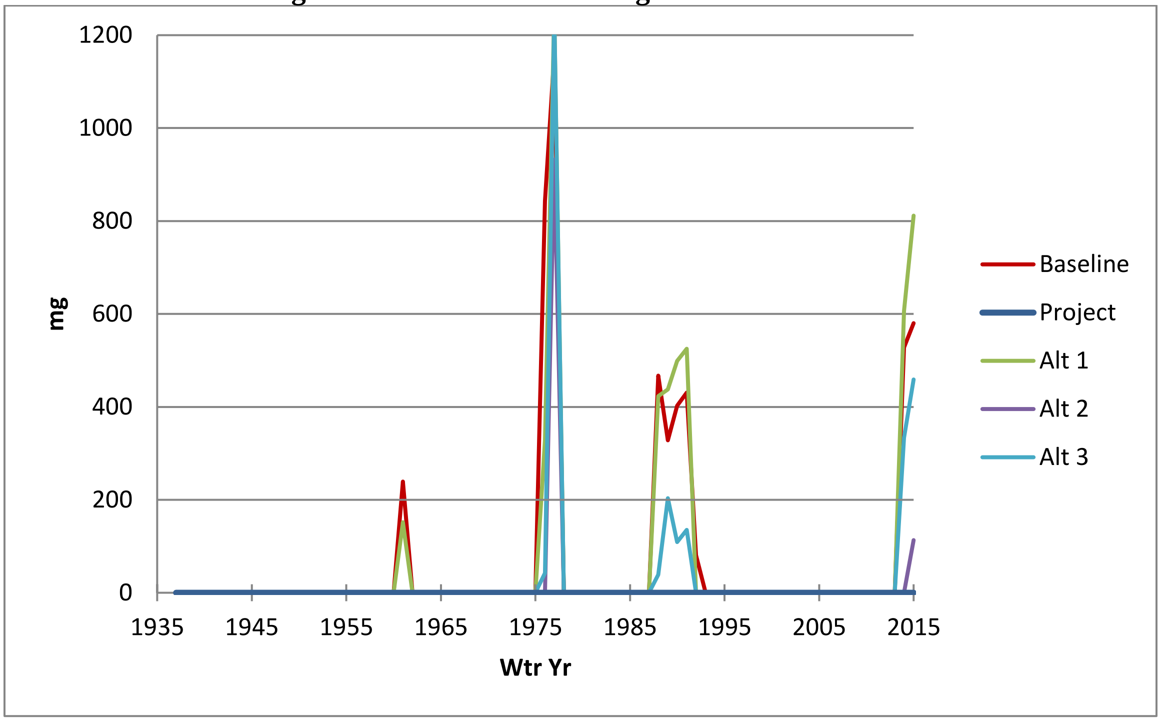
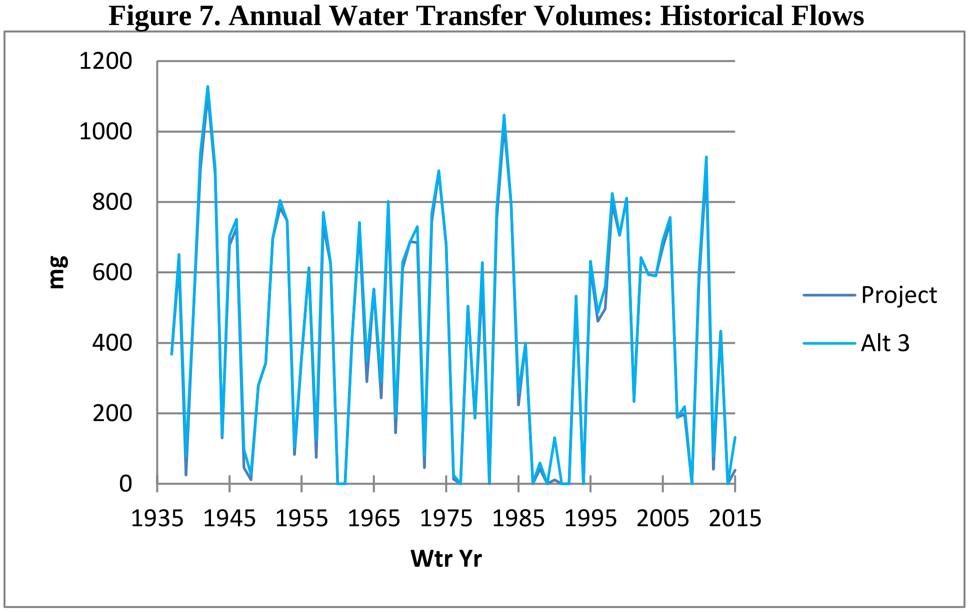


Figure 7 compares the annual volumes transferred to neighboring agencies.

Figure 7. Annual Water Transfer Volumes: Historical Flows



Figures 8 and 9 show exceedence curves for end-of-April (beginning of dry season) usable storage volumes, including Loch Lomond Reservoir and ASR.

Figure 8. End-of-April Usable Loch Lomond Reservoir Storage: Historical Flows

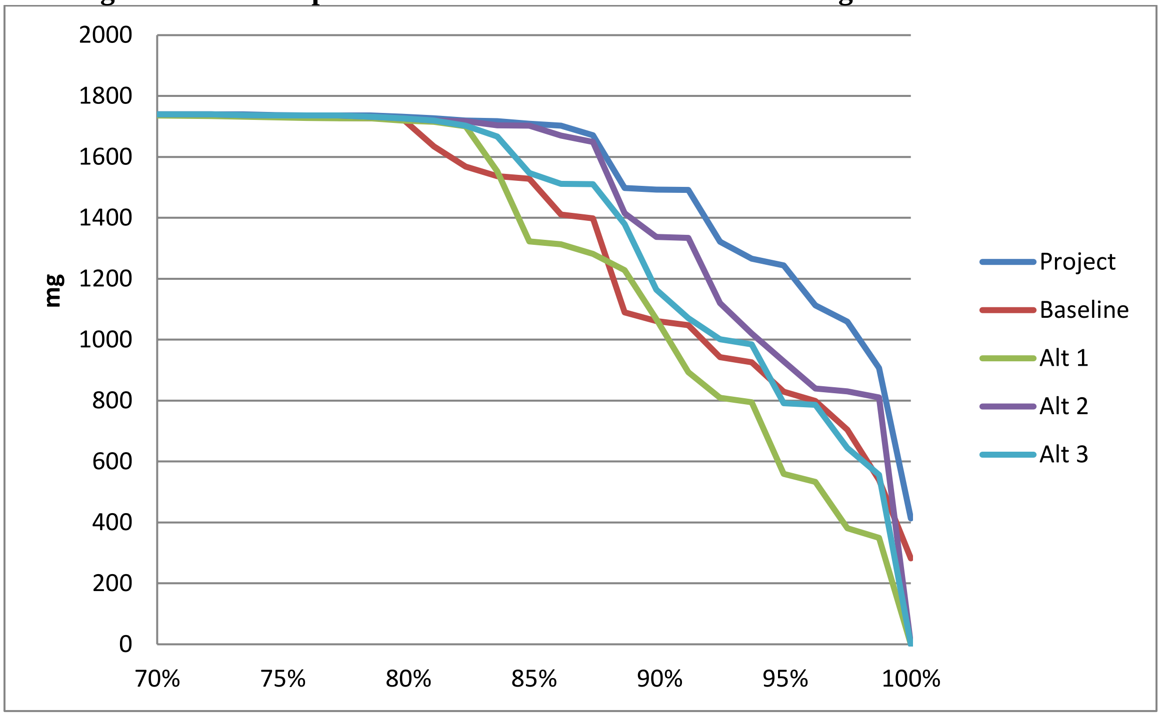
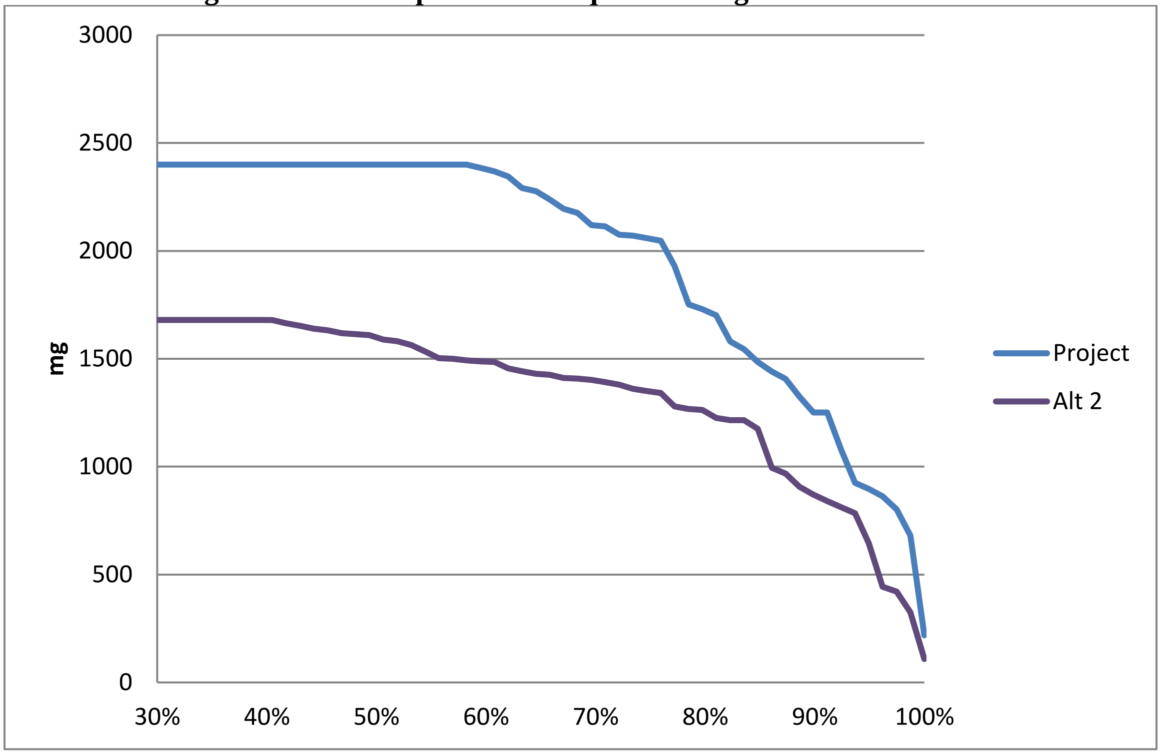


Figure 9. End-of-April Usable Aquifer Storage: Historical Flows



Climate Change

For CMIP-5 climate change flows, the ASR injection and extraction capacities needed to achieve the water supply reliability goal (zero worst-drought peak-season shortage) for our Proposed Project are 6.0 mgd and 7.0 mgd respectively. The following charts compare the Baseline and Proposed Project.

Figure 10. Annual Diversions from San Lorenzo River: Climate Change

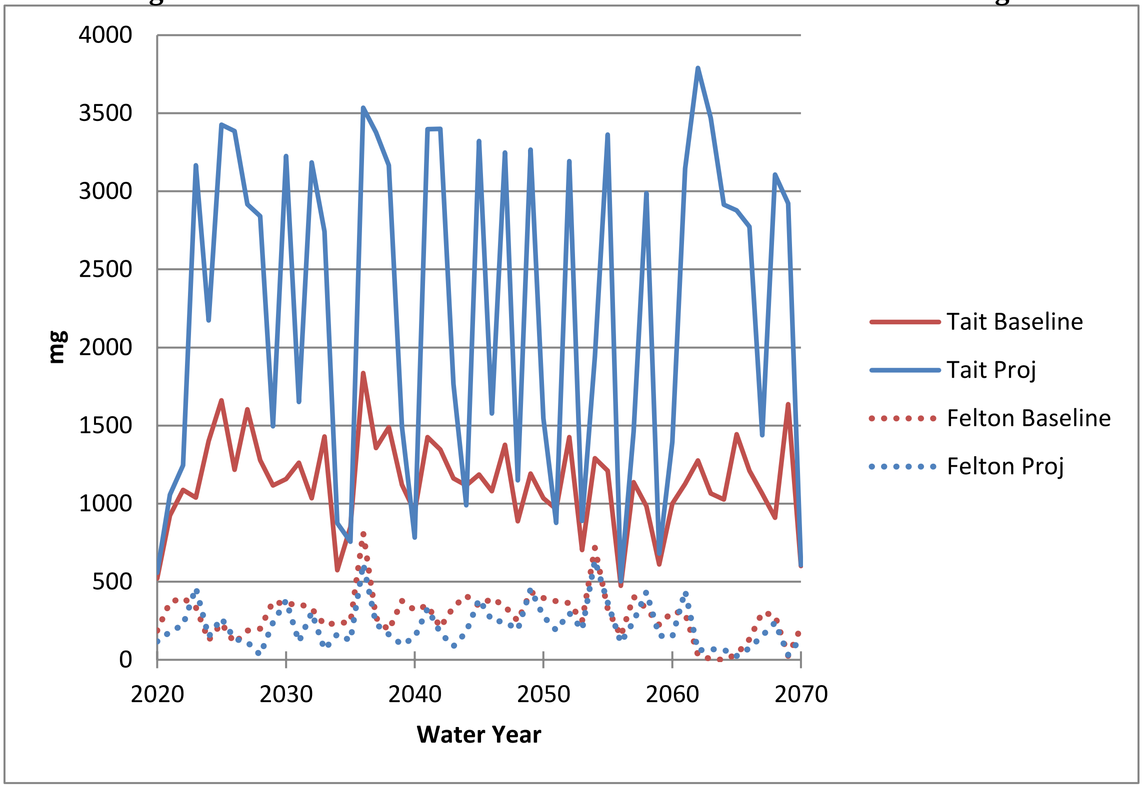


Figure 11. Annual Diversions from the North Coast: Climate Change

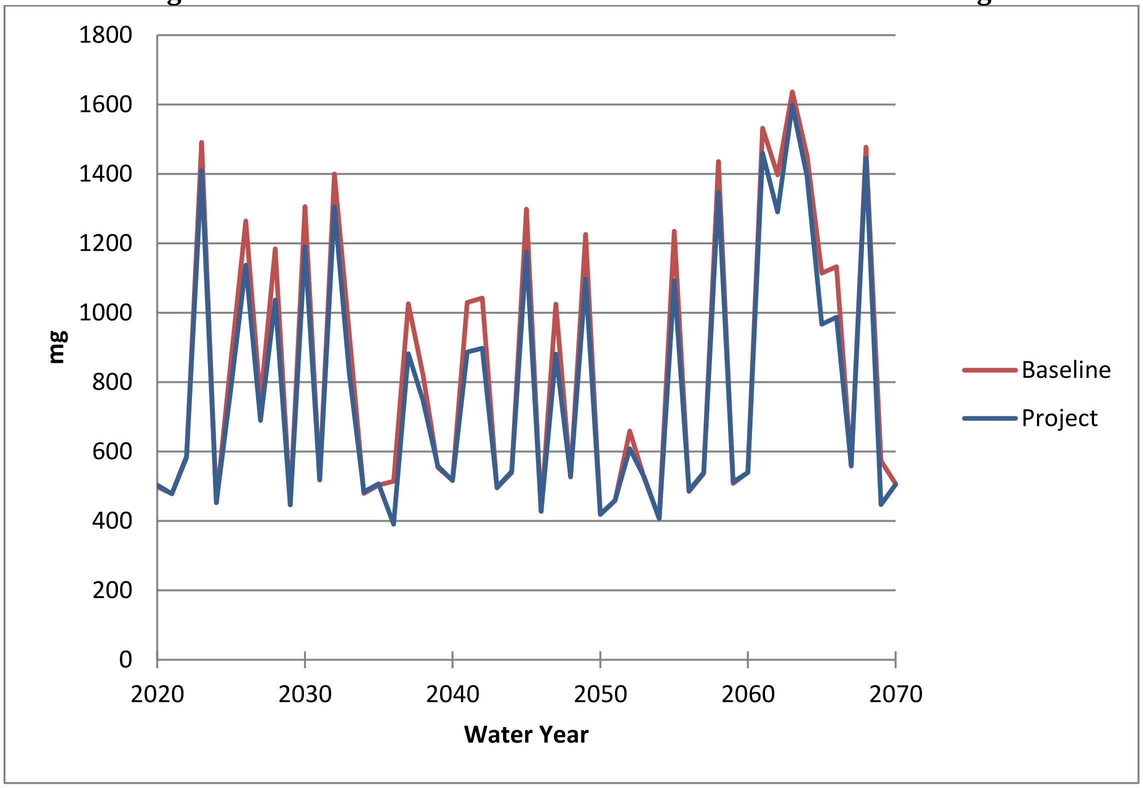


Figure 12. Annual Project ASR Injection and Extraction Volumes: Climate Change

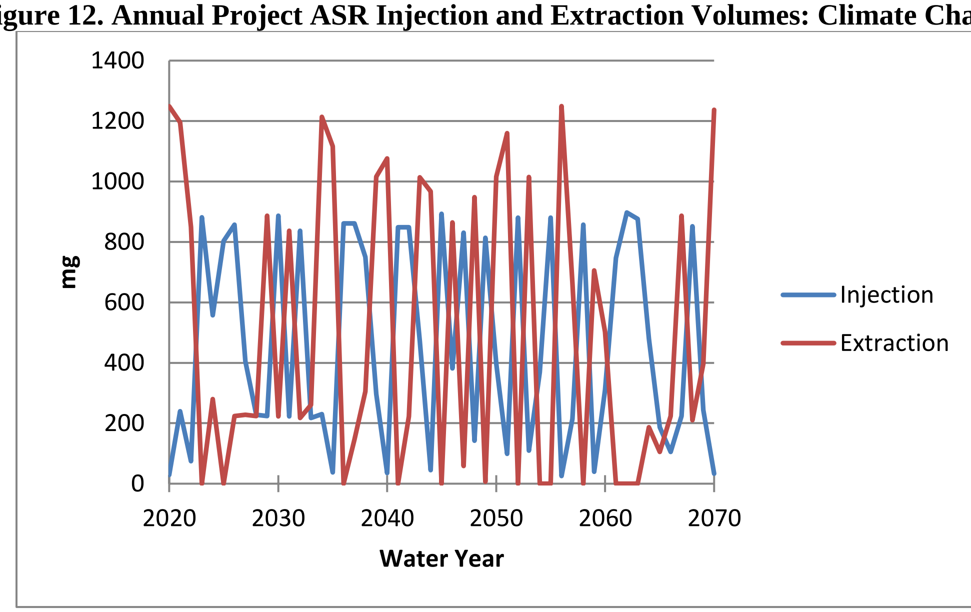


Figure 13. Peak-Season Shortages: Climate Change

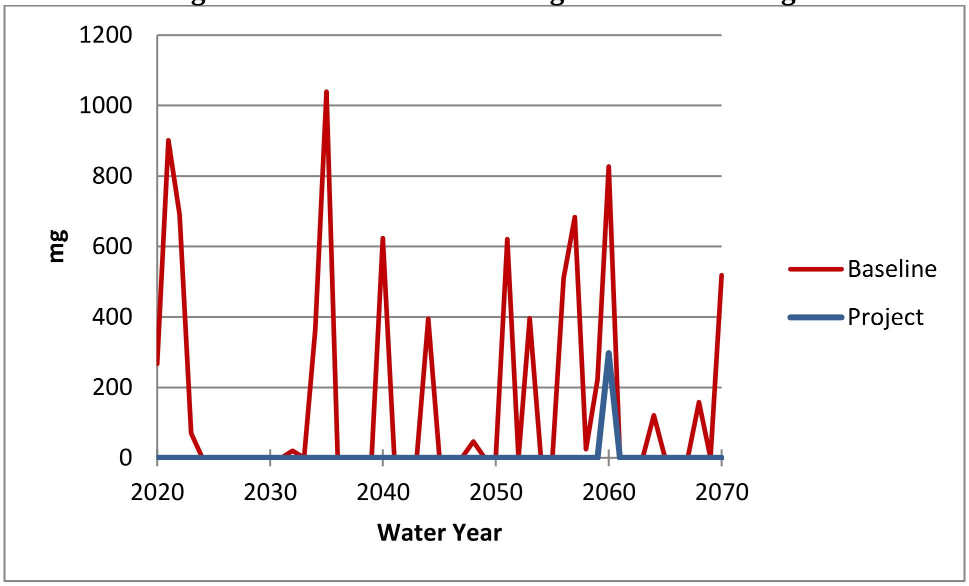


Figure 14. Annual Project Water Transfer Volumes: Climate Change

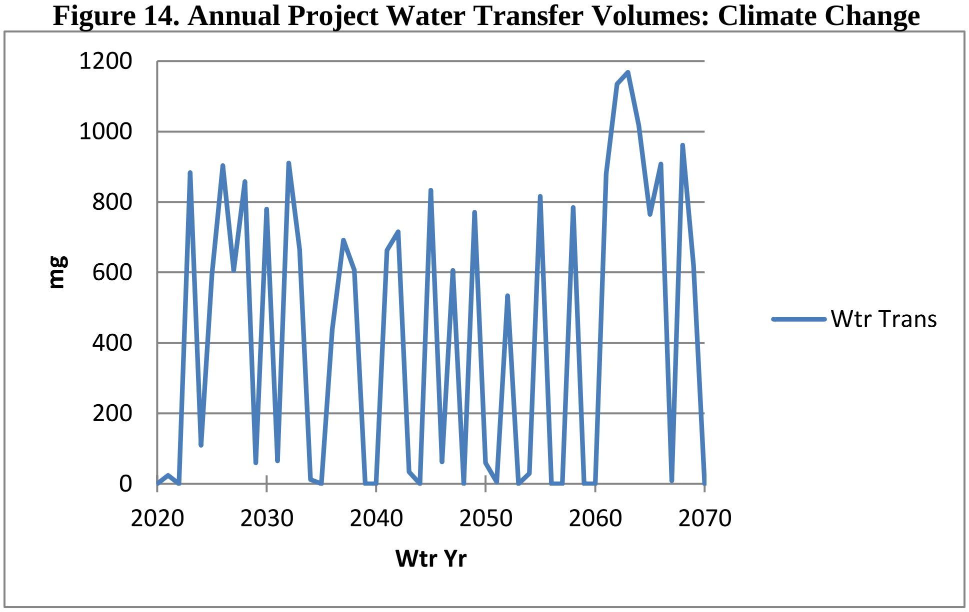


Figure 15. End-of-April Usable Loch Lomond Storage: Climate Change

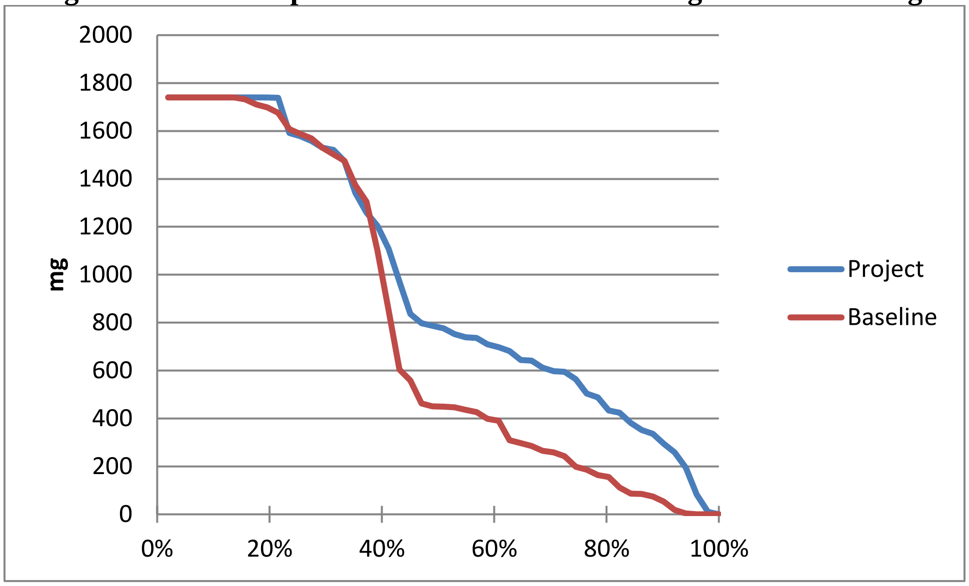
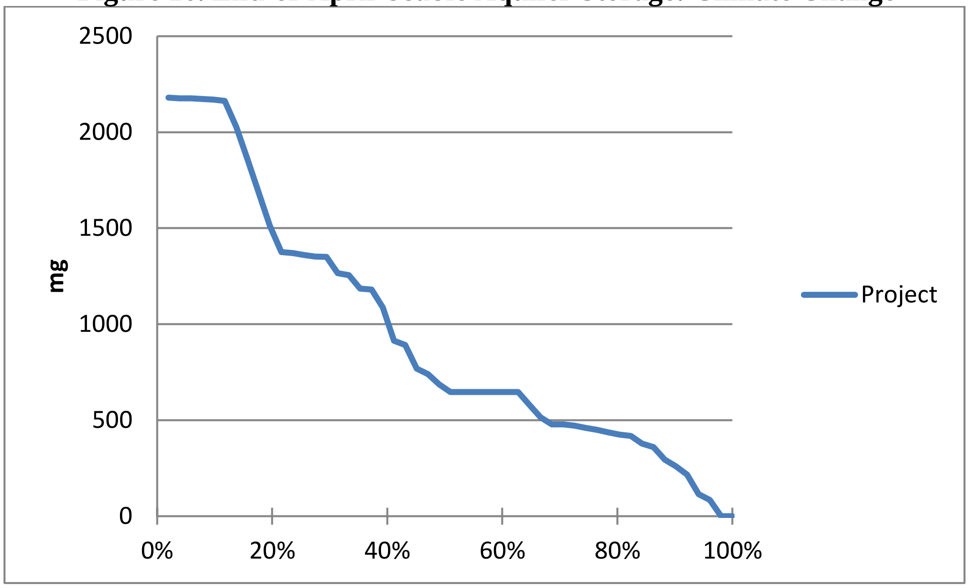


Figure 16. End-of-April Usable Aquifer Storage: Climate Change



ATTACHMENT 1

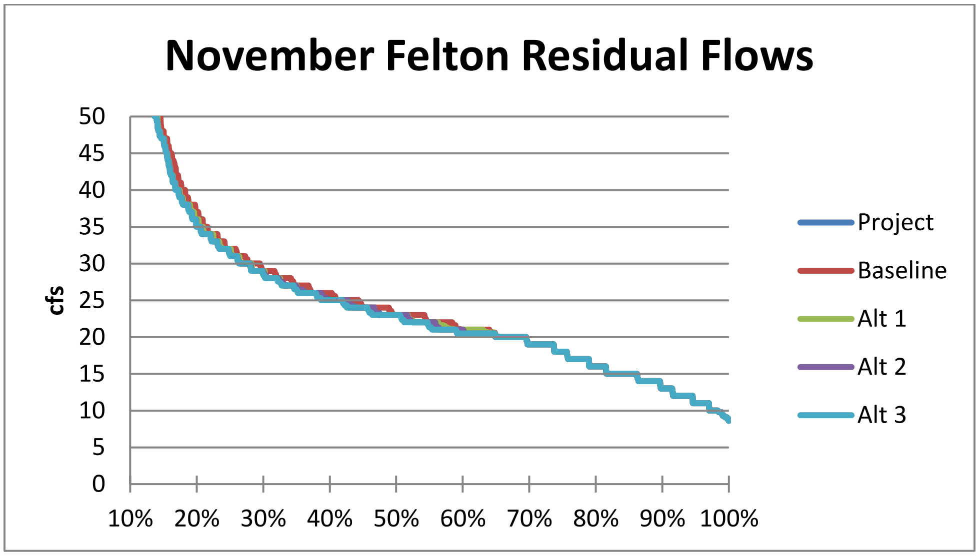
RESIDUAL FLOW EXCEEDENCE CURVES

This attachment contains the modeled exceedence curves and associated data for the monthly residual flows in the anadromous reaches below each of City's six diversions. The daily residual flows are defined as follows:

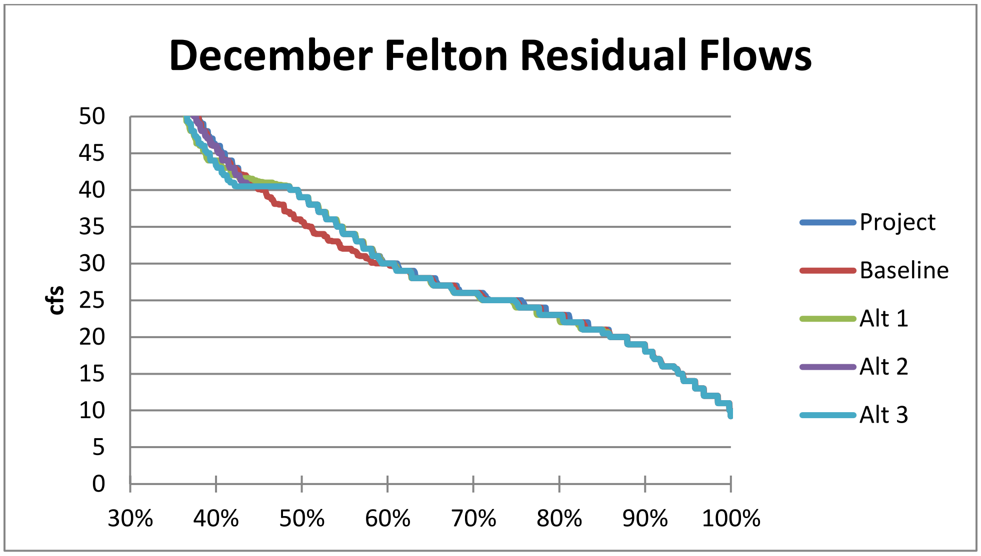
Natural streamflow - Diversion volume + Tributary inflows below point of diversion

The charts all show the exceedence probabilities for flows up to 50 cfs.

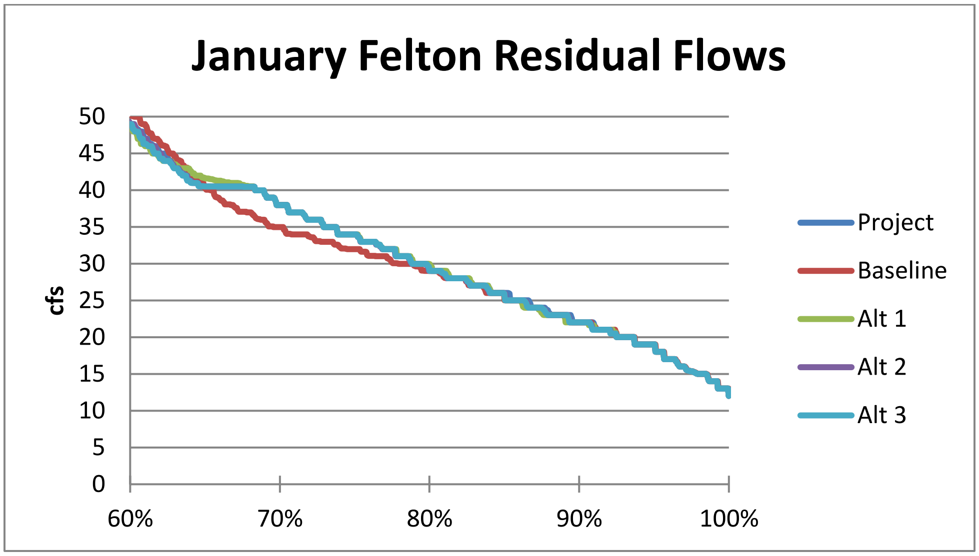
FELTON DIVERSION



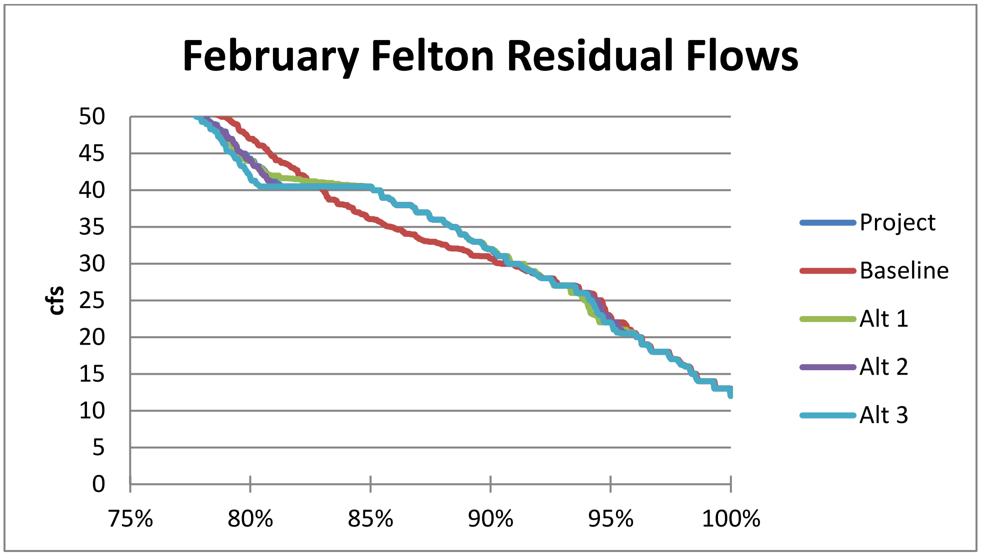
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	72	73	72	72	71
20%	36	37	36	35	35
30%	29	29	29	29	29
40%	25	26	25	25	25
50%	23	23	23	23	23
60%	21	21	21	21	21
70%	19	19	19	19	19
80%	16	16	16	16	16
90%	13	13	13	13	13
100%	9	9	9	9	9



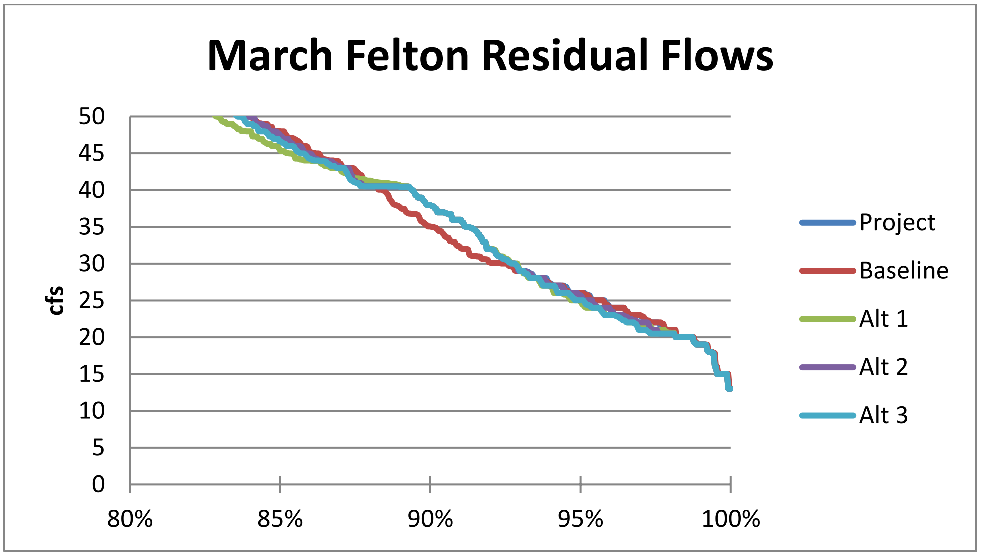
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	358	358	358	358	358
20%	133	139	132	133	132
30%	71	73	71	71	71
40%	46	46	44	46	43
50%	39	36	39	39	39
60%	30	30	30	30	30
70%	26	26	26	26	26
80%	23	23	23	23	23
90%	18	18	18	18	18
100%	9	9	9	9	9



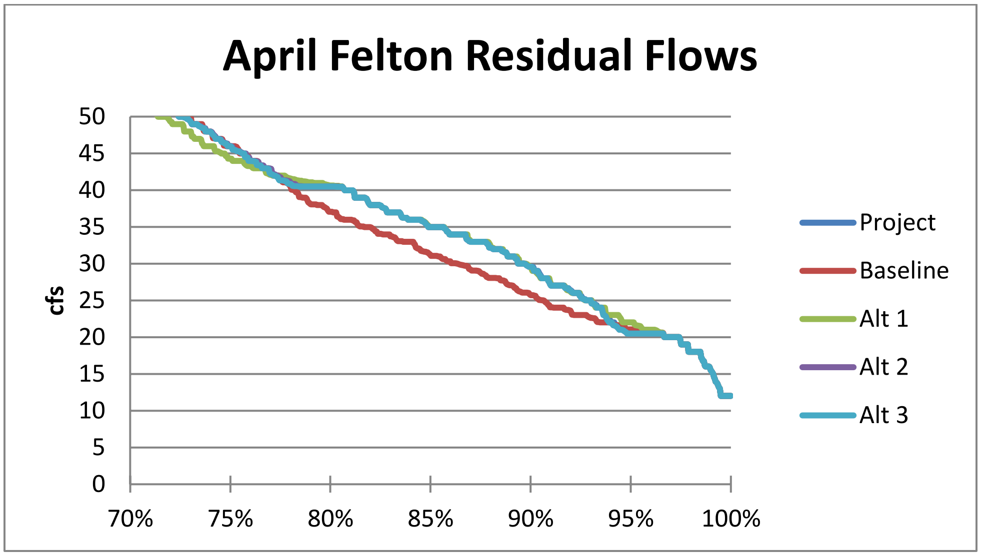
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	708	708	708	708	708
20%	337	337	337	337	337
30%	202	203	202	202	202
40%	123	123	123	123	122
50%	75	76	76	75	75
60%	49	51	48	49	49
70%	38	35	38	38	38
80%	30	29	30	29	29
90%	22	22	22	22	22
100%	12	12	12	12	12



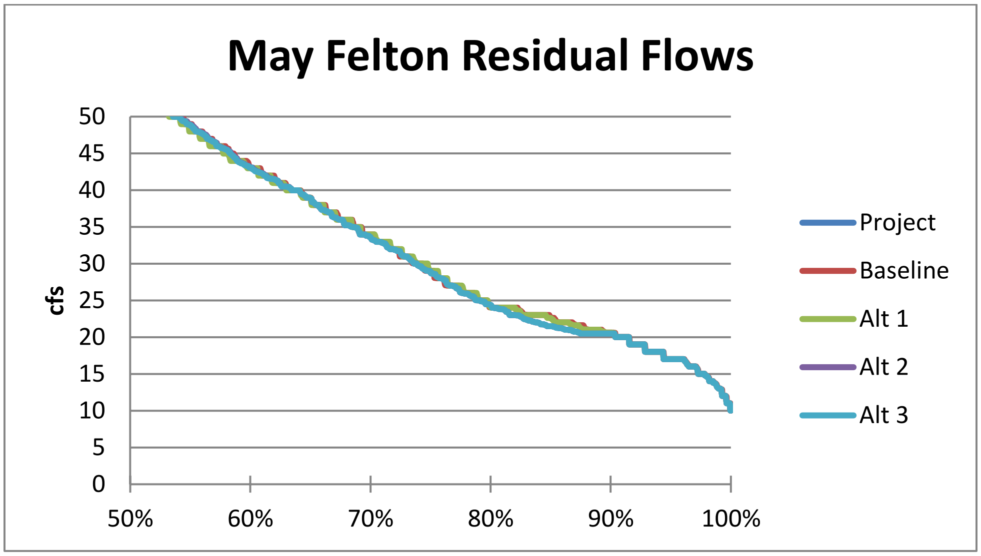
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	872	872	872	872	872
20%	486	493	486	486	486
30%	303	304	303	303	303
40%	204	205	203	204	204
50%	146	146	145	146	146
60%	106	106	105	106	105
70%	76	76	74	76	75
80%	44	47	44	44	42
90%	32	31	32	32	32
100%	12	12	12	12	12



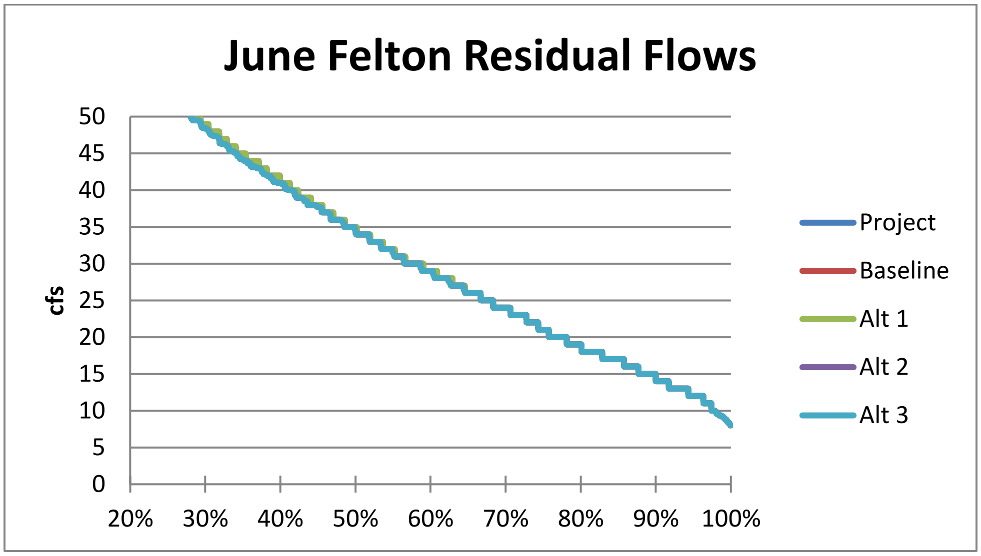
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	606	606	606	606	606
20%	397	396	396	396	396
30%	276	277	276	275	274
40%	196	195	195	196	194
50%	144	144	143	144	142
60%	105	105	104	105	104
70%	79	79	78	79	78
80%	58	58	56	58	58
90%	38	35	38	38	38
100%	13	13	13	13	13



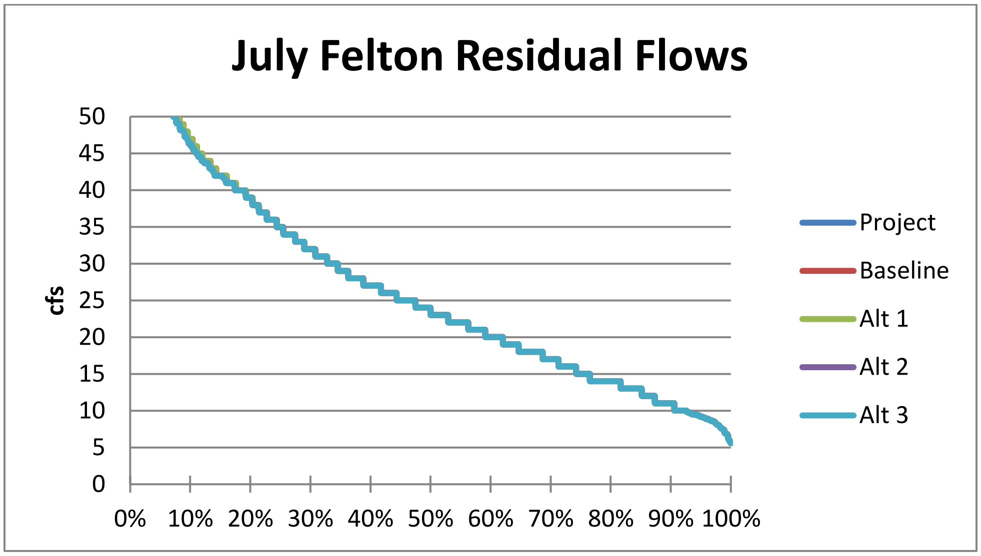
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	345	345	345	345	345
20%	214	215	215	214	214
30%	157	158	158	157	157
40%	114	114	114	114	114
50%	87	87	87	87	87
60%	68	68	67	68	68
70%	54	54	53	54	54
80%	41	37	41	41	41
90%	30	26	30	30	30
100%	12	12	12	12	12



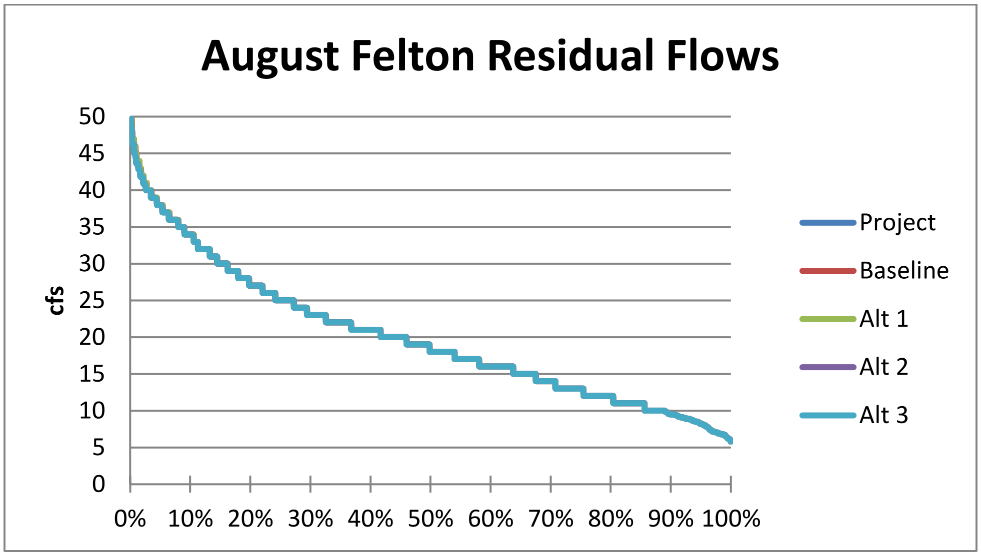
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	140	140	140	140	140
20%	99	99	99	99	99
30%	80	80	80	80	80
40%	68	67	67	68	67
50%	54	54	54	54	54
60%	43	43	43	43	43
70%	34	34	34	34	34
80%	24	24	24	24	24
90%	21	21	21	21	21
100%	10	10	10	10	10



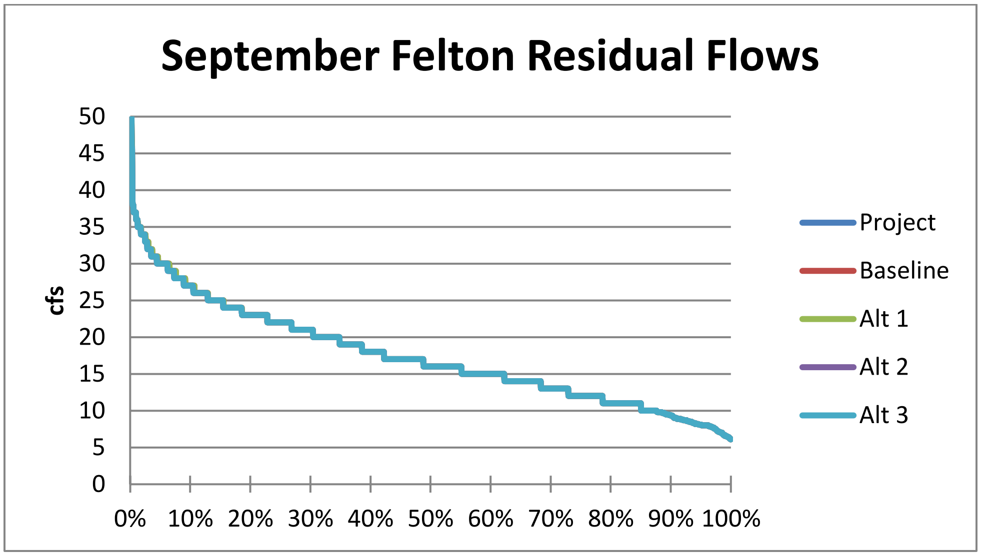
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	75	75	75	75	75
20%	59	59	59	59	59
30%	48	49	49	48	48
40%	41	41	41	41	41
50%	35	35	35	35	35
60%	29	29	29	29	29
70%	24	24	24	24	24
80%	19	19	19	19	19
90%	14	14	14	14	14
100%	8	8	8	8	8



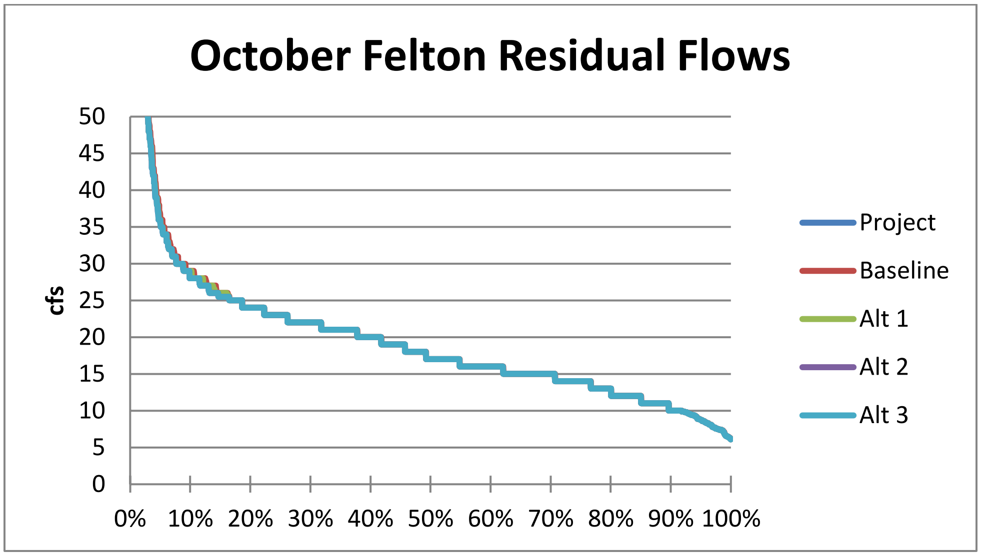
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	46	47	47	46	46
20%	39	39	39	39	39
30%	32	32	32	32	32
40%	27	27	27	27	27
50%	23	23	23	23	23
60%	20	20	20	20	20
70%	17	17	17	17	17
80%	14	14	14	14	14
90%	11	11	11	11	11
100%	6	6	6	6	6



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	34	34	34	34	34
20%	27	27	27	27	27
30%	23	23	23	23	23
40%	21	21	21	21	21
50%	18	18	18	18	18
60%	16	16	16	16	16
70%	14	14	14	14	14
80%	12	12	12	12	12
90%	10	10	10	10	10
100%	6	6	6	6	6

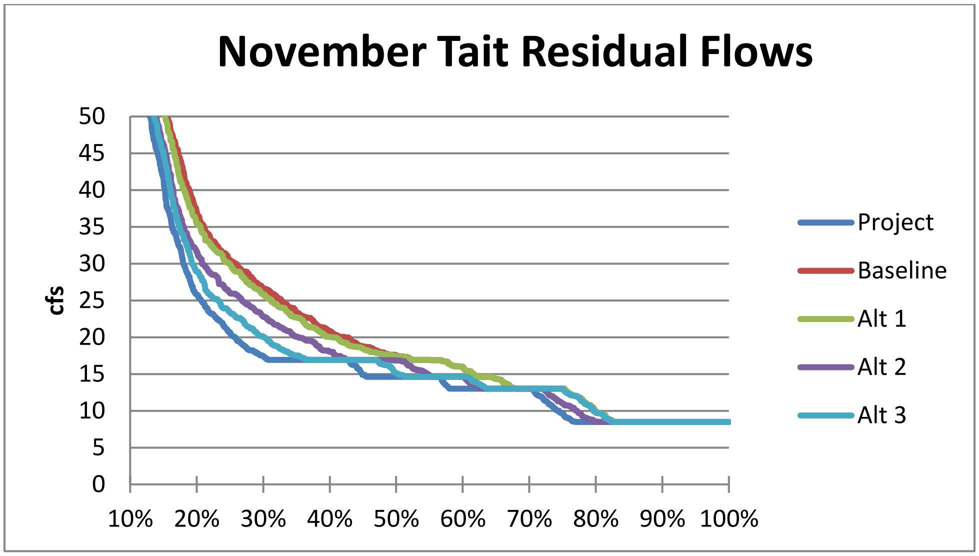


Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	27	27	27	27	27
20%	23	23	23	23	23
30%	21	21	21	21	21
40%	18	18	18	18	18
50%	16	16	16	16	16
60%	15	15	15	15	15
70%	13	13	13	13	13
80%	11	11	11	11	11
90%	9	9	9	9	9
100%	6	6	6	6	6

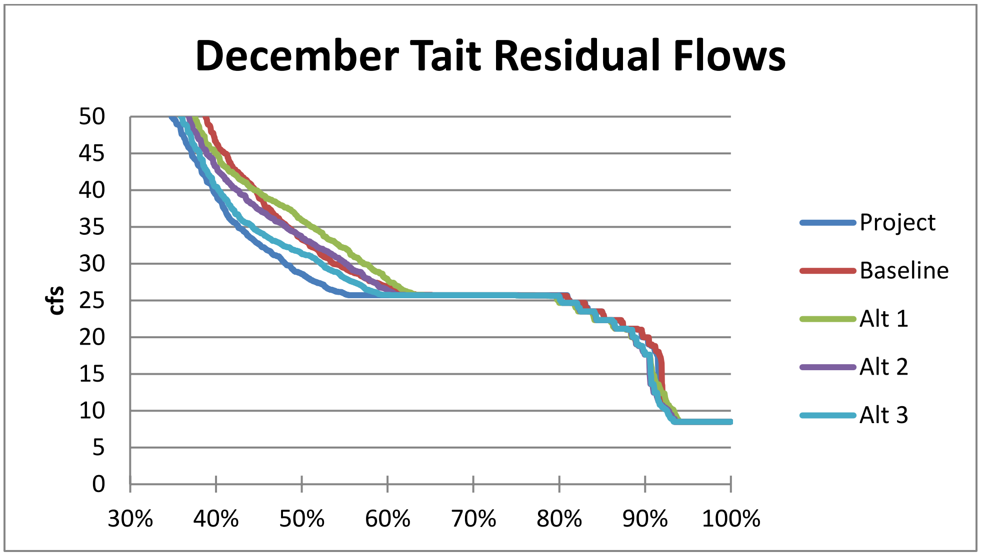


Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	28	29	29	28	28
20%	24	24	24	24	24
30%	22	22	22	22	22
40%	20	20	20	20	20
50%	17	17	17	17	17
60%	16	16	16	16	16
70%	15	15	15	15	15
80%	13	13	13	13	13
90%	10	10	10	10	10
100%	6	6	6	6	6

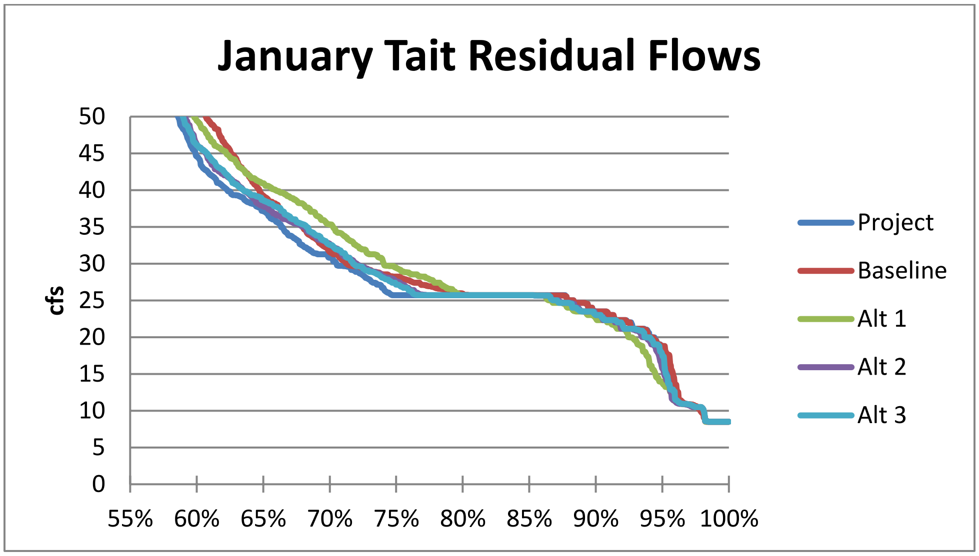
TAIT DIVERSION



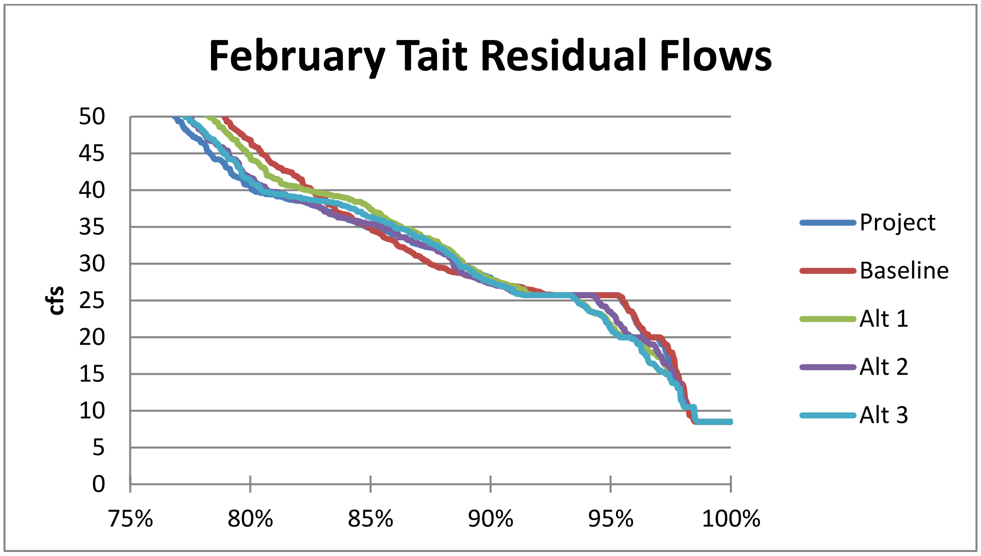
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	73	84	83	77	74
20%	26	37	36	32	29
30%	17	27	26	23	20
40%	17	21	20	18	17
50%	15	18	17	17	15
60%	13	16	16	15	15
70%	13	13	13	13	13
80%	9	10	10	9	10
90%	9	9	9	9	9
100%	8	8	8	8	8



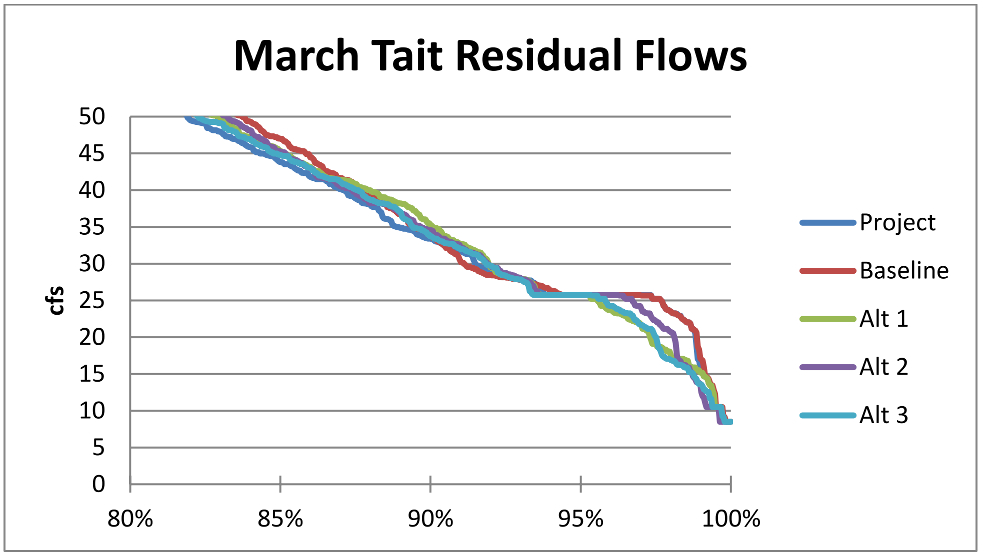
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	394	399	398	394	394
20%	145	157	153	149	147
30%	70	80	77	74	71
40%	39	46	45	43	40
50%	29	33	36	34	31
60%	26	27	28	26	26
70%	26	26	26	26	26
80%	26	26	25	26	25
90%	20	20	18	18	18
100%	8	8	8	8	8



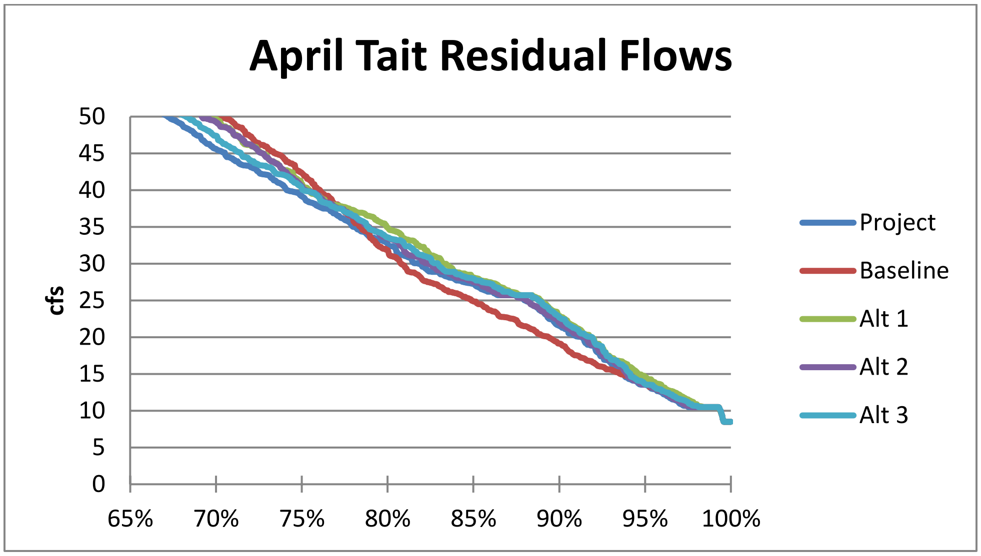
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	791	796	796	795	792
20%	377	388	388	384	383
30%	211	222	221	217	215
40%	125	132	132	128	126
50%	76	82	80	78	76
60%	45	52	49	46	46
70%	31	32	35	33	33
80%	26	26	26	26	26
90%	23	23	23	23	23
100%	9	8	8	8	8



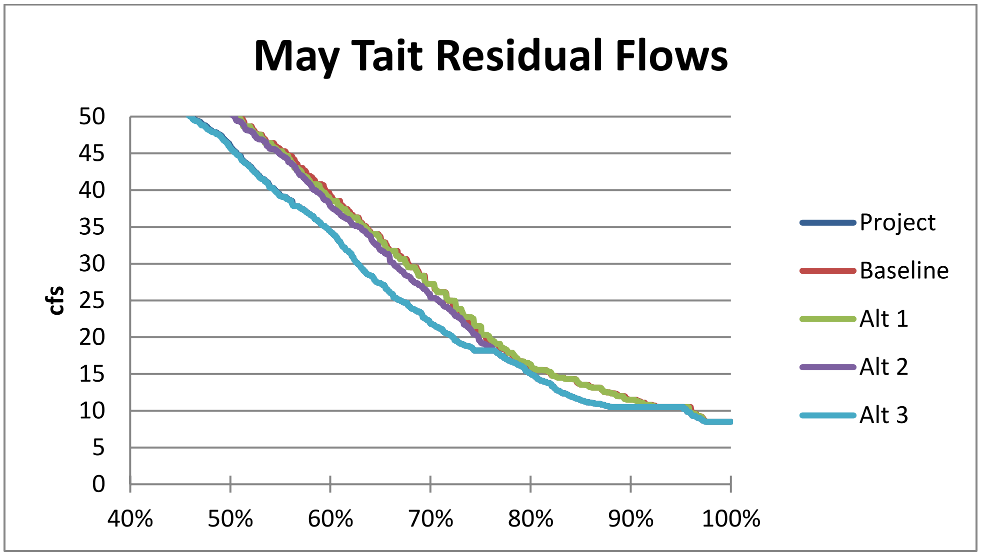
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	977	985	985	979	979
20%	540	550	542	541	541
30%	324	330	331	327	326
40%	212	219	219	217	215
50%	146	152	152	150	149
60%	105	112	111	109	107
70%	73	77	75	75	74
80%	41	46	44	42	41
90%	28	28	28	27	27
100%	8	8	8	8	8



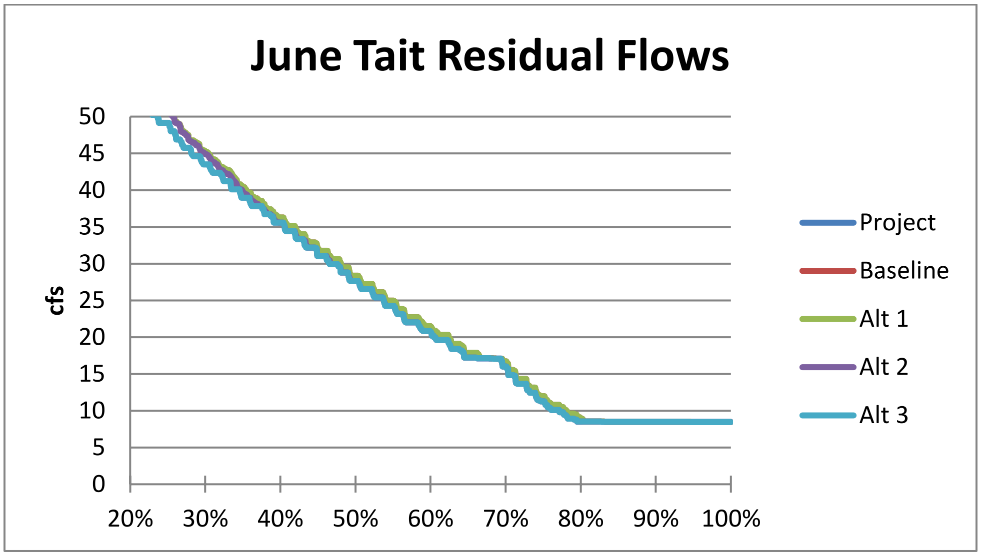
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	671	682	682	676	673
20%	432	440	440	436	433
30%	293	297	297	294	293
40%	204	211	210	208	207
50%	145	152	152	149	148
60%	103	110	108	106	104
70%	77	82	80	80	78
80%	54	59	57	57	55
90%	33	34	35	35	34
100%	9	8	8	8	8



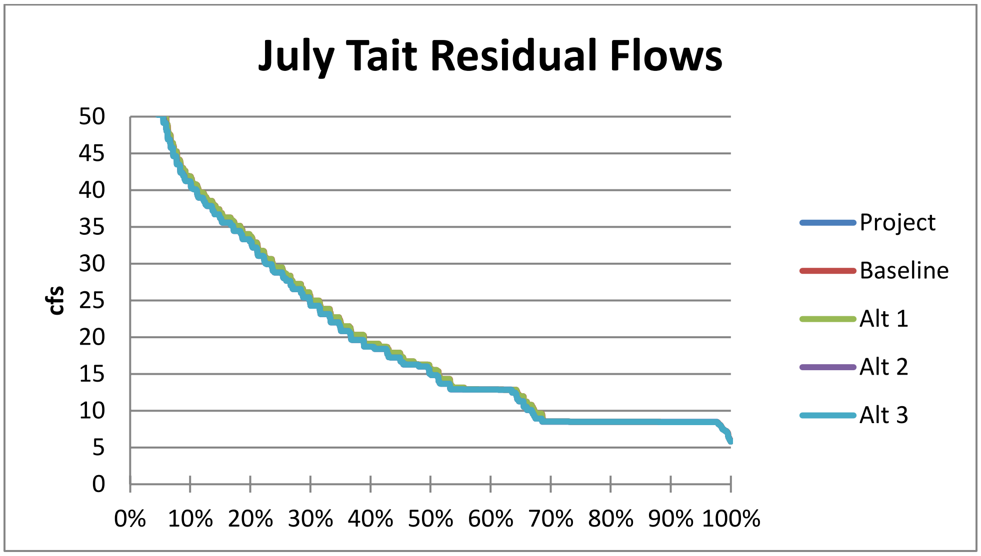
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	372	386	385	379	376
20%	221	233	230	225	224
30%	154	169	166	162	159
40%	113	123	121	118	116
50%	82	90	89	87	84
60%	63	67	66	65	64
70%	46	51	50	49	47
80%	33	32	35	33	34
90%	22	19	23	22	23
100%	9	8	8	8	8



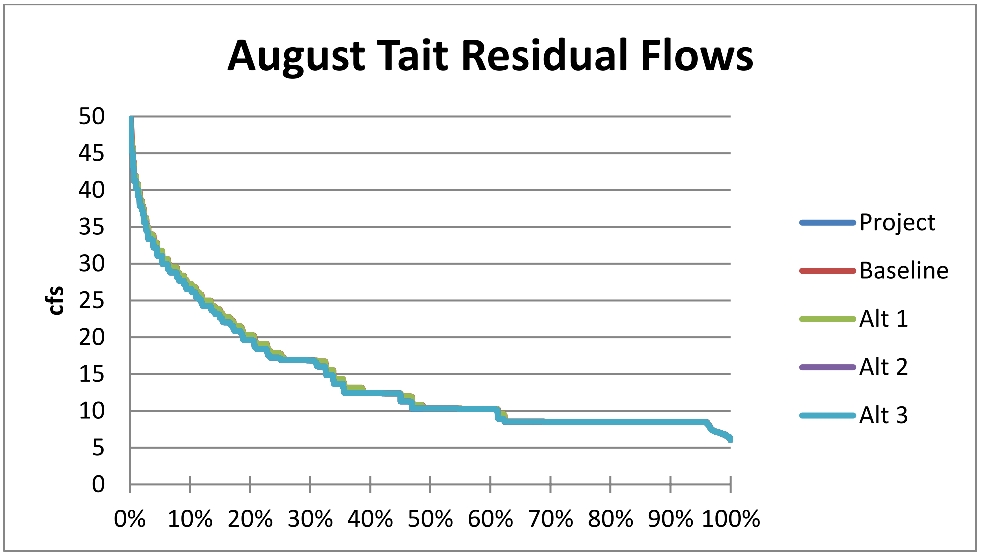
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	143	151	150	149	142
20%	96	105	103	103	96
30%	73	81	79	80	73
40%	59	67	66	66	59
50%	46	51	51	51	46
60%	34	39	39	38	34
70%	22	27	27	25	22
80%	15	16	16	15	15
90%	11	11	11	11	11
100%	8	8	8	8	8



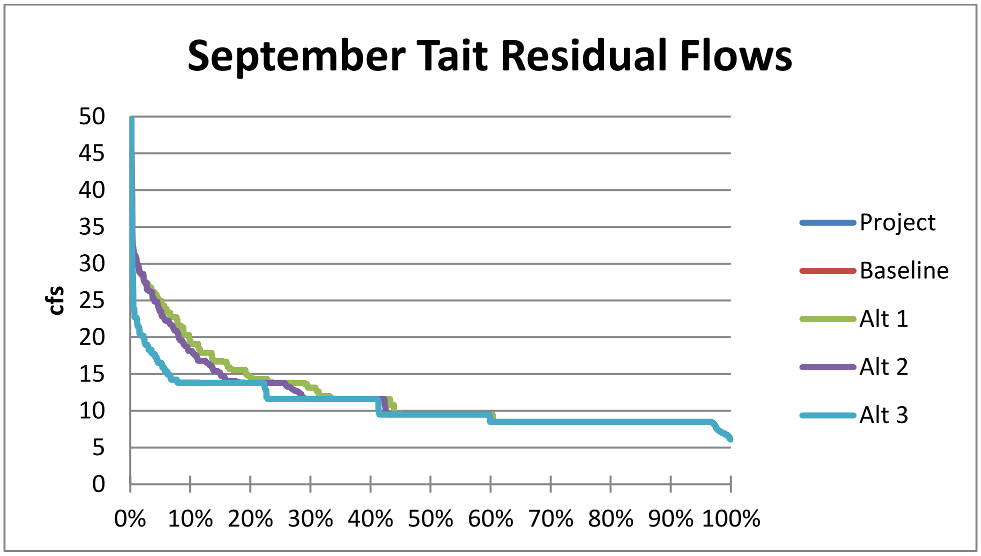
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	71	75	75	75	71
20%	55	57	57	57	55
30%	43	45	45	45	43
40%	36	36	36	36	36
50%	28	28	28	28	28
60%	21	22	22	21	21
70%	16	17	17	16	16
80%	9	9	9	9	9
90%	9	9	9	9	9
100%	8	8	8	8	8



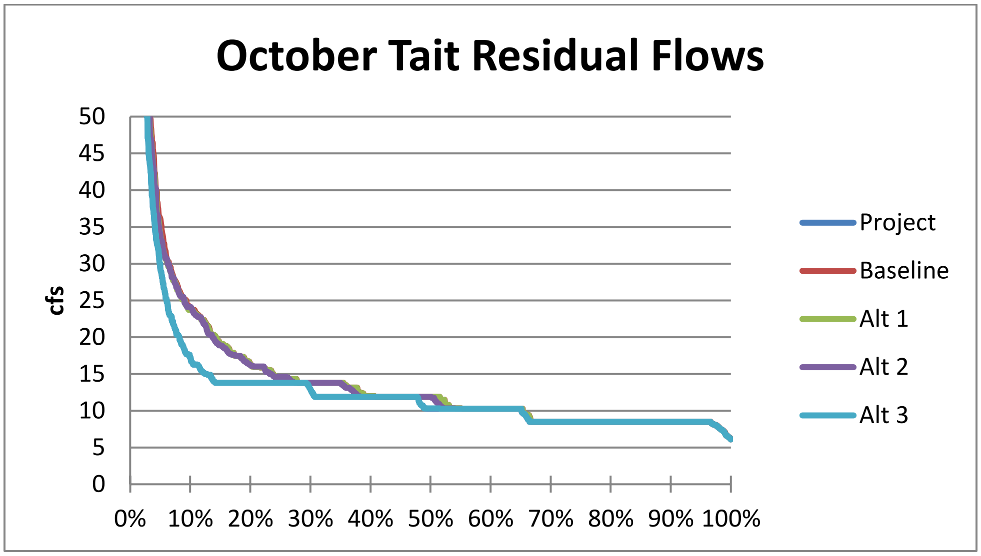
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	41	42	42	41	41
20%	33	34	34	33	33
30%	24	25	25	24	24
40%	19	19	19	19	19
50%	15	16	16	15	15
60%	13	13	13	13	13
70%	9	9	9	9	9
80%	9	9	9	9	9
90%	9	8	8	8	8
100%	6	6	6	6	6



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	27	27	27	27	27
20%	20	20	20	20	20
30%	17	17	17	17	17
40%	12	12	12	12	12
50%	10	10	10	10	10
60%	10	10	10	10	10
70%	9	9	9	9	9
80%	9	9	9	9	9
90%	9	8	8	8	8
100%	6	6	6	6	6

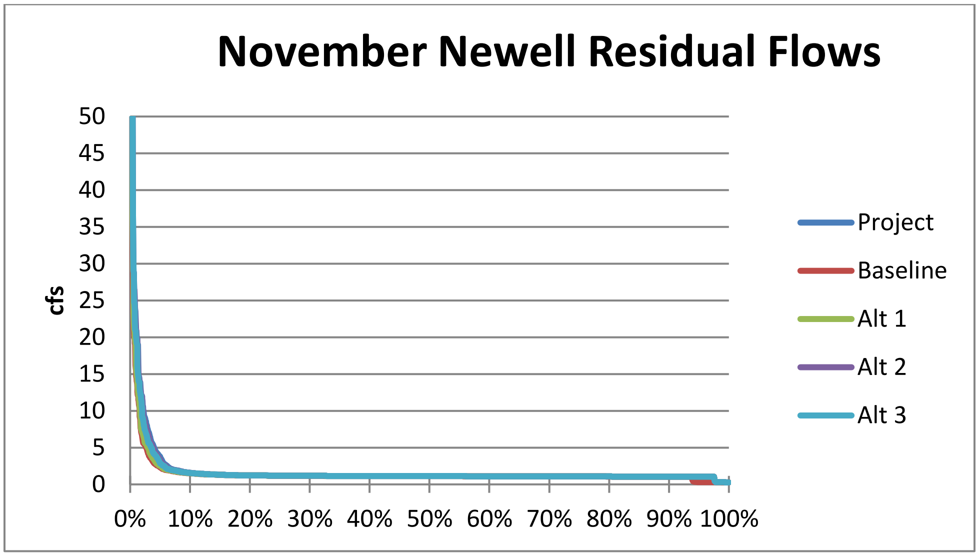


Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	14	19	19	18	14
20%	14	15	15	14	14
30%	12	13	13	12	12
40%	12	12	12	12	12
50%	10	10	10	9	9
60%	9	9	9	9	9
70%	9	9	9	9	9
80%	9	9	9	9	9
90%	9	8	8	8	8
100%	6	6	6	6	6

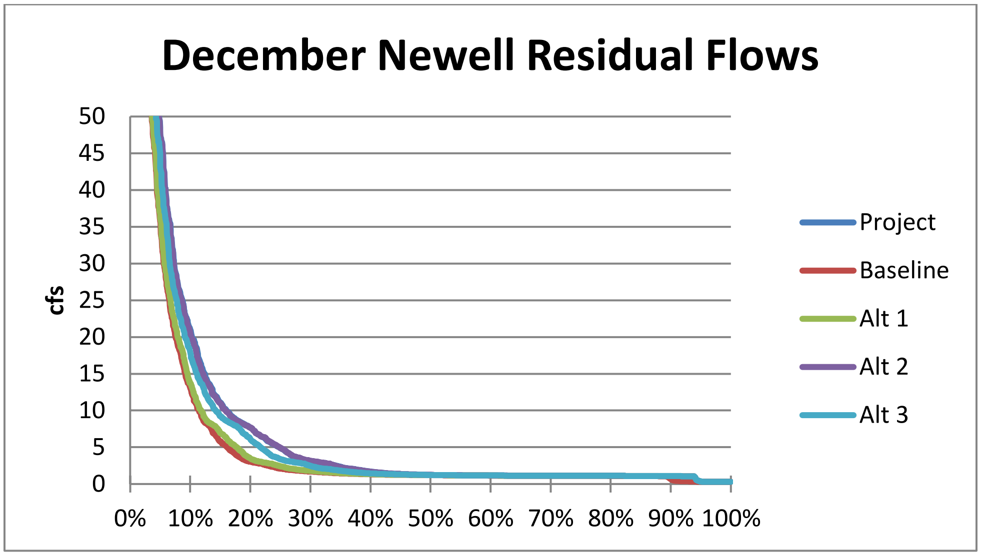


Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	17	24	24	24	17
20%	14	16	16	16	14
30%	13	14	14	14	13
40%	12	12	12	12	12
50%	10	12	12	12	10
60%	10	10	10	10	10
70%	9	9	9	9	9
80%	9	8	8	8	8
90%	9	8	8	8	8
100%	6	6	6	6	6

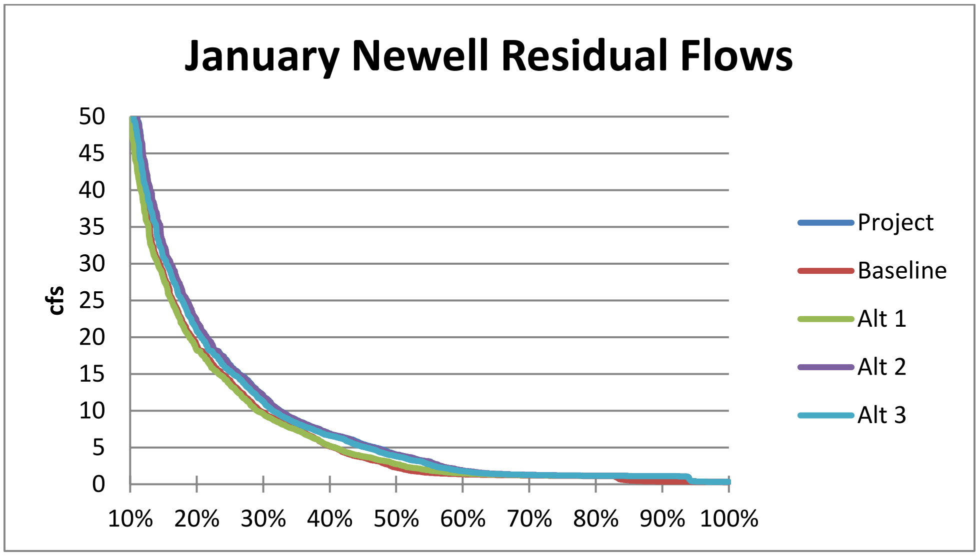
NEWELL CREEK



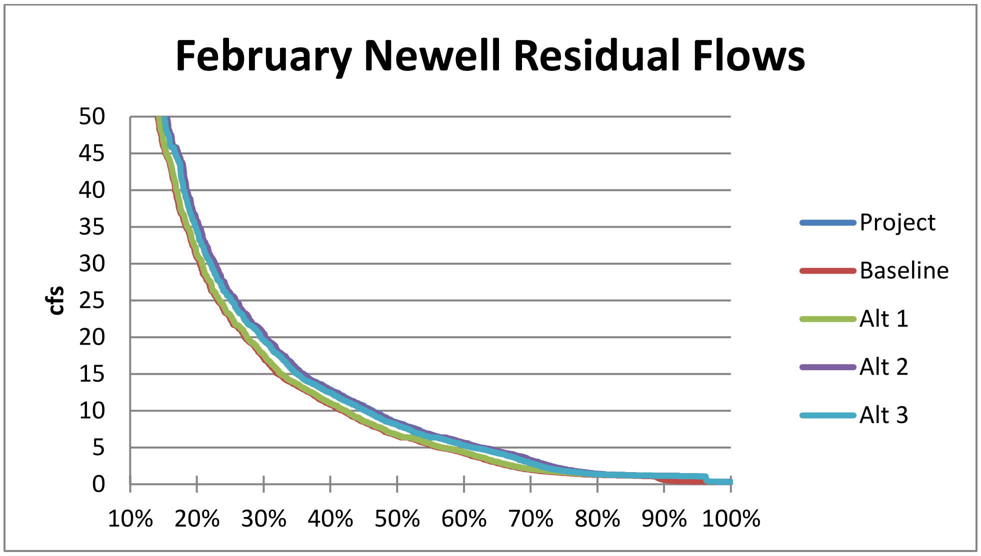
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



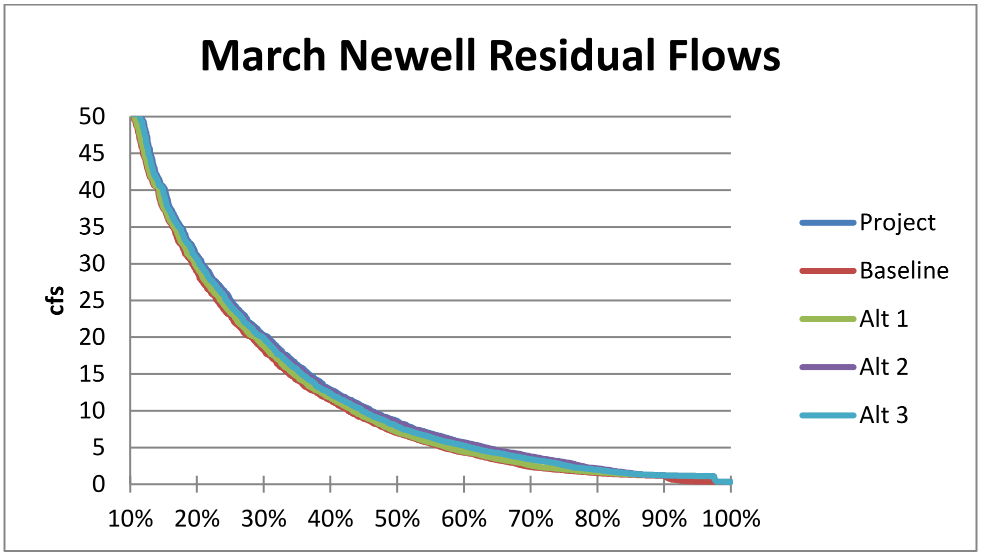
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	21	13	14	20	18
20%	8	3	3	8	6
30%	3	2	2	3	2
40%	2	1	1	2	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



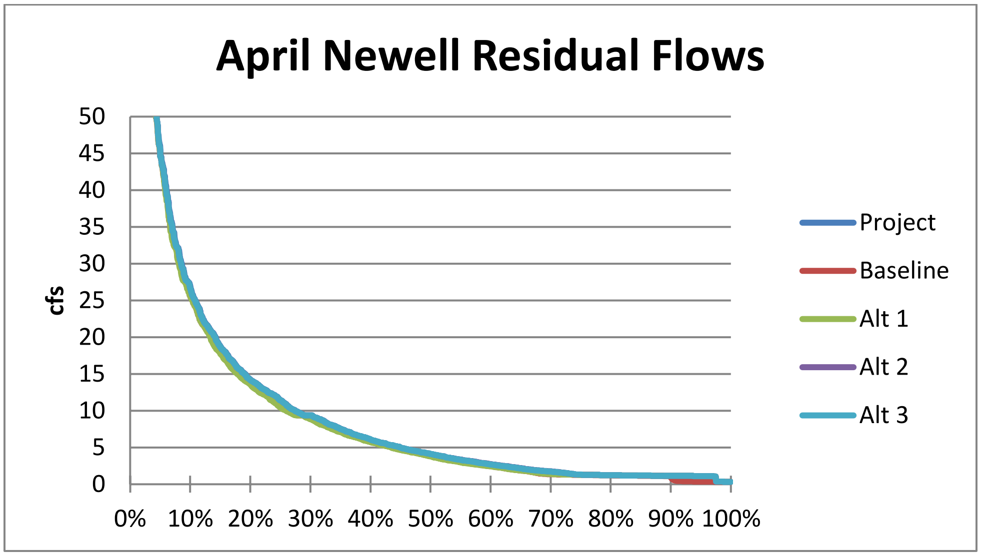
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	55	49	49	54	52
20%	22	19	18	22	21
30%	12	10	10	12	11
40%	7	5	5	7	7
50%	4	2	3	4	4
60%	2	1	1	2	2
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	0	1	1	1
100%	0	0	0	0	0



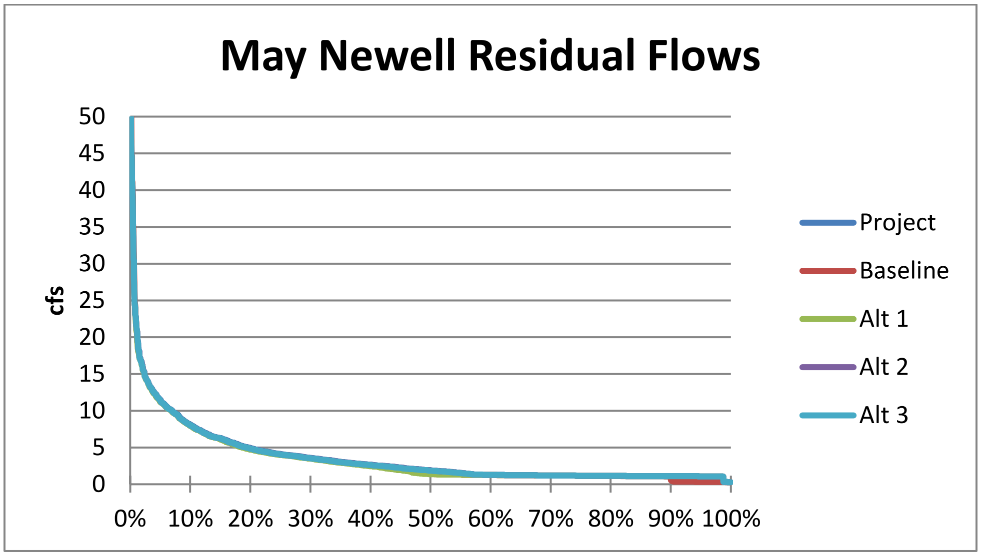
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	78	72	73	78	77
20%	36	31	31	36	35
30%	20	17	18	20	20
40%	13	11	11	13	12
50%	8	7	7	8	8
60%	6	4	4	6	5
70%	3	2	2	3	3
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



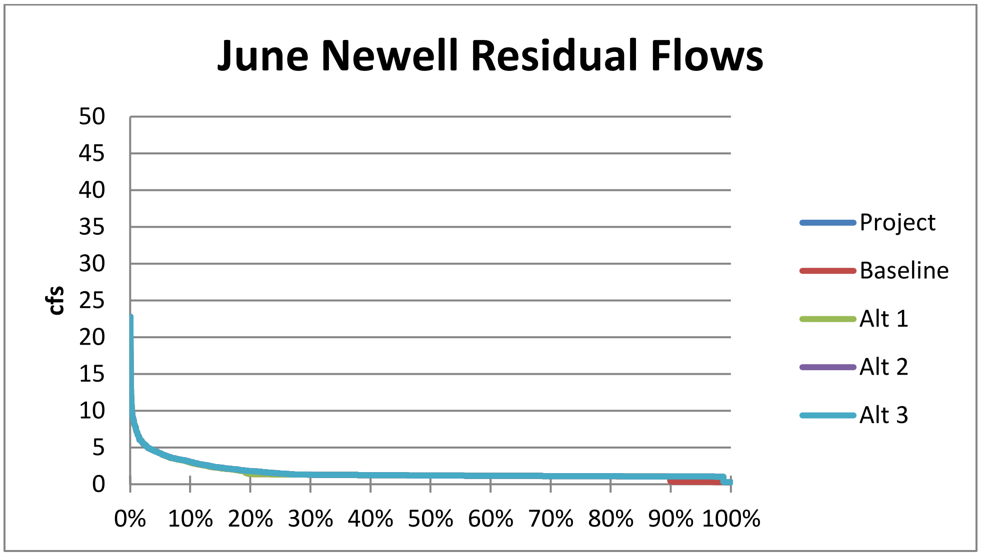
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	53	50	50	52	52
20%	31	29	30	31	31
30%	20	18	19	20	20
40%	13	11	12	13	12
50%	9	7	7	8	8
60%	6	4	4	6	5
70%	4	2	3	4	3
80%	2	2	2	2	2
90%	1	1	1	1	1
100%	0	0	0	0	0



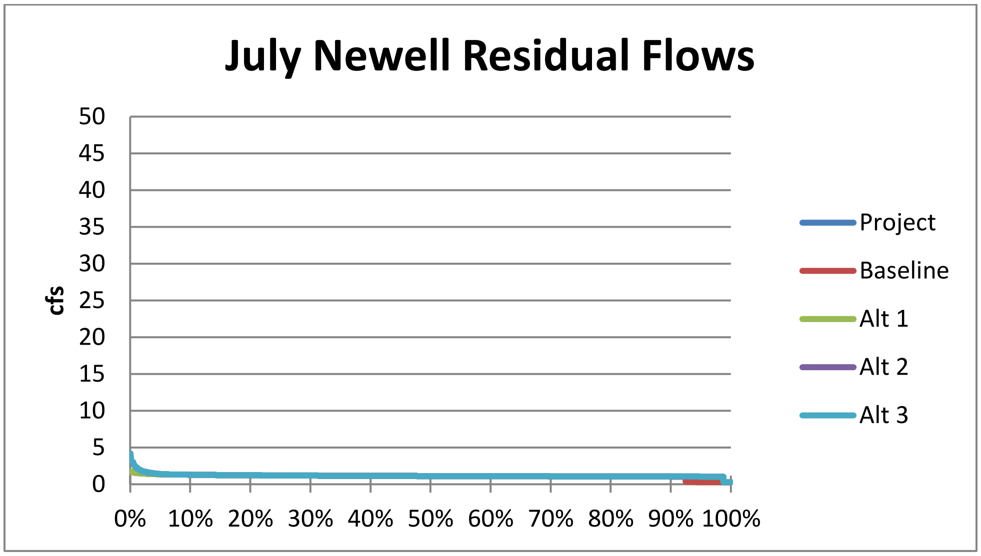
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	27	26	26	27	27
20%	14	14	14	14	14
30%	9	9	9	9	9
40%	6	6	6	6	6
50%	4	4	4	4	4
60%	3	2	2	3	3
70%	2	1	1	2	2
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



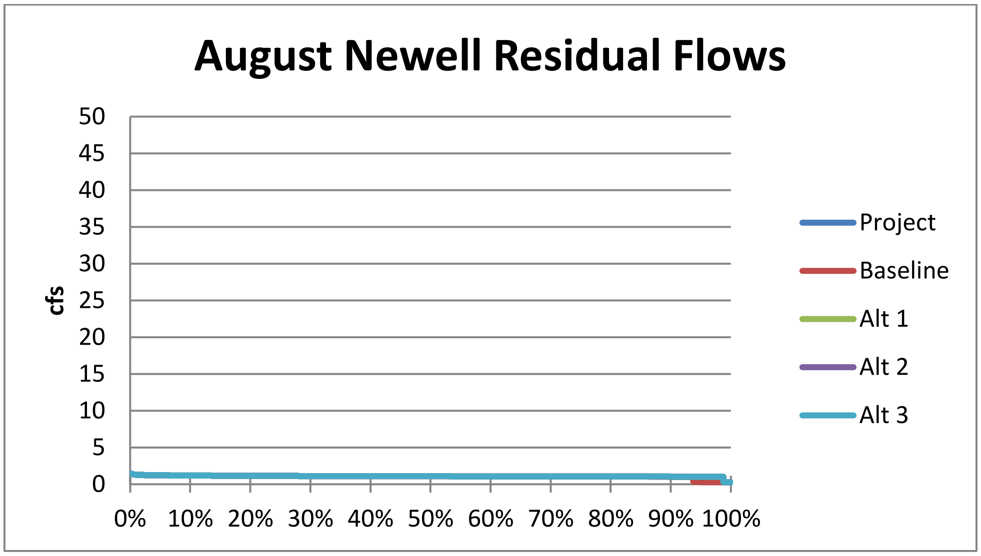
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	8	8	8	8	8
20%	5	5	5	5	5
30%	4	4	3	4	4
40%	3	3	2	3	3
50%	2	1	1	2	2
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



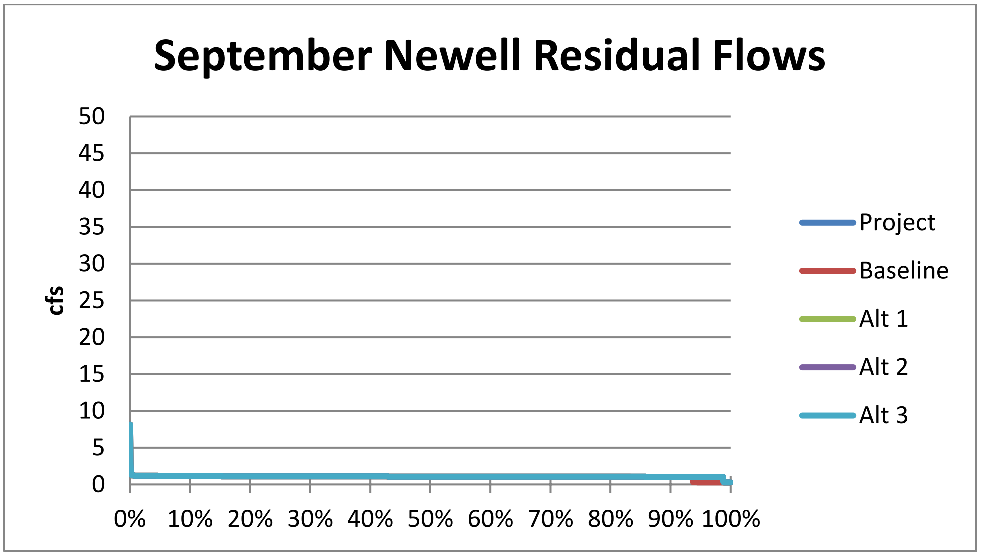
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	3	3	3	3	3
20%	2	1	1	2	2
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	0	1	1	1
100%	0	0	0	0	0



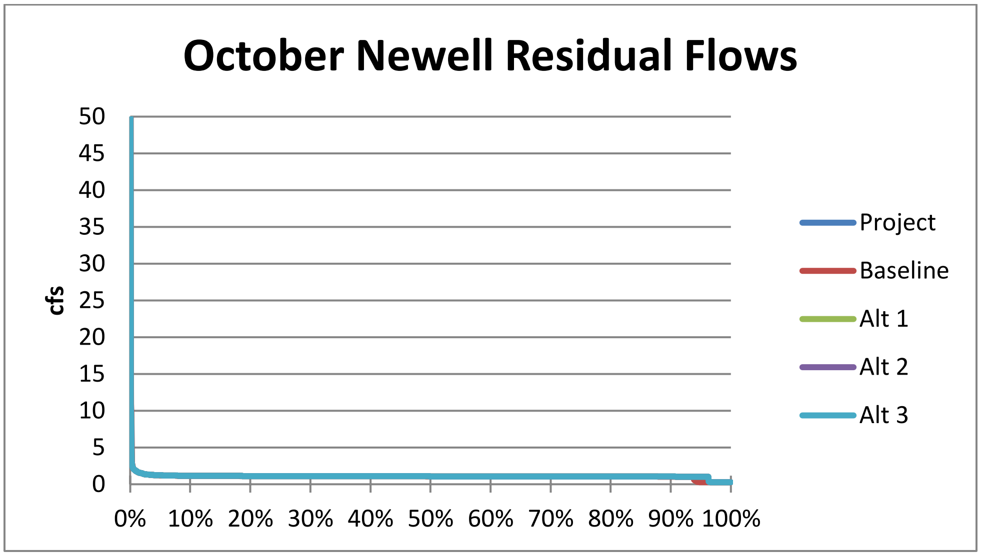
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	1	1	1	1	1
20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	1	1	1	1	1
20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0

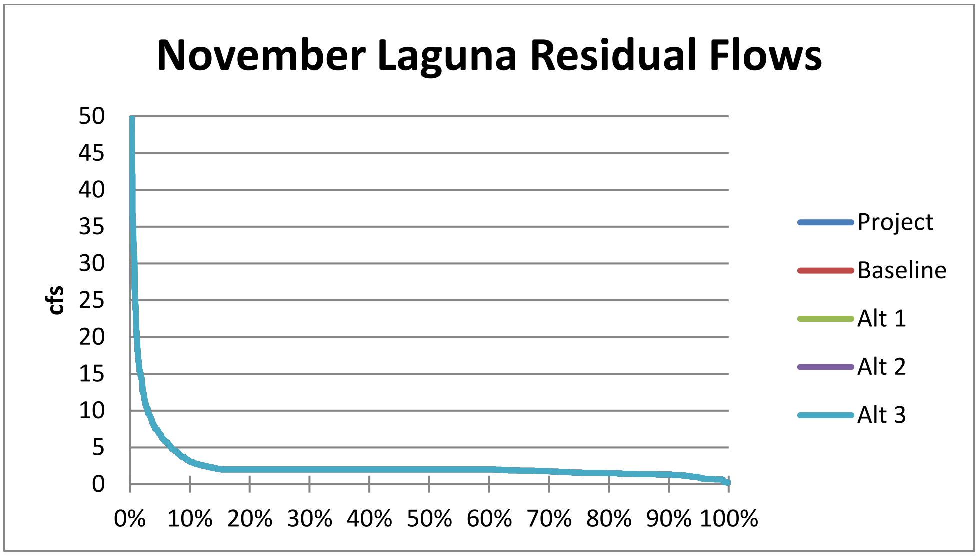


Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	1	1	1	1	1
20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0

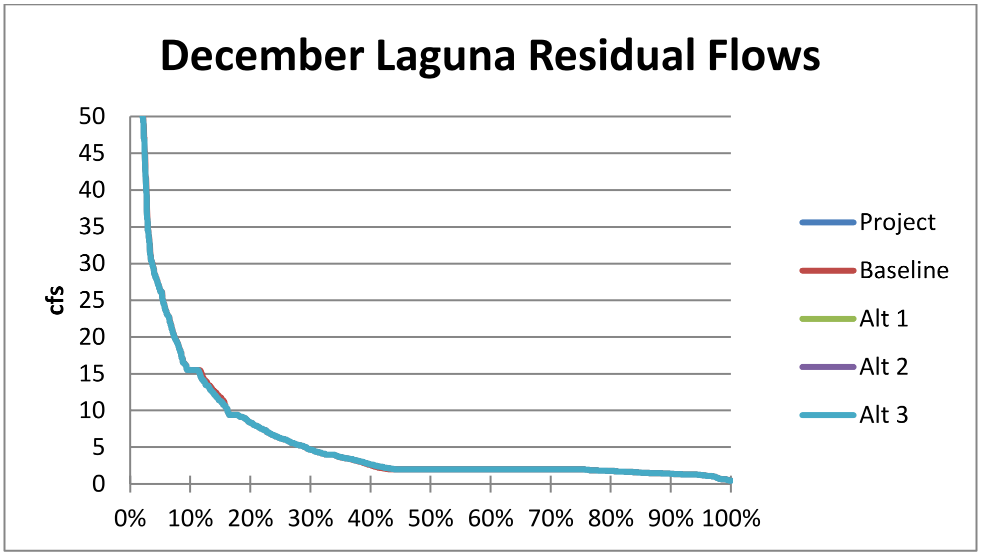


Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	1	1	1	1	1
20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0

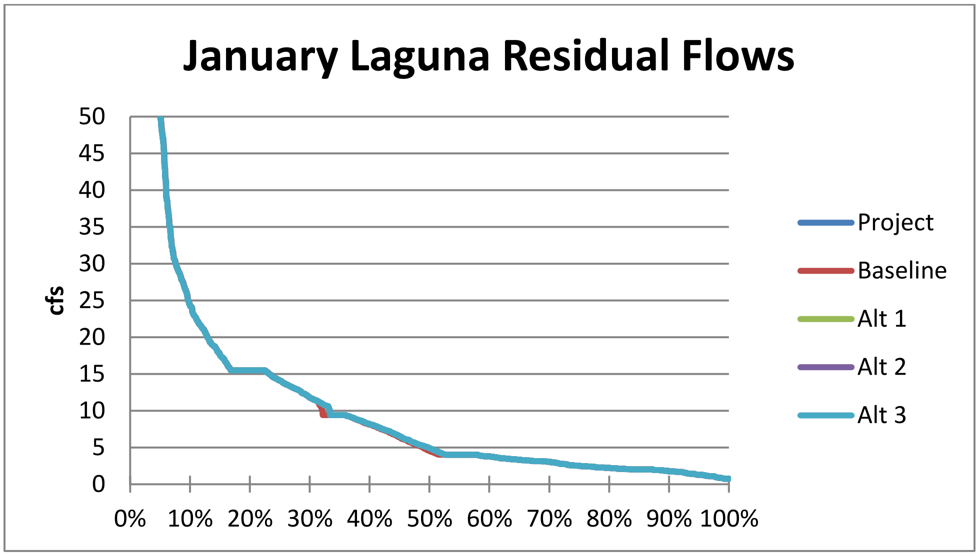
LAGUNA



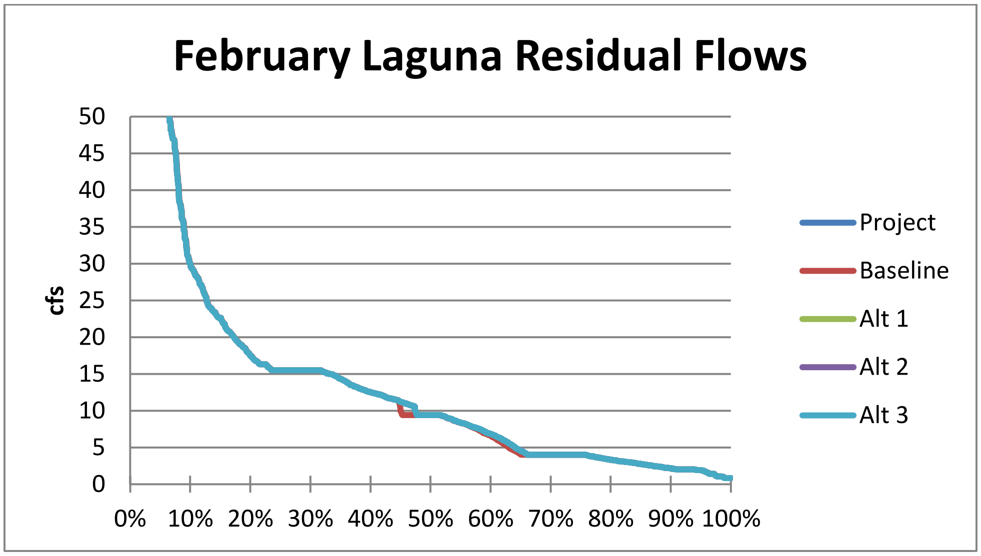
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	3	3	3	3	3
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	2	2	2	2	2
50%	2	2	2	2	2
60%	2	2	2	2	2
70%	2	2	2	2	2
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



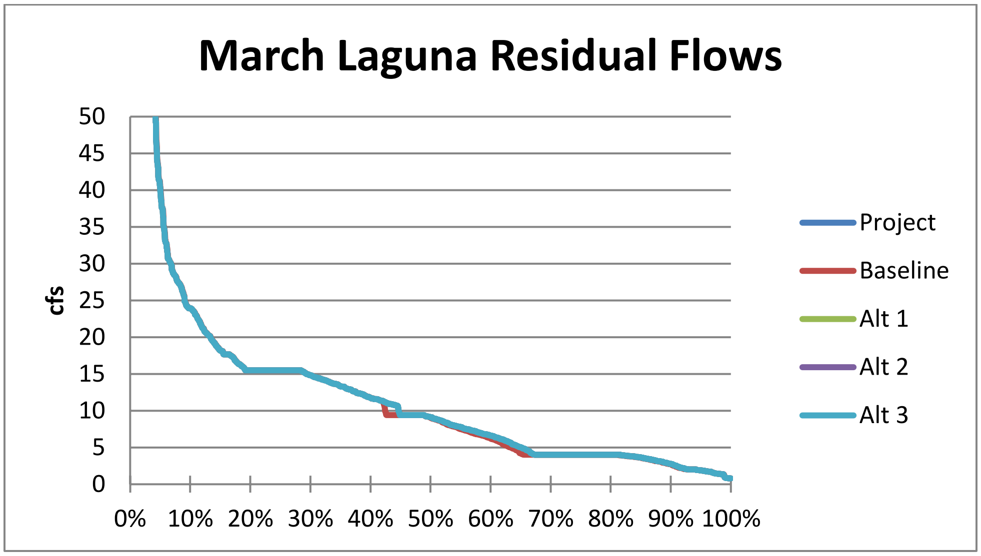
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	16	16	16	16	16
20%	8	8	8	8	8
30%	5	5	5	5	5
40%	3	3	3	3	3
50%	2	2	2	2	2
60%	2	2	2	2	2
70%	2	2	2	2	2
80%	2	2	2	2	2
90%	1	1	1	1	1
100%	0	0	0	0	0



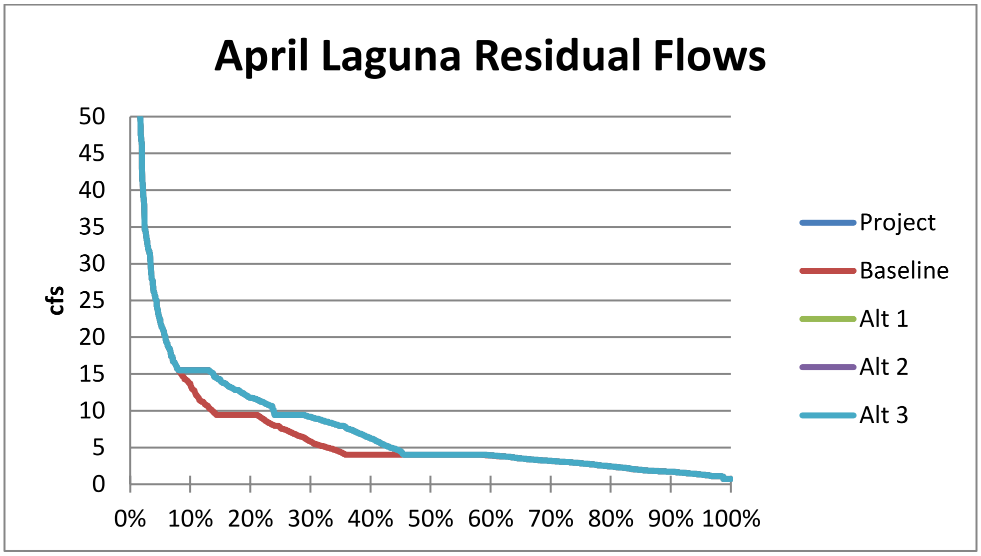
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	24	24	24	24	24
20%	16	16	16	16	16
30%	12	12	12	12	12
40%	8	8	8	8	8
50%	5	5	5	5	5
60%	4	4	4	4	4
70%	3	3	3	3	3
80%	2	2	2	2	2
90%	2	2	2	2	2
100%	1	1	1	1	1



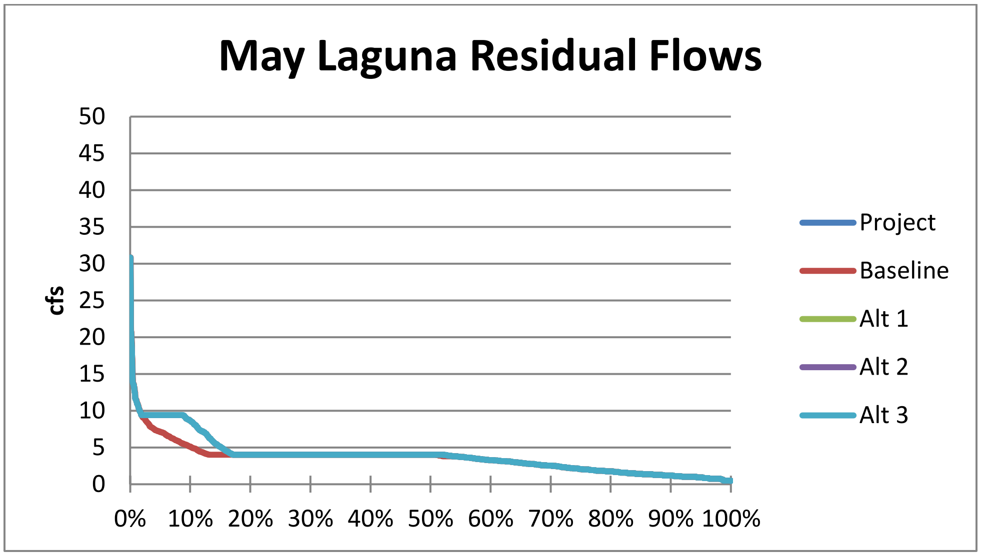
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	30	30	30	30	30
20%	17	17	17	17	17
30%	15	15	15	15	15
40%	13	13	13	13	13
50%	9	9	9	9	9
60%	7	7	7	7	7
70%	4	4	4	4	4
80%	3	3	3	3	3
90%	2	2	2	2	2
100%	1	1	1	1	1



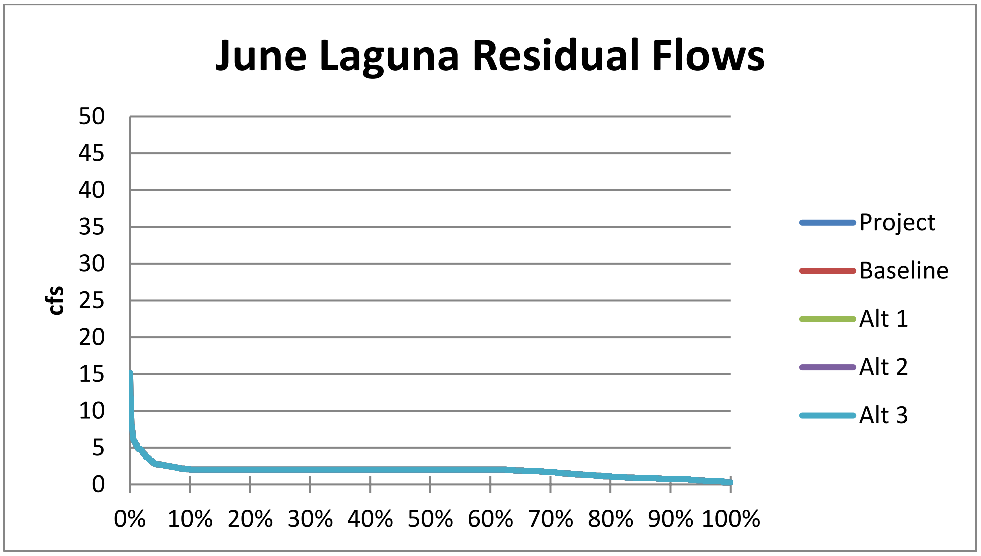
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	24	24	24	24	24
20%	16	16	16	16	16
30%	15	15	15	15	15
40%	12	12	12	12	12
50%	9	9	9	9	9
60%	7	6	7	7	7
70%	4	4	4	4	4
80%	4	4	4	4	4
90%	3	3	3	3	3
100%	1	1	1	1	1



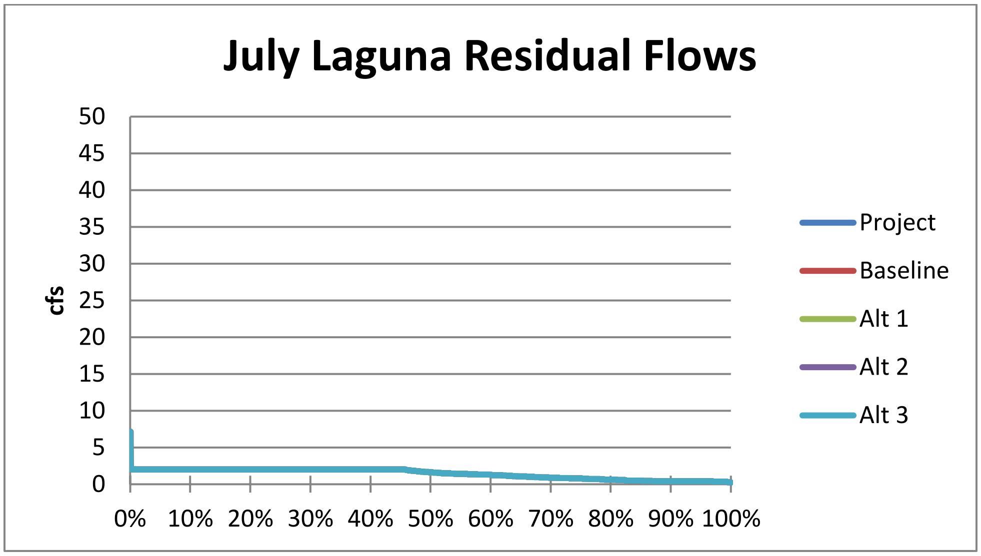
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	16	14	16	16	16
20%	12	9	12	12	12
30%	9	6	9	9	9
40%	6	4	6	6	6
50%	4	4	4	4	4
60%	4	4	4	4	4
70%	3	3	3	3	3
80%	2	2	2	2	2
90%	2	2	2	2	2
100%	1	1	1	1	1



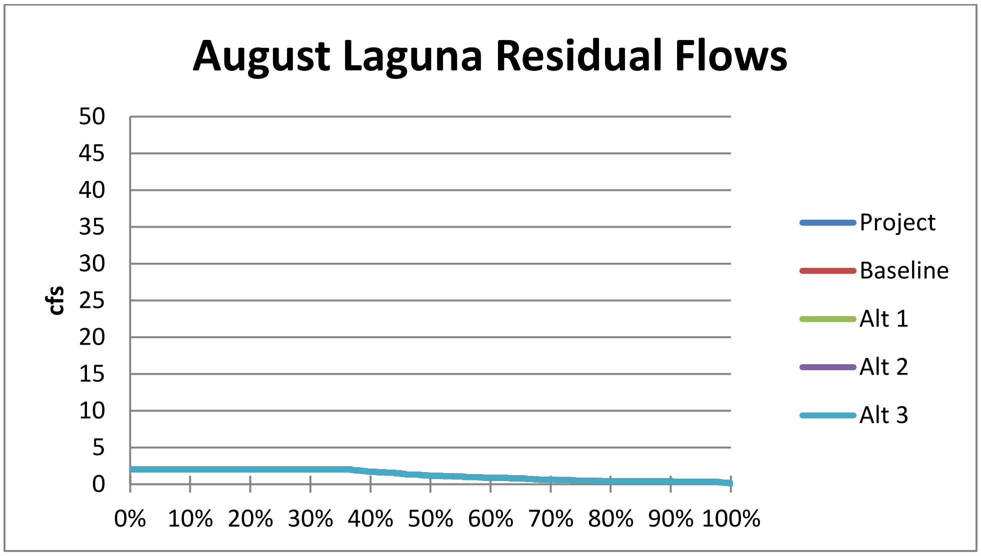
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	9	5	9	9	9
20%	4	4	4	4	4
30%	4	4	4	4	4
40%	4	4	4	4	4
50%	4	4	4	4	4
60%	3	3	3	3	3
70%	3	3	3	3	3
80%	2	2	2	2	2
90%	1	1	1	1	1
100%	0	0	0	0	0



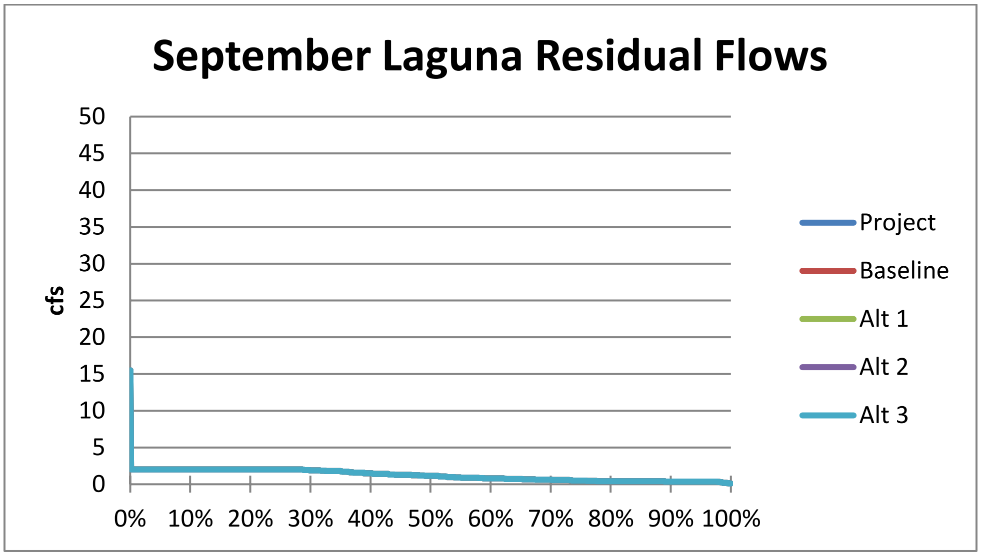
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	2	2	2	2	2
50%	2	2	2	2	2
60%	2	2	2	2	2
70%	2	2	2	2	2
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



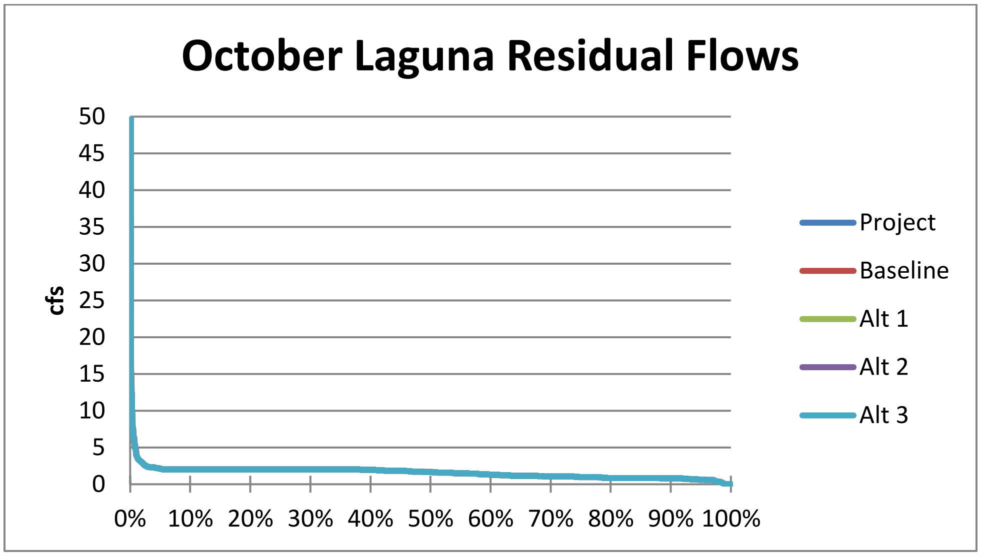
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	2	2	2	2	2
50%	2	2	2	2	2
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	2	2	2	2	2
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	2	2	2	2	2
50%	2	2	2	2	2
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0

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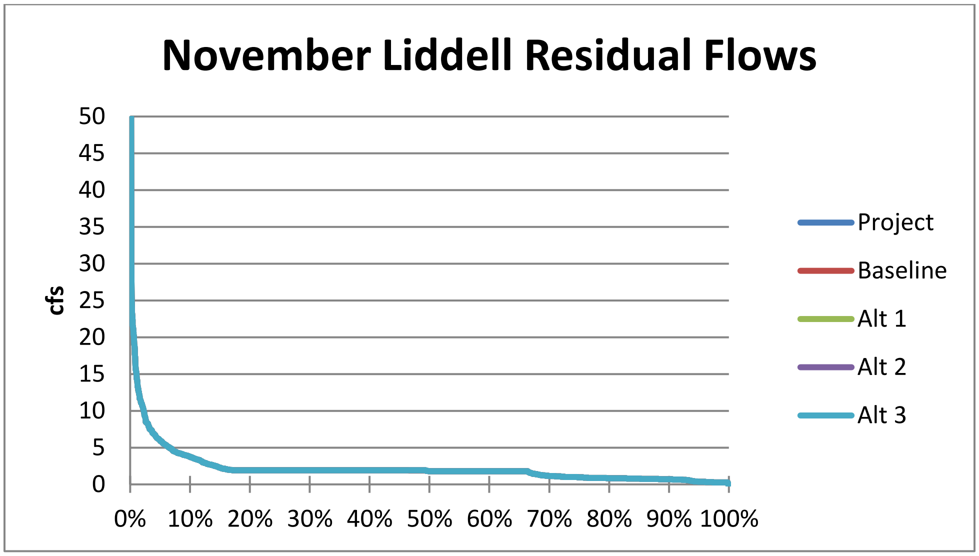
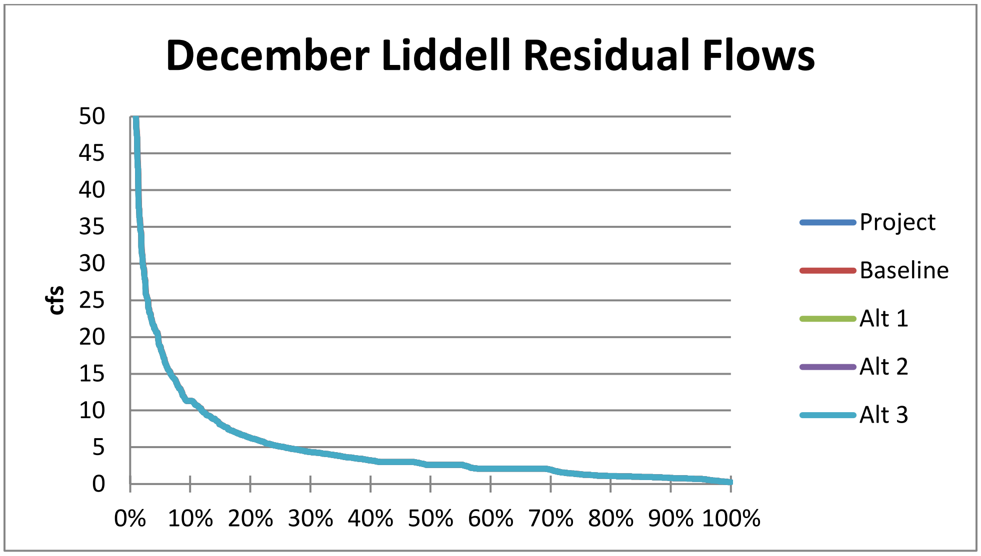
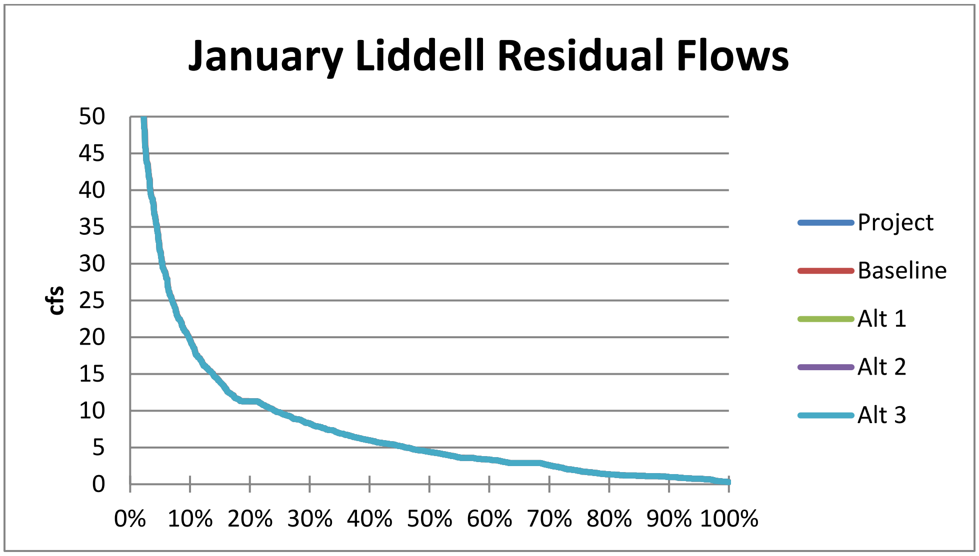


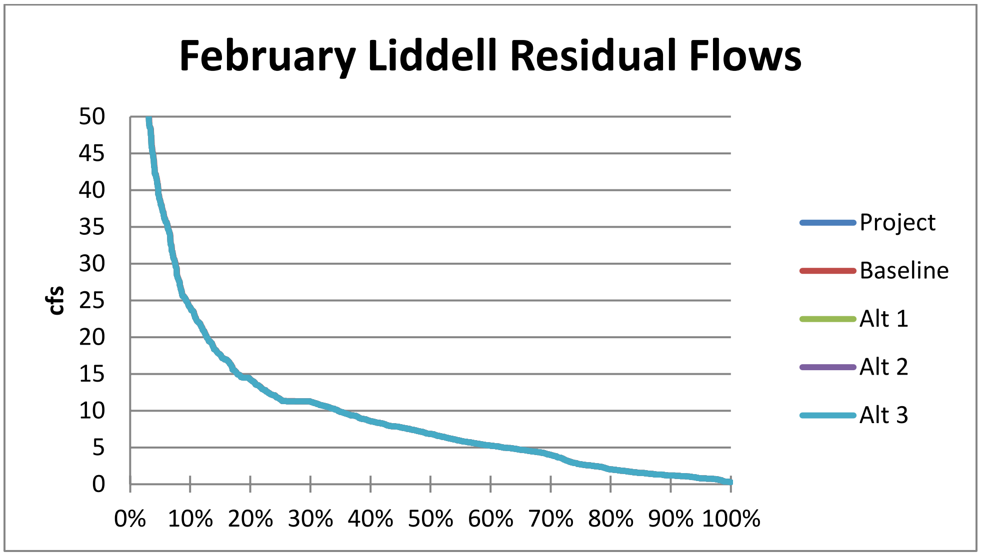
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	4	4	4	4	4
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	2	2	2	2	2
50%	2	2	2	2	2
60%	2	2	2	2	2
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



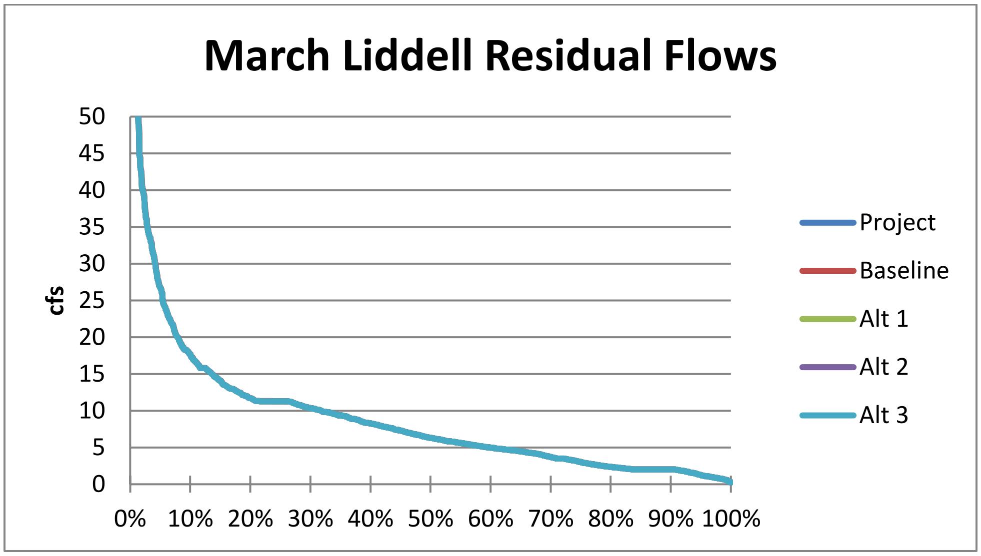
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	11	11	11	11	11
20%	6	6	6	6	6
30%	4	4	4	4	4
40%	3	3	3	3	3
50%	3	3	3	3	3
60%	2	2	2	2	2
70%	2	2	2	2	2
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



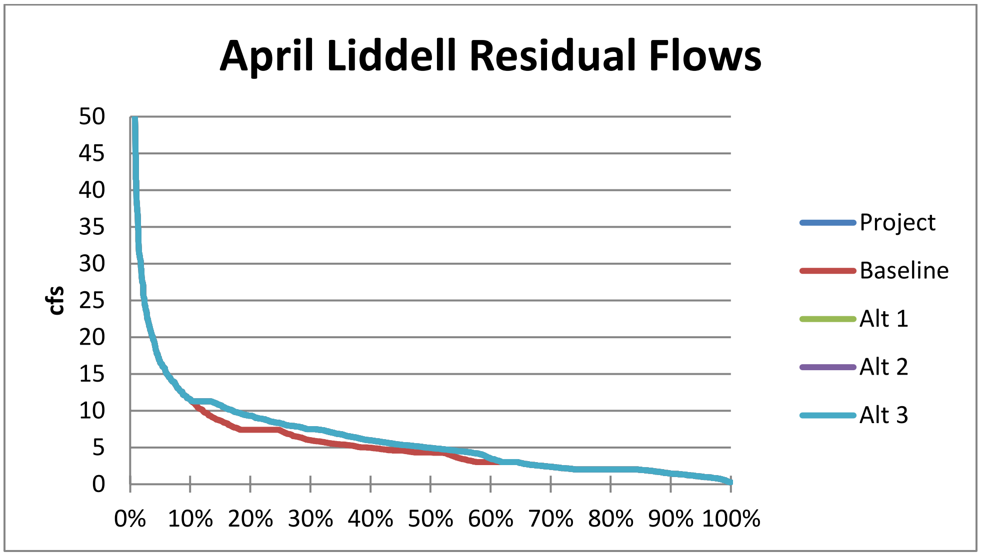
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	20	20	20	20	20
20%	11	11	11	11	11
30%	8	8	8	8	8
40%	6	6	6	6	6
50%	4	4	4	4	4
60%	3	3	3	3	3
70%	3	3	3	3	3
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



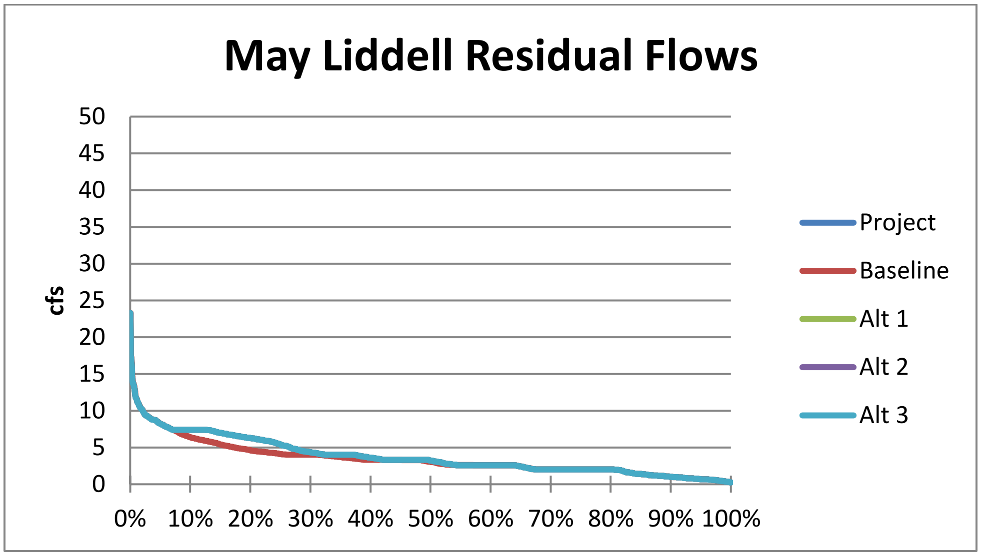
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	24	24	24	24	24
20%	14	14	14	14	14
30%	11	11	11	11	11
40%	9	9	9	9	9
50%	7	7	7	7	7
60%	5	5	5	5	5
70%	4	4	4	4	4
80%	2	2	2	2	2
90%	1	1	1	1	1
100%	0	0	0	0	0



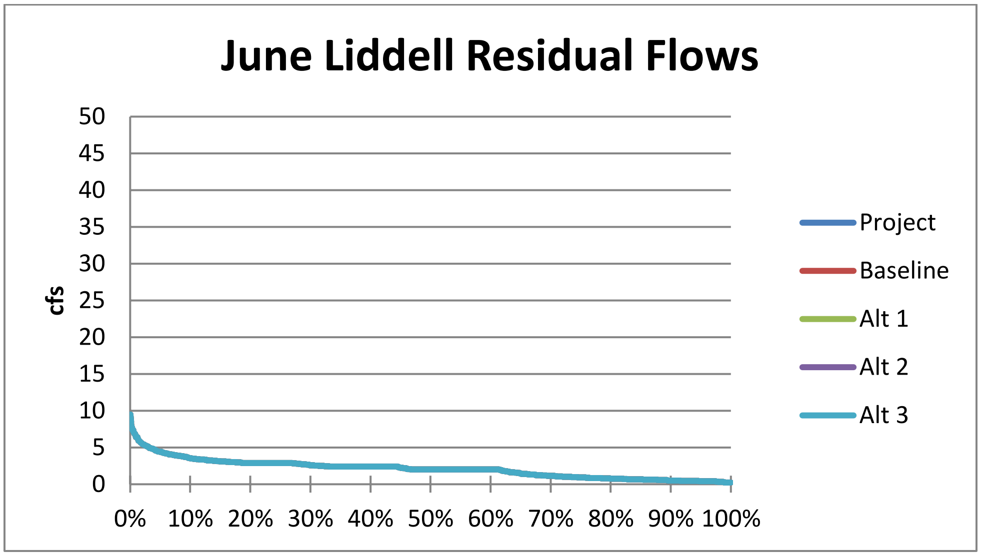
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	18	18	18	18	18
20%	12	12	12	12	12
30%	10	10	10	10	10
40%	8	8	8	8	8
50%	6	6	6	6	6
60%	5	5	5	5	5
70%	4	4	4	4	4
80%	2	2	2	2	2
90%	2	2	2	2	2
100%	0	0	0	0	0



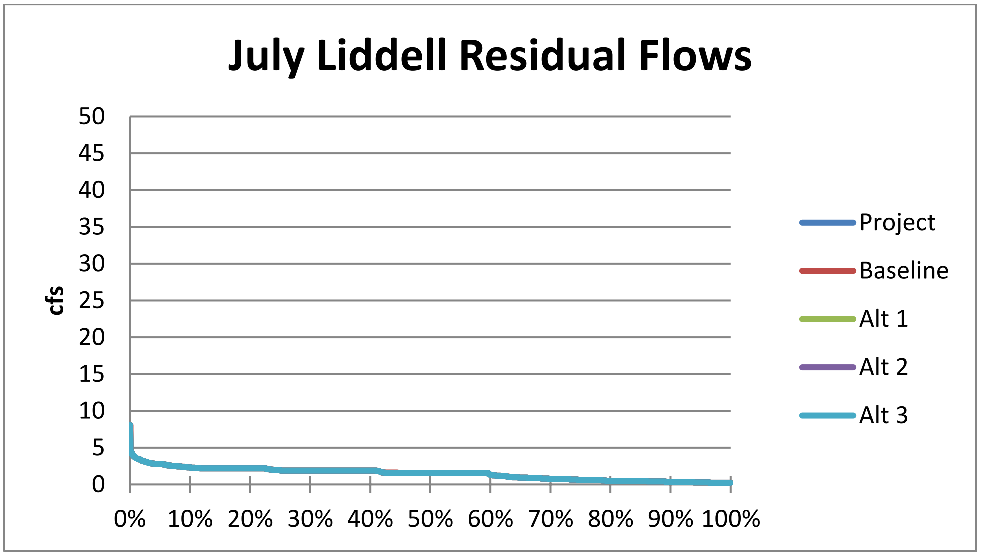
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	12	12	12	12	12
20%	9	7	9	9	9
30%	8	6	8	8	8
40%	6	5	6	6	6
50%	5	4	5	5	5
60%	3	3	3	3	3
70%	2	2	2	2	2
80%	2	2	2	2	2
90%	1	1	1	1	1
100%	0	0	0	0	0



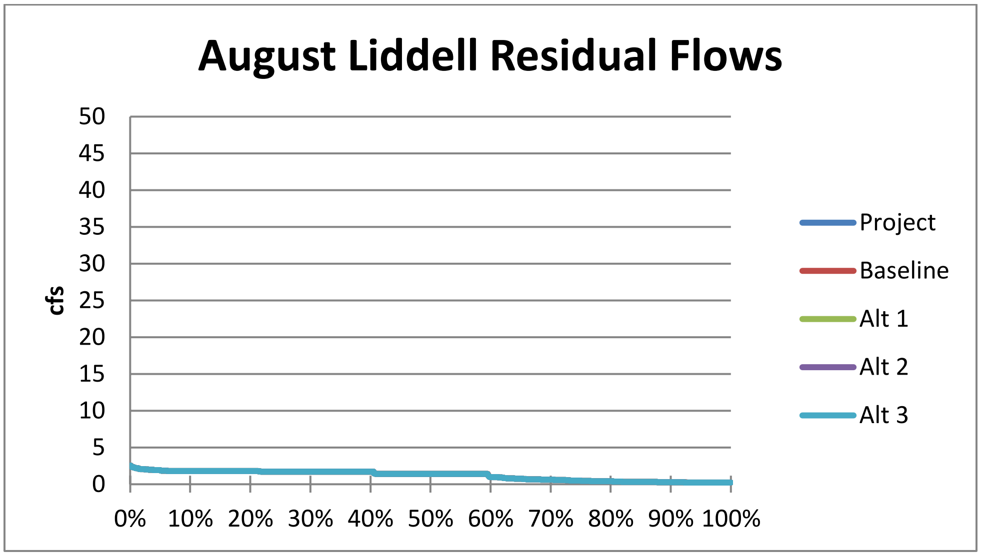
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	7	6	7	7	7
20%	6	5	6	6	6
30%	4	4	4	4	4
40%	4	3	4	4	4
50%	3	3	3	3	3
60%	3	3	3	3	3
70%	2	2	2	2	2
80%	2	2	2	2	2
90%	1	1	1	1	1
100%	0	0	0	0	0



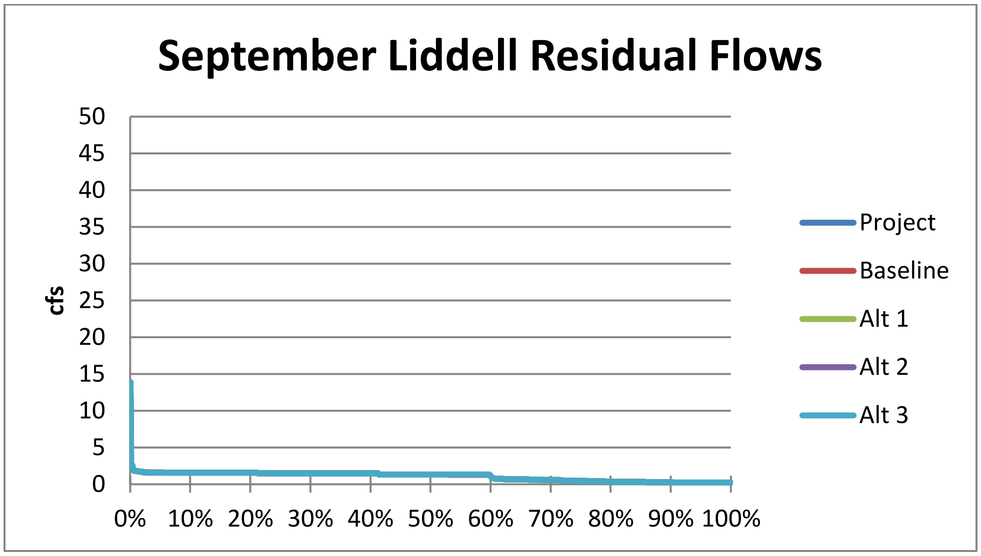
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	4	4	4	4	4
20%	3	3	3	3	3
30%	3	3	3	3	3
40%	2	2	2	2	2
50%	2	2	2	2	2
60%	2	2	2	2	2
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	1	1	1	1	1
100%	0	0	0	0	0



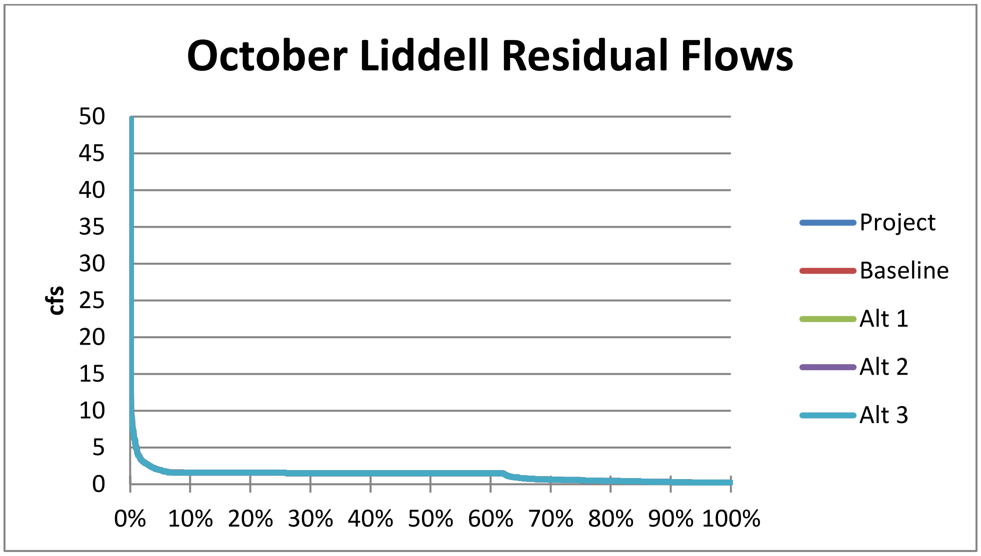
Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	2	2	2	2	2
50%	2	2	2	2	2
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	2	2	2	2	2
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0

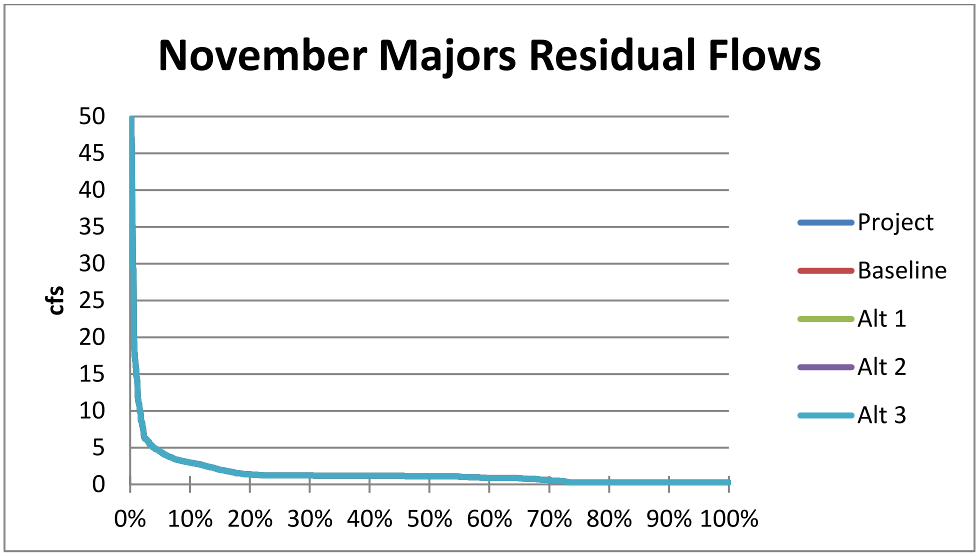


Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	2	2	2	2	2
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	2	2	2	2	2
20%	2	2	2	2	2
30%	2	2	2	2	2
40%	2	2	2	2	2
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0

MAJORS



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
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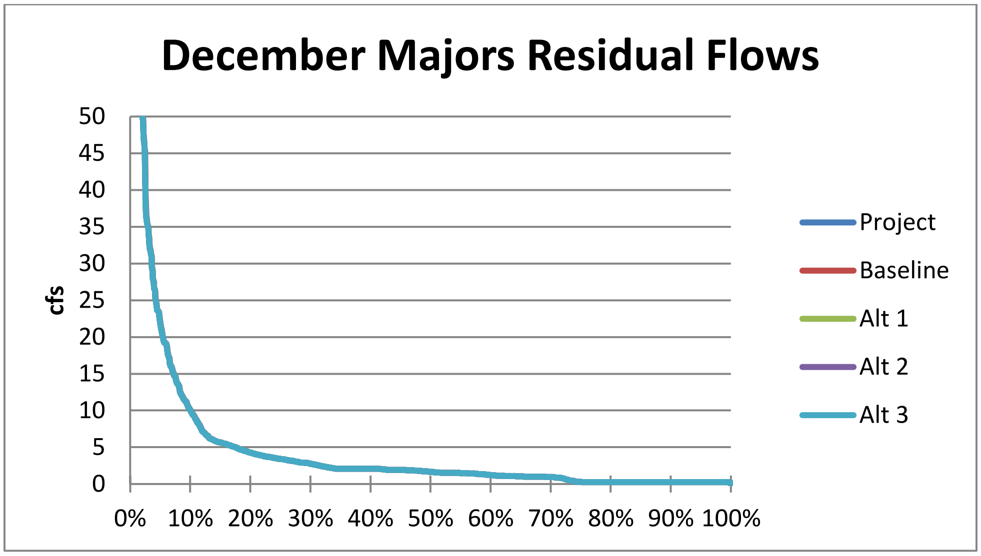
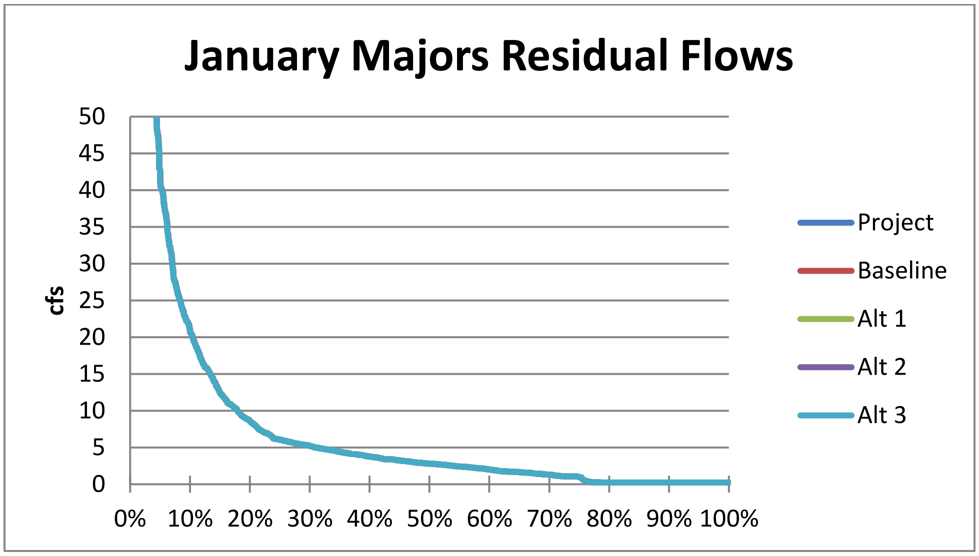
20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	10	10	10	10	10
20%	4	4	4	4	4
30%	3	3	3	3	3
40%	2	2	2	2	2
50%	2	2	2	2	2
60%	1	1	1	1	1
70%	1	1	1	1	1
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
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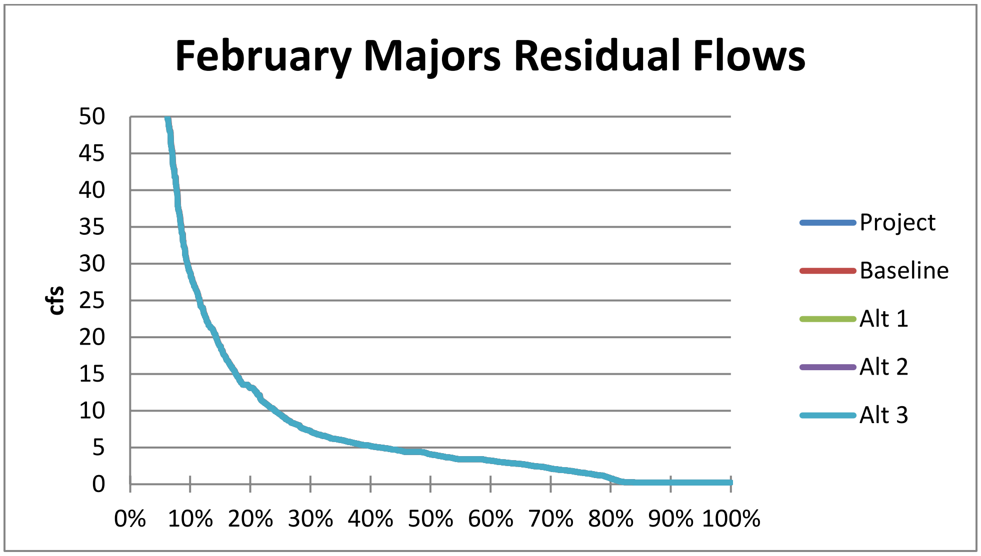
20%	9	9	9	9	9
30%	5	5	5	5	5
40%	4	4	4	4	4
50%	3	3	3	3	3
60%	2	2	2	2	2
70%	1	1	1	1	1
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
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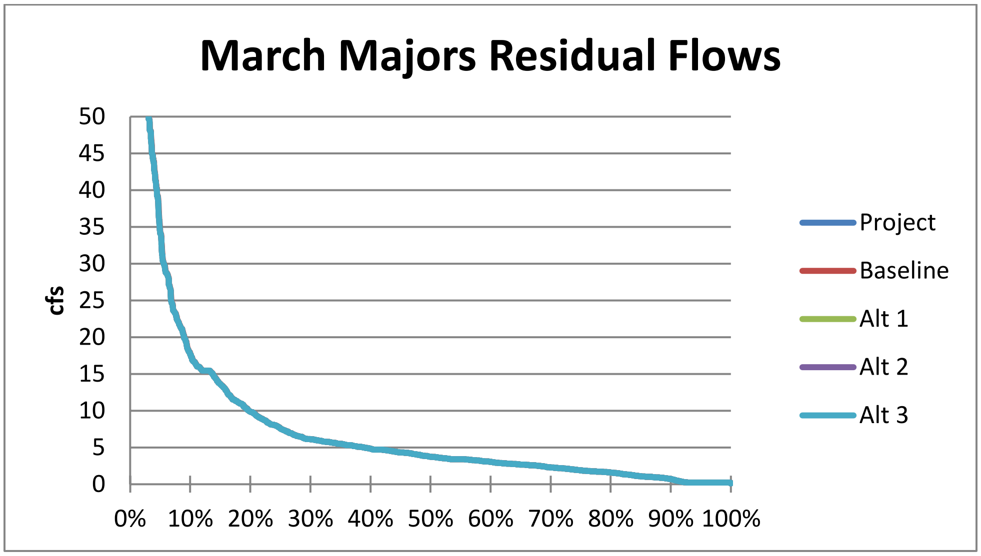
20%	13	13	13	13	13
30%	7	7	7	7	7
40%	5	5	5	5	5
50%	4	4	4	4	4
60%	3	3	3	3	3
70%	2	2	2	2	2
80%	1	1	1	1	1
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
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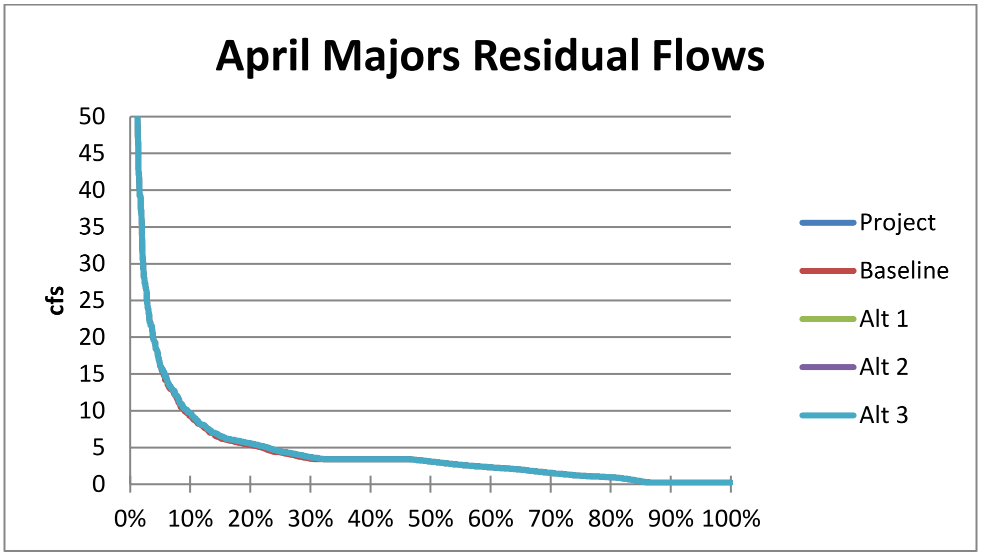
20%	10	10	10	10	10
30%	6	6	6	6	6
40%	5	5	5	5	5
50%	4	4	4	4	4
60%	3	3	3	3	3
70%	2	2	2	2	2
80%	2	2	2	2	2
90%	1	1	1	1	1
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
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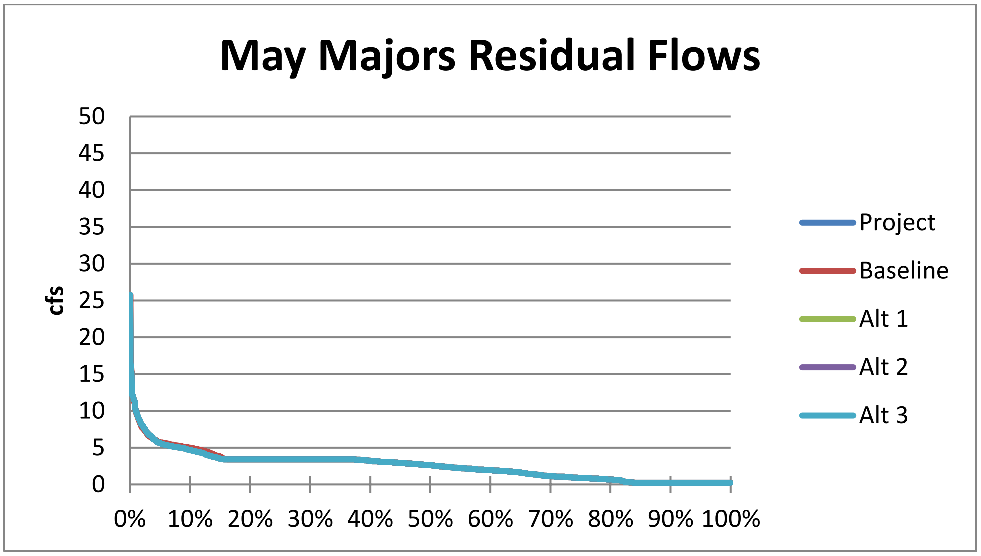
20%	6	5	6	6	6
30%	4	3	4	4	4
40%	3	3	3	3	3
50%	3	3	3	3	3
60%	2	2	2	2	2
70%	2	2	2	2	2
80%	1	1	1	1	1
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
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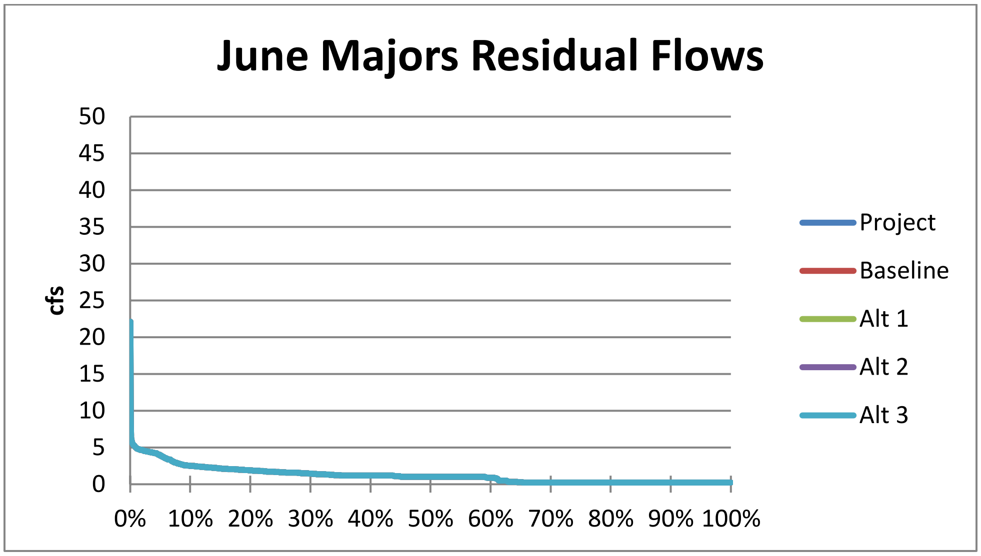
20%	3	3	3	3	3
30%	3	3	3	3	3
40%	3	3	3	3	3
50%	3	3	3	3	3
60%	2	2	2	2	2
70%	1	1	1	1	1
80%	1	1	1	1	1
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
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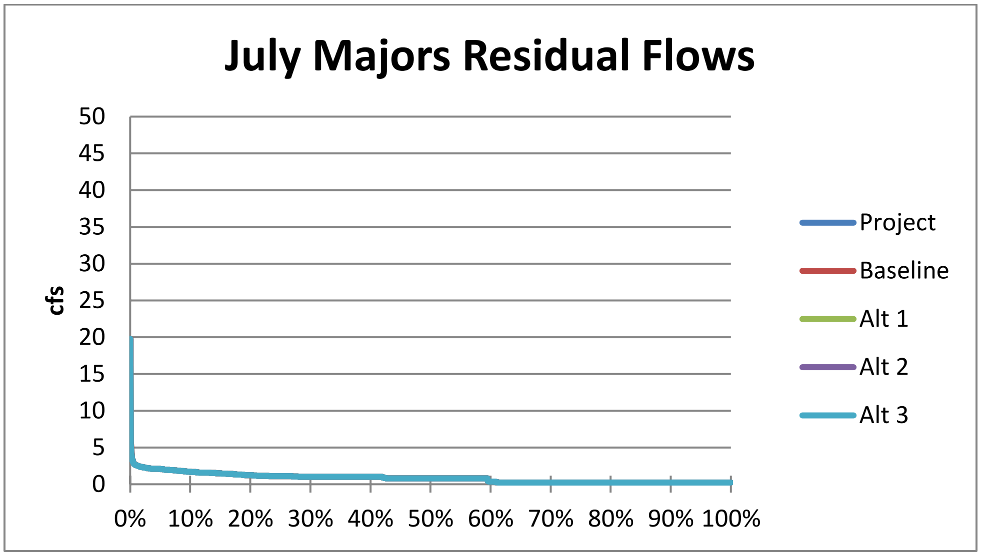
20%	2	2	2	2	2
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	0	0	0	0	0
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
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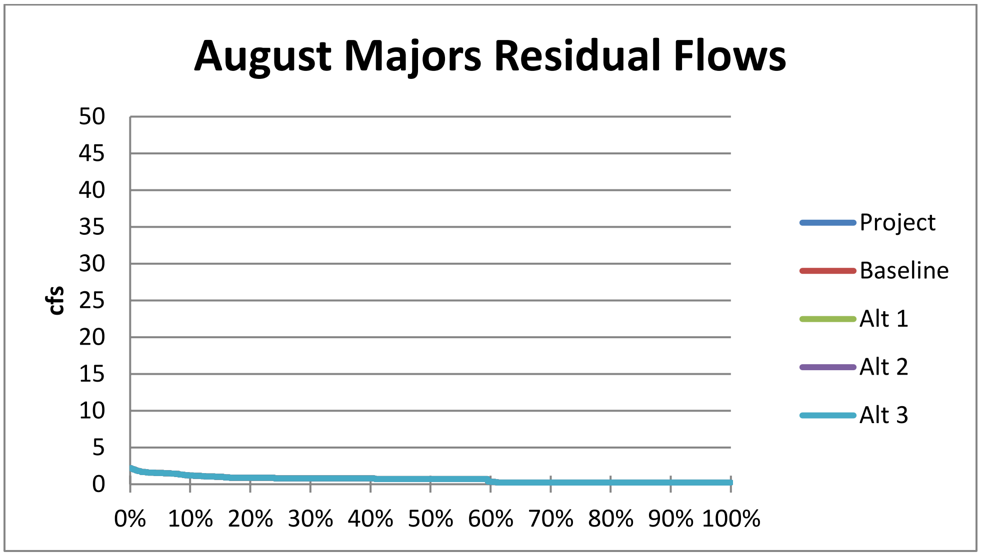
20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	0	0	0	0	0
70%	0	0	0	0	0
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
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20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	0	0	0	0	0
70%	0	0	0	0	0
80%	0	0	0	0	0
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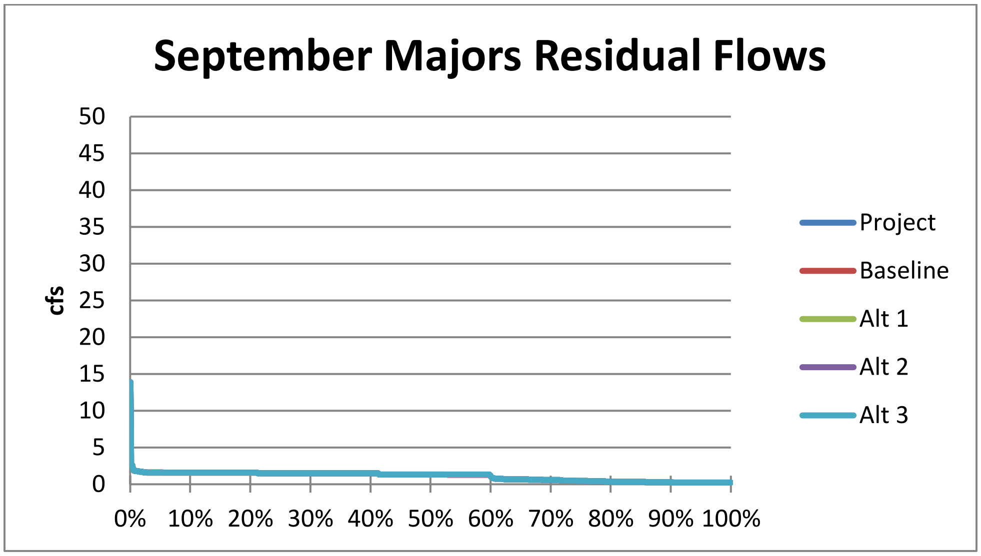
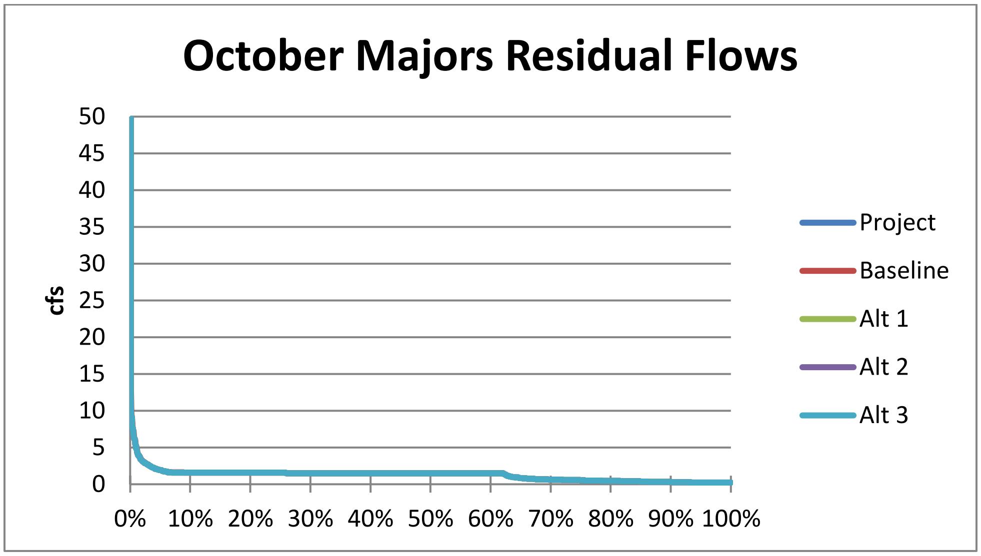
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	1	1	1	1	1
20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	0	0	0	0	0
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0



Percentile	Project	Baseline	Alt 1	Alt 2	Alt 3
10%	1	1	1	1	1
20%	1	1	1	1	1
30%	1	1	1	1	1
40%	1	1	1	1	1
50%	1	1	1	1	1
60%	1	1	1	1	1
70%	0	0	0	0	0
80%	0	0	0	0	0
90%	0	0	0	0	0
100%	0	0	0	0	0

1. Purpose

This document provides a description of the methodology and results of habitat modeling conducted to evaluate the effects of the Santa Cruz Water Rights Project (Proposed Project) on habitat for Central California Coast steelhead (steelhead) (*Oncorhynchus mykiss*) and Central California Coast coho salmon (coho) (*Oncorhynchus kisutch*) due to changes in streamflows.

2. Introduction and Background

Operation of diversions for the City's water system involves potential effects on salmonid populations inhabiting the streams that also serve as the City's water supply sources. Evaluation of effects on salmonid populations in the EIR for the Proposed Project relies on information, tools, and methods developed to determine and evaluate instream flow requirements under the City's pending Anadromous Salmonid Habitat Conservation Plan (ASHCP) (City of Santa Cruz 2021). The objective of this work has been to provide a means of linking streamflow to habitat values for steelhead and coho inhabiting stream reaches influenced by City water supply operations. The methodology is based on the 79-year daily streamflow database developed by Balance Hydrologics (see Appendix D-1) and uses modeled daily residual streamflows,[1] that are output from the Confluence model (see Appendix D-2). The information, tools, and methods were developed as a collaborative process involving the City and its consultants, representatives of the National Marine Fisheries Service, and representatives of the California Department of Fish and Wildlife over a multi-year period beginning in 2005 as part of the development of the pending ASHCP.

The City operates three diversions from North Coast streams (Liddell Spring, Laguna Creek/Reggiardo Creek, and Majors Creek), diversions from the San Lorenzo River at the Felton Diversion and the Tait Diversion, and diversion from Newell Creek at Loch Lomond Reservoir.[2] Only the Felton Diversion (CDFW 1998) and Newell water rights have required bypass flows currently. A major objective of developing the ASHCP has been to identify opportunities to minimize the effect of the City's diversions on steelhead and coho by managing diversion operations to meet in-stream flow levels to support salmonid habitat in coordination with City water supply functions. Toward this end, the City has negotiated long-term minimum bypass flow requirements (Agreed Flows) with CDFW and NMFS as part of the ASHCP process. As both the California Department of Fish and Wildlife (CDFW) and the National Marine Fisheries Service (NMFS) have tentatively agreed on the bypass flow requirements, the City has committed to implement the Agreed Flows as part of the Proposed Project regardless of the final outcome of the ASHCP process. The Agreed Flows are described in Chapter 3 and Appendix C of the EIR and are the minimum bypass flows for the Proposed Project and Alternatives 1 through 3.

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[1] Residual streamflow is the amount of streamflow left in the stream after diversion, assuming diversion is possible after the applicable minimum bypass flows are met. Residual streamflow may be different than the applicable minimum bypass flows if there is more flow in the stream than needed by the diversion or if flow is less than the agreed bypass with no diversion.

[2] The name of the dam that impounds Newell Creek, forming Loch Lomond Reservoir, is Newell Creek Dam.

3. Methodology

3.1. Analytical Tools

There are many components of an aquatic system that potentially influence the suitability of habitat for each life stage of steelhead and coho. During the freshwater portion of their life history, these species are dependent on flowing waters and they are uniquely adapted to the Mediterranean seasonal hydrologic pattern and dynamic annual precipitation variability influencing streams flowing from the Central California coast. The major factor linking the City's water supply activity and the suitability of habitat for salmonids is alteration of the magnitude and timing of instream flows. Therefore, development and evaluation of bypass flows focused on physical habitat parameters related to flows and was supported by existing analytical tools including the Physical Habitat Simulation Model (PHABSIM) component of the Instream Flow Incremental Methodology (Bovee et al. 1998, see following Section 3.1.1), the Critical Riffle or Thompson Method (Bjornn and Reiser 1991; Thompson 1972; CDFW 2013), the Powers and Orsborn method (Powers and Orsborn 1985), and R2 (Berry 2016). These methods are summarized below and described in more detail in HES (2014).

Habitat conditions for steelhead and coho are also influenced by water temperature. As described further in Section 3.15, effects of the Proposed Project and alternatives on water temperature are limited to operation of Loch Lomond Reservoir. Modeling of water temperature was not conducted but City records for reservoir water temperature profiles and reservoir spill were evaluated to assess potential effects. Additionally, to evaluate the potential for water temperature effects, modeling results for the Baseline, Proposed Project and alternatives were reviewed to assess potential changes in Loch Lomond Reservoir spill under each of these scenarios. Loch Lomond Reservoir spill data are provided for the Baseline, Proposed Project and alternatives in Chapter 8, Alternatives of the Draft EIR.

Other habitat components such as benthic macro-invertebrate food sources, substrate characteristics, channel features, riparian vegetation, human disturbance, predation, disease, etc. are potentially important but were not incorporated directly in the analytic structure because either there is not an apparent, quantifiable direct linkage between the Proposed Project and a given habitat component, or there is not sufficient knowledge to evaluate or quantify linkages. Other components are considered qualitatively based on expert judgment in relation to the Proposed Project.

3.1.1. Analysis of Spawning and Rearing Habitat Using PHABSIM

The PHABSIM method assesses habitat conditions by measuring hydraulic conditions at representative cross sections and constructing computer models to predict changes in suitability of habitat with discharge. The model output includes an index representing habitat suitability based on depth and velocity conditions. For spawning, the suitability index also incorporates substrate size characteristics. The PHABSIM analysis was conducted in 2005 through 2010 by Hagar Environmental Science (HES) in coordination with a technical team representing CDFW, NMFS, and the City.

PHABSIM study sites were selected by walking the stream and identifying locations where conditions were generally favorable for either spawning or rearing of steelhead or coho. Spawning transects were generally near the transition areas between a pool-tail and the head of a riffle where substrate and velocity conditions favor spawning. Some transects were also placed in run type habitat or in deeper riffles where suitable substrate occurred. Rearing transects were located in pool, flatwater, or deeper riffle habitat roughly in proportion to the abundance of each type. Habitat type composition was based on information in ENTRIX (2004) for North Coast Streams; HES (2007) for Newell Creek; and a 2005 HES survey of the Lower San Lorenzo River (HES 2014). Sites were selected to cover the range of variability in factors such as stream width, cross-section depth, and substrate conditions. Sites were located close to access wherever possible. One or more transects were marked perpendicular to the flow at each site to cover the range of conditions at individual sites.

Data Collection and Pre-processing

The PHABSIM study required collection of channel geometry and hydraulic data including an elevation profile, depth and velocity cross-sections, and water surface elevation (stage) at each study site across a range of flows that bracketed the suitable range for a given life-stage. Cross-sections were selected and initial surveys were conducted during low-flow conditions since channel features and substrate conditions are more easily observed at that time. Initial transect data collection included an elevation cross-section (channel geometry) and substrate code for stations at intervals sufficient to describe the habitat and provide a maximum number of data points for hydraulic modeling. Substrate particle size classes and relative abundance were characterized at each measurement point on the transect using the Bovee substrate coding system (Bovee 1978). Water stage data were collected at each cross-section to serve as the low-flow point for stage/discharge relationships. One transect in each study area was selected for flow estimation and a depth and velocity set was collected for this purpose. The flow transect was usually one of the passage or spawning transects since they were generally placed in more suitable locations for flow measurement. Flow measurements were supplemental to the City’s 15-minute gage data for each stream (HES 2014).

Subsequent data collection required collection of a high flow velocity set (velocity at each station) at the upper end of the model range of flows and a series of stage/discharge measurements over the range of flows to be modeled. These data were collected during storm runoff periods (HES 2014).

Stage measurements were correlated with flow to develop a stage/discharge relationship for each transect location. Flow corresponding to each stage measurement was estimated using either the City gage data, site measured flow, or a correlation of site measured flow with City gage data (HES 2014).

Hydraulic Model Development and Calibration

The data collected were used to develop a hydraulic simulation under the PHABSIM framework which was used to simulate depths and velocities in streams under varying stream flow conditions. Simulated depth and velocity data were then used to calculate the physical habitat index, either with or without substrate information. First, water surface elevations were predicted for each transect using the IFG-4 component of the PHABSIM model. The IFG-4 method uses an empirical log/log regression formula of stage and discharge (flow) based on the measured data to determine water surface elevations across a series of simulation flows. Each cross section was treated independently of all others in the data set. A minimum of three stage-discharge measurement pairs were used to calibrate the stage-discharge relationship.

Water velocities were calculated using the “one-flow” technique which uses a single set of measured velocities and depths to estimate the Manning’s n value on an individual cell basis along a transect. The high flow velocity and depth data were used for this purpose whenever possible so that measured values were available for the maximum number of cells on each transect. At the simulated discharges, the model uses Manning’s formula and these previously derived Manning’s n values together with the projected depth to predict velocities. A velocity calibration was performed to determine the adequacy of velocity simulations and adjustments were made where needed and justified (HES 2014).

Habitat Suitability Criteria

Hydraulic parameters (depth and velocity) and substrate values are linked to habitat value through application of habitat suitability criteria (HSC) that describe the relative suitability of water depth, water velocity, and stream substrate, to the fish species being evaluated. For the ASHCP, existing HSC data developed on the Trinity River by the U.S. Fish and Wildlife Service were used (Hampton 1997). The Trinity River HSC were used because they were considered the best quality criteria available within a reasonable geographic distance from the North Coast streams, the San Lorenzo River, and Newell Creek. The Trinity River HSC were developed by direct observation and measurement of depth and velocity at locations used by spawning steelhead and coho and rearing juveniles. Suitability criteria for spawning substrates were taken from Bovee (1978) due to a lack of data from Hampton (1997).

Habitat Index Simulation

Habitat index simulation is the process that combines hydraulic estimates of velocity and depth (i.e., the results of the hydraulic simulation) with the suitability values for those attributes (i.e., the habitat suitability criteria) to weight the area of each cell along a transect at the simulated flow. The weighted values for all cells are summed to give a single habitat index, called weighted usable area or relative suitability index (WUA/RSI). The WUA/RSI index of aquatic habitat suitability describes the incremental relationship between physical habitat and stream discharge. Hydraulic and habitat index modeling were conducted using RHABSIM Version 3.0 (Riverine Habitat Simulation, Payne 1994).

3.1.2. Analysis of Flows for Migration Passage Using Critical Riffle Analysis

This method identifies sites that are exceptionally wide and shallow (critical riffles) as limiting to fish migration and establishes the level of flow that meets minimum migration criteria for depth of flow at these sites (HES 2014). The migration passage flow assessment is based on standards developed in the fisheries literature (Thompson 1972; Bjornn and Reiser 1991; CDFW 2013). These standards assume that there must be sufficient depth over the shallowest riffles for the target species to swim upstream with its body completely covered.

The critical riffle analysis was conducted from 2005 through 2010 and used a methodology attributed to Thompson (1972). Thompson's method entails identifying a series of shallow riffles that potentially affect fish passage, establishing transects across the shallowest locations, and then determining, for each transect, the flow at which a minimum depth criterion is maintained across at least 25% of the total channel width and a contiguous minimum width of 10% of the channel. Thompson (1972) recommends a minimum passage depth criterion of 0.6 feet for adult steelhead, although other depth criteria have been used depending on specific site conditions and objectives. This basic methodology has been widely adapted and modified since its introduction as a proposed method in 1972.

In this analysis, the Technical Team (NMFS, CDFW, City of Santa Cruz and consultants) agreed on minimum passage depth criteria (critical depths) of 0.6 feet for migrating adults and 0.3 feet for smolts. Factors to consider in choosing a depth or width criteria are the number, length, and difficulty of critical passage points; distance from the ocean; and size and condition of the fish. In each of the study streams where the critical riffle analysis was used, the reach between the mouth and the upper limit of the anadromous reach is quite short (from 0.7 to 1.6 miles) and generally has low gradient. Riffles make up a relatively small portion of the habitat in each stream (ENTRIX 2004; HES 2007) and other obstructions are infrequent. The riffles are relatively short and interspersed with pools with good cover characteristics, including undercut banks and roots. Therefore, migrating adults should be in good condition at each of the critical passage locations and fatigue from having to pass many obstacles over great distances should not be an issue. Given swimming speeds cited previously, high velocity was not a factor at any of the identified passage sites.

Site Selection and Field Data Collection

Three to four critical riffles were identified during an initial walk-through of the anadromous reach of each of the North Coast streams during the fall of 2006. Critical passage locations in the San Lorenzo River downstream of the Tait Diversion were identified during a habitat survey conducted in October 2005 and critical passage locations were identified in Newell Creek downstream of Newell Creek Dam/Loch Lomond Reservoir during the fall of 2007 and during the winter of 2009-2010 (HES 2014). A single transect was placed along the shallowest cross-section of each riffle and marked with head pins for location of future measurements. Transects incorporated the shallowest portion on the probable route a migrating salmonid would follow. Streambed elevations were measured at regular intervals along a survey tape and tied to a reference elevation at each transect (one of the head pins). Water surface elevations were also measured at both sides of the channel and at the thalweg (deepest point on the cross-section), including the time of each measurement. Water surface elevation measurements were repeated at each transect under varying flow conditions during the following winter and early spring. Flow associated with water surface elevations or velocity transects was determined from site measurements or estimated from the 15-minute gage record maintained by the City in the anadromous reach of the North Coast streams and in Newell Creek below Newell Creek Dam, and the USGS gage in the San Lorenzo River at the Tait Diversion.

Data Analysis

Cross-section data were entered in a spreadsheet configured to allow determination of the critical water surface elevation at which depth criteria were met. Each measurement point on the cross-section represented a cell with boundaries extending halfway to both adjacent measurement points. Depth of each cell was calculated for any given water surface level as the water surface elevation minus the bed elevation. A depth criterion (i.e., 0.6 feet for adults or 0.3 feet for smolts) was set for each iteration of the spreadsheet and both the total width of cells meeting that depth criteria as well as the longest contiguous group of cells meeting the criteria were tallied and compared to the total wetted width corresponding to that stage. A stage was selected for which 25% of the wetted channel width and a contiguous portion totaling at least 10% of the wetted width had a depth equal to or greater than the criteria value. A stage/discharge relationship was estimated for each transect using the field stage measurements and discharge data. The stage/discharge relationship was used to calculate the flow required to meet critical water surface elevations at each cross-section. This was the minimum migration flow at the cross-section.

For each reach where passage was evaluated, a flow window was defined with suitable conditions for adult migration. The lower threshold was defined by the cross-section with passage criteria met at the lowest flow and the upper threshold was defined by the cross-section with the highest flow required to meet passage criteria. This is a departure from the standard method (which uses the average value of the transects) but was requested by CDFW as a buffer against potential error in the method. This provides a protected “window” for migration passage with diversion halted when the lower threshold is reached and not resumed until flows exceed the upper threshold. The amount of flow in excess of the upper threshold is available for diversion. If flow drops below the lower threshold, either spawning, rearing, or smolt migration flows would then be governing.

3.1.3. Analysis of Passage at Bedrock Sheets in Newell Creek Using Powers and Orsborn

Two bedrock sheets that are passage obstacles upstream of Rancho Rio Bridge in Newell Creek were more complex than the critical riffles and were assessed using methods described by Powers and Orsborn (1985). Both obstacles were analyzed as chutes, using the Powers and Orsborn terminology, since they were relatively uniform in cross-section with steep but relatively constant slope. These bedrock sheets present an obstacle to migrating salmonids due to the very shallow depth of flow and high flow velocity. Both had shallow entrances (downstream end) and negative exit slopes (the bed slope at the top of the chute is downward in the upstream direction). The shallow depth at the base of the chute precludes steelhead from jumping so, in order to pass the obstacle, they must swim up it. At each site a bed cross-section and profile were surveyed. Water surface and spot velocity measurements were made at different flow levels. Water velocity and depth were calculated for a range of flow conditions using the Manning's Equation. The Manning's Equation predicts mean velocity from wetted width, cross-sectional area, bed slope, and an empirical roughness coefficient (the Manning's coefficient). Cross-sections were also placed through the hydraulic control below each chute and a stage/discharge relationship developed at each control to determine the water surface elevation below each chute for given flows. This affects the length of the chute that must be negotiated by a migrating fish.

For each cross-section, the stage allowing passage was calculated for a range of depth criteria between 0.3 and 0.6 feet. This part of the analysis used criteria as described previously for evaluation of critical riffles (i.e., the criteria depth is achieved across 25% of the wetted channel width and at least a contiguous portion equaling 10% of the wetted channel width). Because the Manning's Equation is sensitive to the choice of roughness coefficient, minimum and maximum velocity (and corresponding flow estimates) were calculated. For this analysis we used Manning's coefficient values of 0.025 and 0.040 as minimum and maximum values consistent with smooth rock substrate.

The analysis assumes that adult steelhead require a depth of flow at least equal to their body depth in order for the fish to make full use of its propulsive power. Steelhead body depth was assumed to be between 0.4 and 0.6 feet. Steelhead are assumed to have burst speeds of 13.7 to 26.5 feet per second (fps) and coho are assumed to have burst speeds of 10.6 to 21.5 fps (Powers and Orsborn 1985). It is assumed that burst speed can be maintained for an estimated 5 to 10 seconds (Powers and Orsborn 1985). Maximum speed for passing an obstacle was assumed to be a percentage of burst speed depending on fish condition. Condition coefficients were 100% for fish fresh out of salt water or still a long way from spawning areas, 75% for fish in the river a short time and still migrating upstream (good condition), and 50% for fish in the river a long time and close to the spawning grounds (poor condition) after Powers and Orsborn (1985). The distance from the mouth of the San Lorenzo River to Newell Creek is relatively short (about 14 miles) and migrating steelhead or coho should be able to reach the barrier location within a few days of entering freshwater. Therefore, fish would be assumed to be in relatively good condition and a condition coefficient of 75% to 100% would be appropriate.

The distance a fish can swim at an obstacle is computed as:

$$LFS = ((VF*c) - VW) * TF \qquad 1)$$

where LFS is the length a fish can swim, VF is the fish swimming velocity, c is the coefficient of condition, VW is the water velocity, and TF is the time to fatigue.

For short chutes velocity may be determined by the equation:

$$V_{SC} = (2gH)^{0.5} \qquad 2)$$

where V_{SC} is the velocity down a short chute, g is the acceleration due to gravity (32.2 fps^2), and H is the total vertical drop between two pools (Powers and Orsborn 1985).

Formulas 1 and 2 were used with the preceding assumptions to estimate the length a fish can swim and the velocity of water through the chute at a flow meeting the passage depth criteria. If the length a fish could swim is greater than the length of the chute and if the velocity is less than the fish's burst swimming speed over that distance, then the chute is passable at that flow. An upper level of flow beyond which passage is not possible can also be calculated as the flow at which LFS becomes less than the chute length.

3.1.4. Analysis of Passage in the San Lorenzo River downstream of the Felton Diversion Using the R2 Method

PHABSIM studies were not conducted in the San Lorenzo River between the Felton Diversion and Tait Diversion as part of the ASHCP since operation of the City's diversion was subject to a previous agreement with CDFW (CDFW 1998) and evaluation of the effects of water rights changes indicated little effect on flows (ENTRIX 2006). As development of the ASHCP progressed and as the need for facilities improvements and water rights changes to meet supply under agreed bypass flows became better developed, the ASHCP technical team identified the need for increased focus on effects of Felton operations on streamflow and instream habitat resulting from increased use of the facility. In late 2016 the ASHCP technical team decided to evaluate adult passage requirements in this reach via a desktop method utilized by CDFW (the R2 method, developed by R2 Resource Consultants) and to correlate it with other adult passage sites where physical datum is available to evaluate comparability instead of initiating new instream flow studies (Berry 2016). Further, it was agreed that adult migration is usually the life stage requiring the most flow, so other life stages would be protected as well (Berry 2016).

The R2 assessment was developed to provide an estimate of bypass flow that would be protective of anadromous salmonid spawning habitat and upstream passage in as many streams as possible based on measures of channel size expressed in terms of drainage area and mean annual flow (R2 Resource Consultants 2008). The analysis used the following formula provided by CDFW (Gray 2016).

$$Q_{fp} = 19.3\ Q_m\ D_{min}^{2.1}\ DA^{-0.72} \qquad 3)$$

where Q_{fp} is the minimum fish passage flow (cfs), Q_m is mean annual flow (cfs), D_{min} is minimum passage depth criterion (feet), and DA is drainage area (square miles).

Results of the R2 analysis were also compared to a critical passage study in the San Lorenzo River gorge using the Powers and Orsborn methodology, surveys at other sites using the Thompson method, observations of movement of large juvenile steelhead in the San Lorenzo River, and estimates of passage flow requirements by local fishery biologists in the San Lorenzo Watershed Management Plan (Berry 2016).

3.1.5. Analysis of Effects of the Project on Water Temperature

Steelhead are generally expected to survive and grow well at temperatures up to about 19°C to 21°C if food is abundant. Temperatures of 19°C or less is considered optimal under most conditions (Bidgood and Berst 1969, Hokanson et al. 1977, Smith and Li 1983, Armour 1991, see also HES 2014 for a summary of these findings). Steelhead may actually grow faster at higher temperatures if food is abundant (Smith and Li 1983) but at temperatures in excess of 21°C, increased mortality may offset the benefits of increased growth rates at the population level Hokanson *et al.* 1977 (see HES 2014 for discussion of temperature suitability). Temperatures of 25°C to 26°C are generally considered lethal (Bidgood and Berst 1969, Hokanson *et al.* 1977).

The north coast streams (Liddell, Laguna, and Majors Creeks) have water temperature conditions which are relatively cool due to marine influence and relatively dense, intact riparian canopies (City of Santa Cruz 2021). Temperature monitoring data collected by the City indicate temperature conditions in these streams are within the range of tolerance for both steelhead and coho rearing juveniles and near optimal in many cases (City of Santa Cruz 2021). The City diversions on the North Coast do not create conditions that influence water temperature (i.e. large storage facilities, removal of riparian shading vegetation, or alteration of subsurface flows).

The San Lorenzo River and its tributaries extend further inland than the North Coast streams and water temperature is warmer. Water temperature is suitable for steelhead at all monitoring locations but increases with distance downstream from Newell Creek and is near the upper range of suitability during the seasonal thermal maximum period and in the lower San Lorenzo River from above Tait Street Diversion to the lagoon (City of Santa Cruz, in preparation). Coho require cooler temperature than steelhead, and temperature is relatively warm for coho except in the tributaries and upper mainstem and in Newell Creek downstream of Loch Lomond Reservoir (City of Santa Cruz, in preparation). Coho do not presently maintain viable populations in the San Lorenzo River and its tributaries where the City has its water supply operations.

The existing required release of 1 cfs from Newell Creek Dam is from the lower levels of the Loch Lomond Reservoir and is colder than ambient stream temperatures during the summer and warmer than ambient during the winter. The fish release is typically between 11°C and 14°C. As a result, temperature in Lower Newell Creek below the dam is warmer than Upper Newell Creek, above the dam, during winter and spring and cooler in the summer by up to 4°C on average (City of Santa Cruz 2021). Warmer water in winter and spring can enhance salmonid growth rates if food resources are sufficient. The cooling influence in summer may maintain temperature in a more suitable range during excessively warm conditions but may depress growth rates at other times. The effect would be strongest closest to the dam since there is equilibration with environmental conditions with distance downstream (e.g. air temperature, insolation, subsurface flows). The cooling influence in summer can extend downstream as far as the San Lorenzo River and at these times the flow from Newell Creek can reduce temperature in the main stem .by about 1°C (City of Santa Cruz 2021, HES 2014b).

Operation of the reservoir (required 1 cfs release and reservoir spill) is the only City activity associated with the Proposed Project that has the potential to influence water temperature. The effect of the 1 cfs release is generally beneficial, particularly during the late summer and during dry years, when stream temperature is highest and may limit habitat suitability for steelhead, and particularly for coho.

During periods when the reservoir spills, water from the surface of the reservoir mixes with the fish release downstream of the dam. Since spill is from the reservoir surface, it can be warmer than the fish release during the warmer parts of the year. However, the majority of spill occurs during or after precipitation events in the winter when Loch Lomond temperature is cool. The period when temperature effects are most likely is during the spring and early summer (May through July) when the lake surface is warming and there is still a potential for spill, at least in wetter years when storage is high.

Temperature monitoring data collected by the City indicate that surface water temperatures in Loch Lomond Reservoir closest to the spillway can reach levels that are potentially harmful to steelhead and coho. Sub-optimal temperatures (21°C or greater) have occurred 98% of the time in July, 85% of the time in June, 19% of the time in May, and only 1% of the time in April (Figure 1). Surface temperatures in the City monitoring data have never been recorded above 18.3°C in March. Potentially lethal levels have also been recorded (25°C or higher) in June and July, although the frequency of such occurrence is low in June (less than 1% of readings)[3]. Frequency of reservoir surface temperature of 25°C or higher in July has been observed 11% of the time. These data may slightly underestimate the frequency of temperature in the unsuitable range since it is generally recorded mid-morning while peak temperature usually occurs in the mid to late afternoon.

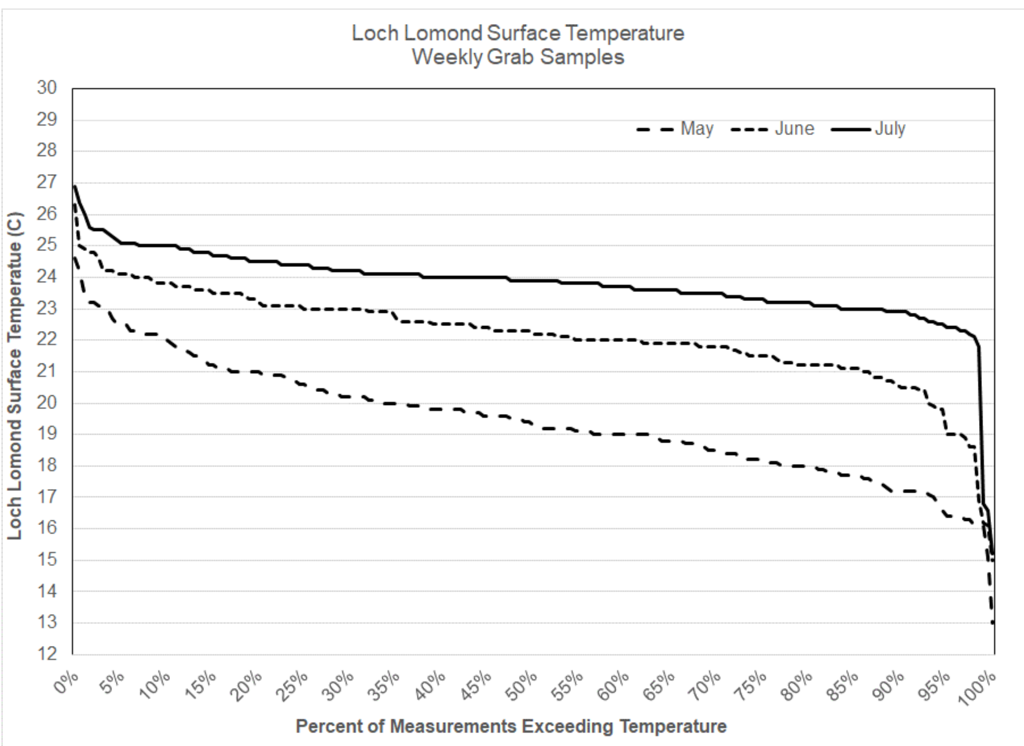


Figure 1. Loch Lomond Surface Temperature Measured by Weekly Grab Sample from 1987 to 2020.

[3] Data are in the form of surface grab samples measured once per week, usually mid-morning, collected since 1987.

The effect of warm reservoir spills is moderated by the frequency, volume, and timing of spill; possible additional warming (during the day) or cooling (at night) as water flows down the spillway; and mixing with the cooler water from the fish release below the dam. Data collected by the City were evaluated to better understand the potential and magnitude of this effect. At times when the spill is warmest later in the spring, the amount of spill tends to be declining under both the Baseline and the Proposed Project and it is diluted to a greater degree by the colder fish release. Daily spill volumes estimated by the Confluence model for the Proposed Project using the historical hydrological record (1937-2015) indicate that spill would occur about 58% of the time in May, 27% of the time in June, and 3% of the time in July (Figure 2). Maximum spill amounts would be 77 cfs in May, 19 cfs in June, and 2.5 cfs in July. The model results predict two days in August during the entire record when spill would occur and a maximum spill of 0.20 cfs. No spill was predicted to occur in September, or October. The highest spill amount for May is a result of data from 1983, which was a very wet year, the second wettest in the hydrologic record. The reservoir was spilling continuously from mid-November 1982 and storms in late April resulted in increased spill through early May of up to 77 cfs. Spill declined to 15 cfs by mid-May and continued dropping until it ceased on August 2. It is likely that reservoir temperature was moderated during this period by cool air temperature and overcast conditions typical during storm passage. Late season storms, such as occurred in 1957, 1996, 1998, 1995, and 1941, were responsible for the majority of high spill events in May that are evident in the Confluence model results. Similar to the 1983 data, these events are likely associated with relatively cool reservoir temperatures. Absent late season storms in May, spill amount is rarely in excess of 16 cfs.

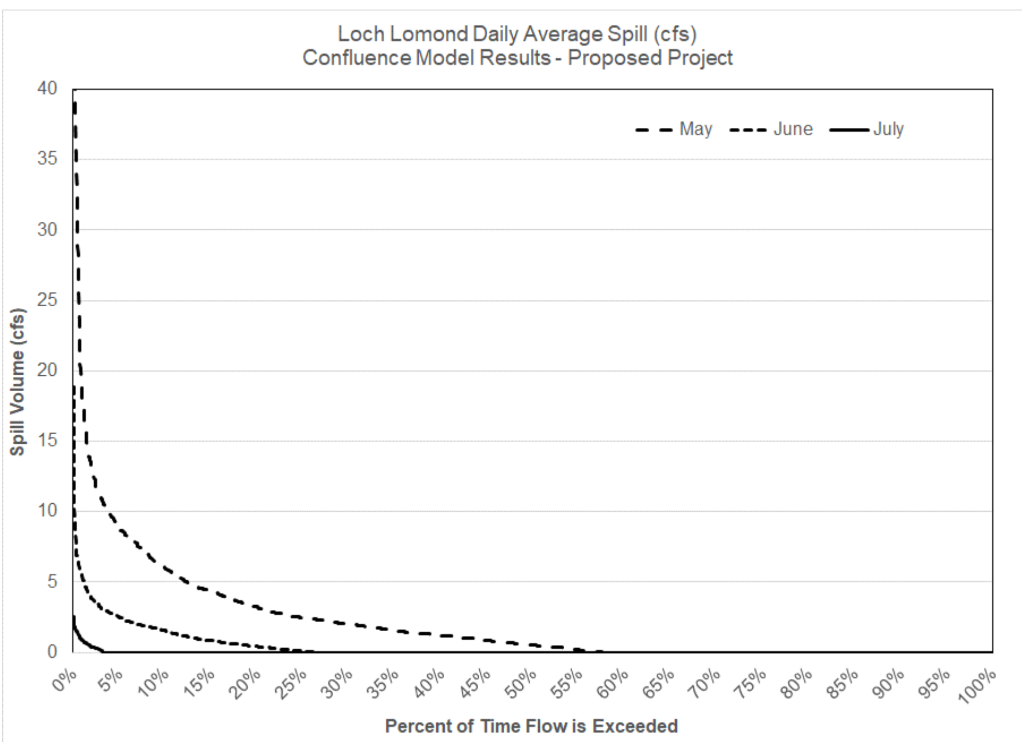


Figure 2. Loch Lomond Daily Average Spill from Confluence Model Results for the Proposed Project.

The effect of warm spill from the reservoir is offset by cold water released through the fish release. In May, the warmest surface temperature in the City database is 24.6°C. If 16 cfs is flowing over the spillway at that temperature, a simple mass/energy balance would predict that the resulting flow in Newell Creek downstream of the spillway would be 23.9°C after mixing with a flow of 1 cfs from the fish release at 12°C. Increasing the fish release to 6.5 cfs would result in a temperature of 21°C. An upgrade to the Newell Creek Dam outlet structure, currently under construction, will allow for significantly higher releases. During June, the Confluence model predicts much lower spill levels. The highest spill amount for June was modeled at 19 cfs but this was the result of a late season storm in the historic hydrologic record for 2011 representing a single day of the record. In all other model years, predicted spill in June was 10 cfs or less and only exceeded 5 cfs about 1% of the time. The amount of cold release to cool this level of spill to 21°C or less (~3 cfs), is well within the capacity of the fish release, even at the maximum observed June reservoir surface temperature of 26.3°C. For July, the maximum spill in the model results is 2.5 cfs but the maximum temperature in the City monitoring data is 26.9°C. Under these conditions a flow of 2 cfs through the fish release at 12°C would be sufficient to lower the resulting temperature to less than 21°C.

Limited temperature data available in Newell Creek downstream of the dam suggests that the effect of the spill on water temperature below the dam can be substantial but appears not to exceed suitable levels for rearing steelhead or coho under the Baseline. During 2019, the reservoir was spilling for most of the period from early February through late June. Maximum water temperature recorded below the dam[4] in April was 20.3°C when the reservoir was spilling at approximately 5 cfs or less. The average daily temperature below the dam, however, was never higher than 18.1°C in April. The reservoir was spilling at no more than 2 cfs in June 2019 and maximum recorded water temperature downstream reached 19.1°C. Average daily temperatures were below 17°C during June and declined to less than 12°C by the time spill ceased near the end of the month.

Temperature increases due to spill are likely to influence temperature conditions in the San Lorenzo River downstream of Newell Creek. There is a limited amount of temperature data for the San Lorenzo River at the Newell Creek confluence (Figure 3). These data indicate that water temperature approaches 20°C during peak summer warming and that Newell Creek appears to have a slight cooling influence during the summer (1°C or less) and a very slight warming influence in winter. The only datapoint potentially influenced by spill is May 9, 2019. Streamgage and reservoir elevation data indicate that the reservoir was spilling at a low volume (1 cfs or less) and temperature data records for Newell Creek below the dam show a value of 14 to 14.1°C bracketing the time temperatures were recorded in the San Lorenzo River. This is consistent with the observation of 13.3°C upstream of the Newell/San Lorenzo confluence and 13.5°C downstream of the confluence. Maintaining water temperature of 21°C or less below Newell Creek dam during periods of spill should also minimize any thermal effects in the San Lorenzo River.

Increased frequency of spill in April and May with associated warmer temperatures may actually be beneficial for rearing steelhead (and coho if present) as long as the temperature is still within the suitable range. Salmonids grow faster at warmer temperatures within the suitable range with adequate food supply. Increased spill in June may also be beneficial as long as it does not result in temperature above the suitable level.

[4] Temperature, reflecting both the fish release and reservoir spill, is continuously recorded by the City at the stream gage downstream of the dam at a 15-minute recording interval. Data has been collected since July 2017.

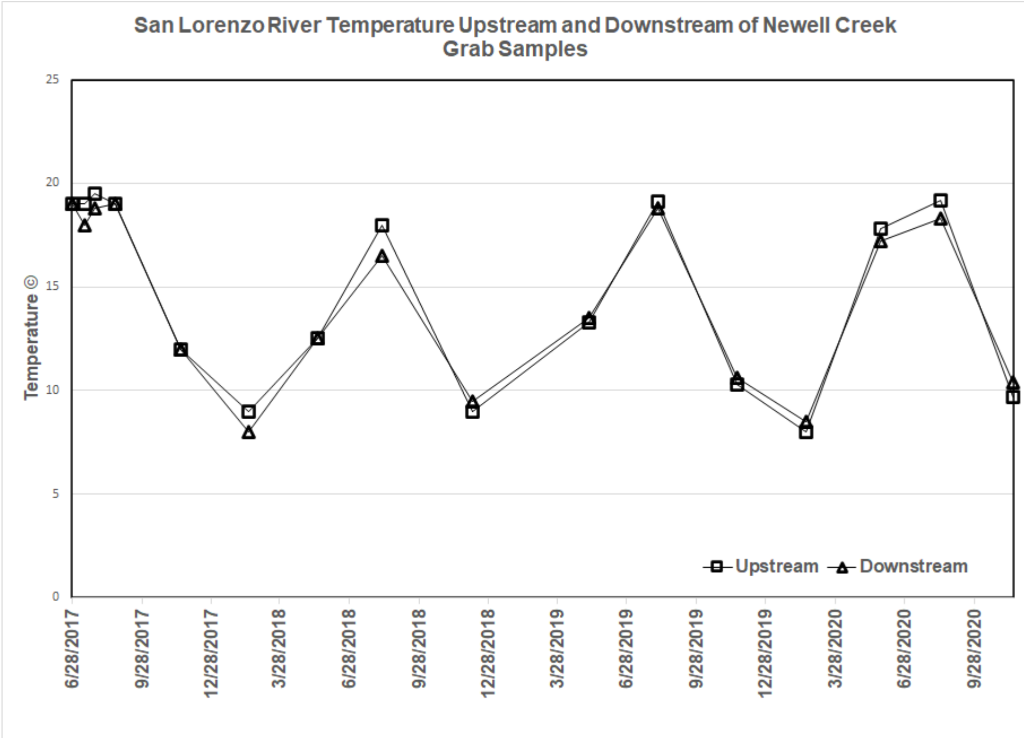


Figure 3. San Lorenzo River Temperature Upstream and Downstream of Newell Creek, 2017-2020.

3.2. Analytical Framework, Model Structure, and Biological Parameters

The methodology takes its structure from the salmonid life cycle and is focused on quantifiable relationships between important aspects of the life cycle that are influenced by streamflow. The habitat models address the effect of flow modification on four key life-history elements: migration of adults from river mouth to upstream spawning areas; deposition and incubation of eggs in the streambed; rearing of juveniles to smolt stage; and downstream migration of smolts to the stream mouth. These elements were selected because they represent key aspects of the species' life history that are potentially influenced by alteration of streamflows by the City. The development of models for each of these four key elements is summarized below and is more fully described in HES (2014).

Adult Migration

The relationship between flow and passage criteria (depth) was evaluated in the stream reaches below five of the City diversions (Liddell, Laguna, Majors, Tait Diversion, and Newell Creek downstream of Newell Creek Dam) by application of the results of the critical riffle analysis. Thresholds for adult migration passage are presented in Table 1.

A different method was used to evaluate adult migration through the San Lorenzo River between the Felton Diversion and the Tait Diversion. As described previously, adult passage requirements in this reach were analyzed using a desktop method provided by CDFW (R2) and correlation with other adult passage sites where physical data were available. This method generates a single value for minimum flow meeting migration requirements downstream of the Felton Diversion (Table 1).

Table 1: Parameter values (flow in cfs) and timing used in effects analysis.

Location	Adult Migration Threshold (Min-Max Flow in cfs)	Spawning	Incubation (Minimum Flow in cfs)	Rearing	Smolt Migration Threshold (Minimum Flow in cfs)
	Timing				
	Dec-Mar/Apr	Dec-May	Jan-May	All	Jan-May
Laguna Creek	10.6-15.5	Fig. 1a	4.0	Fig. 2a	3.8
Liddell Creek	4.9-11.3	Fig. 1b	2.0	Fig. 2b	2.0
Majors Creek	9.0-16.0	Fig. 1c	2.9	Fig. 2c	3.4
San Lorenzo R. @ Tait	17.0-25.2	NA[3]	NA[5]	Fig. 2d	10.0
San Lorenzo R.@ Felton	40.0	Fig. 1d	20.0	Fig. 2e	20.0
Newell Creek	11.4-24.4	Fig. 1e	1.0	Fig. 2f	8.3

Spawning and Incubation

The relationship between flow and spawning habitat quality was assessed in the anadromous reaches of study streams by collecting data to calibrate a PHABSIM model. Salmonid spawning habitat is well-modeled with PHABSIM since salmonids have quite specific preferences for type of substrate, water depth, and flow velocity and tend to select locations that have hydraulic features that are relatively easy to model. Spawning habitat value is expressed in units of WUA per unit length of stream which accounts for both the areal extent and suitability of habitat. The analysis generates a curve of WUA vs. discharge (flow) that, in general, has zero value at low levels of discharge, rises to an optimum level at some intermediate flow, and decreases at higher flows (Figure 4).

Juvenile Rearing

The relationship between flow and rearing habitat quality was described in study streams through application of the PHABSIM model. Diversions throughout the year have the potential to alter habitat conditions for rearing salmonids in the study streams. The suitability of rearing habitat, as with spawning habitat, is expressed as WUA per unit length of stream (Figure 5). Curves of rearing WUA vs. discharge in this application of the model were more variable than the spawning curves. For steelhead the curves show an increase in habitat suitability from low values at lower flows, an increase to higher levels as flows increase and a gradual flattening of the curve (Figure 5). For coho the curves are relatively flat with higher values at minimum flows than steelhead, a low peak at lower discharge than steelhead, and a gradual decline at higher discharge levels.

[5] No spawning occurs in this reach.

Smolt migration

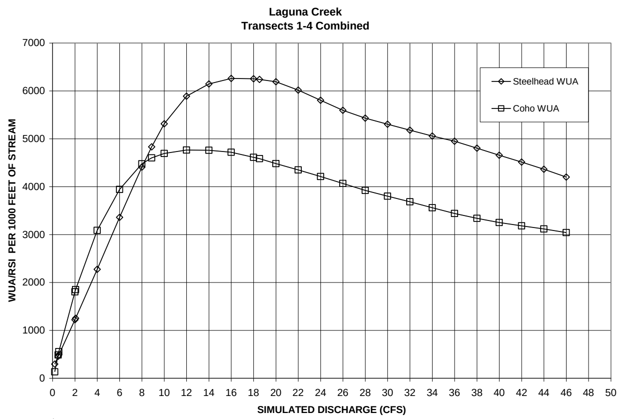
Diversion during the spring, particularly during April and May, may potentially reduce passage opportunities for steelhead and coho smolts at critical passage locations in the anadromous reaches of streams. The relationship between flow and passage criteria (depth) was evaluated in the anadromous reaches of study streams by application of the critical riffle analysis using the same sites, channel data, and hydraulic data as for adult passage; only the depth criteria were altered for evaluation of smolt passage. Thresholds for smolt migration determined by this method are shown in Table 1.

Use of Habitat Models to Evaluate Project Alternatives

Evaluation of project alternatives involves linkage of the hydrologic database, the Confluence operations model, and a suite of habitat models. Using a schedule of bypass flows developed in the ASHCP process that are considered protective of anadromous salmonids (the Agreed Flows) (see Chapter 3 and Appendix C of the EIR for the Proposed Project), the hydrologic record is conditioned by reserving the Agreed Flows and calculating the amount of flow available for diversion on a daily basis (the *available flows*). The Confluence model then uses the *available flows* as input to determine daily diversions from each source (see Appendix D-2). Depending on supply needs, the Confluence model may divert the entire amount or some portion of the *available flows*. The Confluence model output includes the amount of flow left in the stream after diversion for City supply. These are the *residual flows*. The *residual flow* is either the Agreed Flow for that time period, the Agreed Flow plus whatever amount is not needed for City supply, or the natural streamflow if the *available flow* is zero and diversion is precluded. The habitat models use the residual flows rather than the Agreed Flow as the basis for effects analysis since this is what would actually be in the stream and often reflects flows that are in excess of City supply needs, particularly during winter high flow periods and during wetter years.

The habitat models are constructed as linked spreadsheets for each of the six diversion points. Each spreadsheet takes input as daily time-series for up to six flow scenarios. Flow scenarios are the residual flows output from the Confluence model (see Appendix D-2). Each flow scenario has a series of habitat values calculated for each relevant life-stage in each reach. Daily values of migration potential for adults or smolts are calculated based on parameter values in Table 1 as a binary parameter (1 for suitable or 0 for not suitable). WUA for spawning and/or rearing are calculated on a daily timestep with reference to WUA vs. discharge curves (Figures 4 and 5). Figure 4 shows how spawning habitat changes with flow in each of the stream reaches affected by City diversions. As flow (discharge, x-axis) increases, habitat value for spawning (WUA, y-axis) increases rapidly from very low levels at zero flow to a peak and then declines more gradually at higher flows. For example, in Laguna Creek the spawning habitat index peaks at a flow of about 16 cfs for steelhead and about 12 cfs for coho (Figure 4a). Figure 5 shows how rearing habitat changes with flow. In general, the rearing habitat index for steelhead increases from low levels at zero flow and then increases more slowly, remains constant, or declines slightly at higher flows, depending on the stream reach. For coho, the rearing habitat index is higher at zero flow[6], reaches a peak at relatively low flows and declines at higher flows (Figures 5a and 5f). The daily flow from the Confluence model output of residual flows at each diversion point determines the habitat index value for each life stage. The habitat index may be either the WUA value for spawning or rearing or the number of days with suitable conditions for migration of adult or smolt life stages. Index values for each flow scenario are summarized (averages or counts) and tabulated and graphed.

[6] Juvenile coho prefer lower velocities such as occur in pools. Suitable habitat can occur in residual pools with little or no surface flow.



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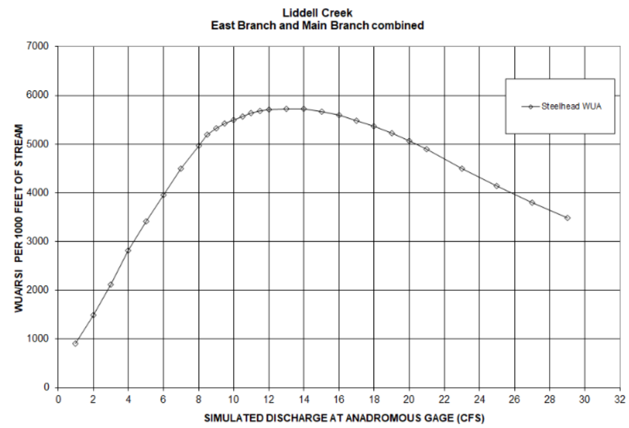

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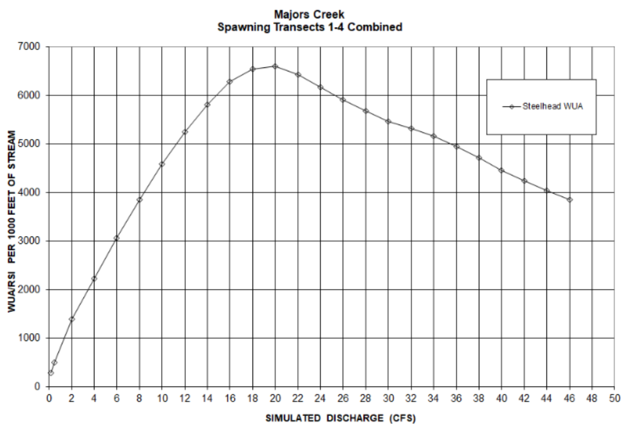

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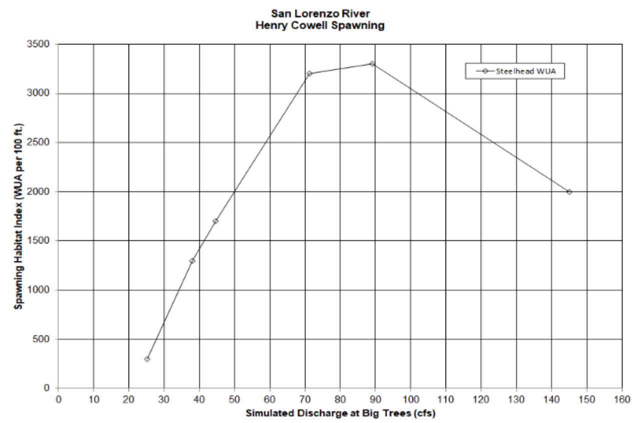

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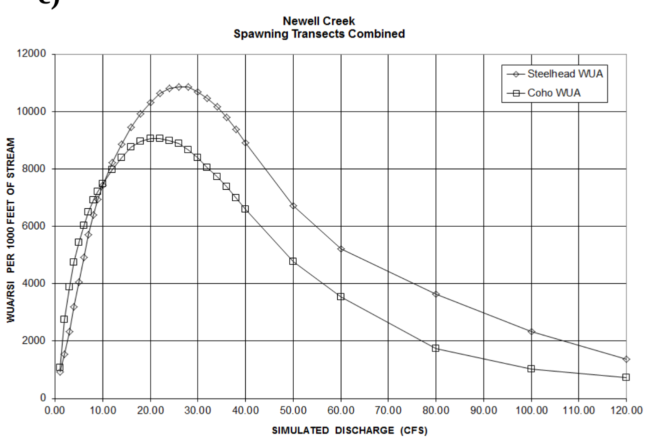

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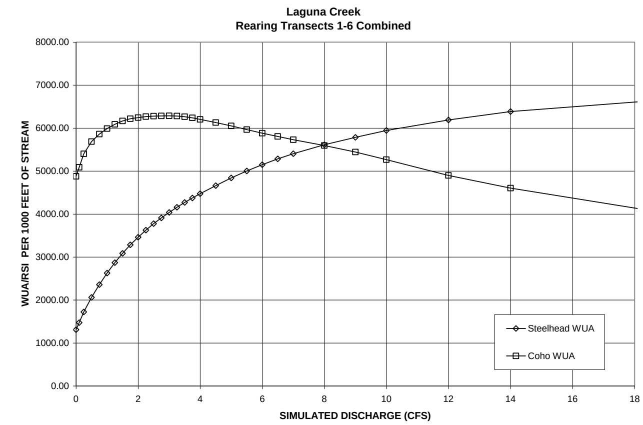
Figure 4. Spawning Habitat Suitability vs. Flow Functions for Steelhead and Coho Used in Effects Analyses



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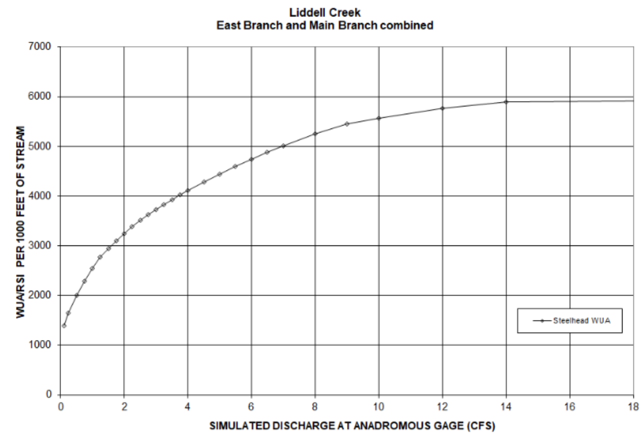

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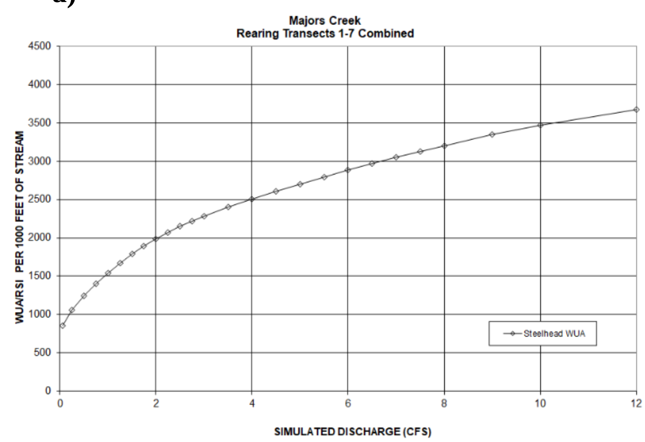

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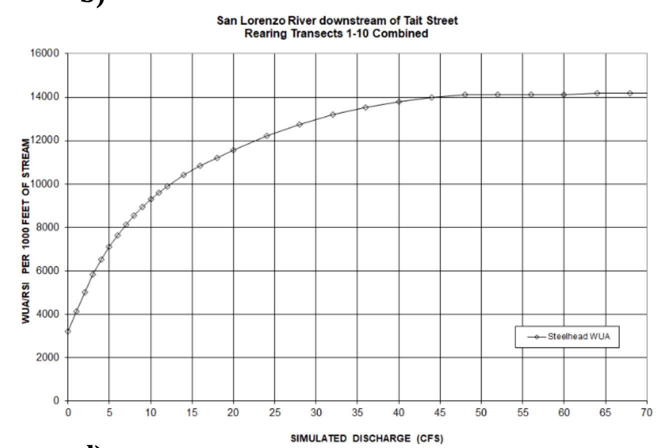

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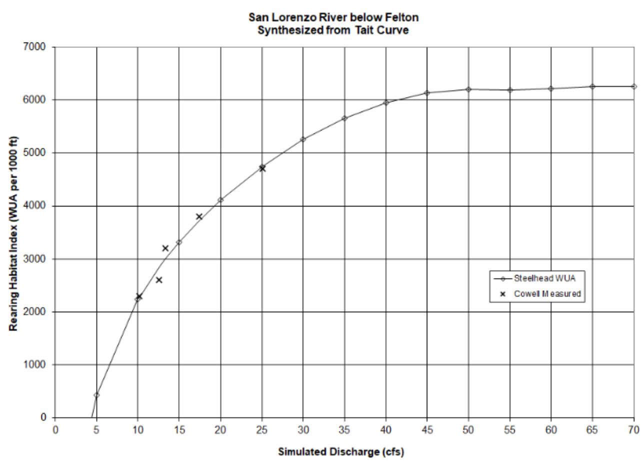

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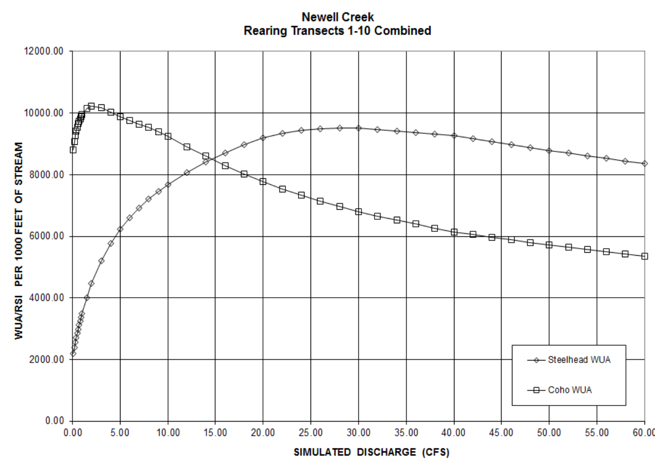

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Figure 5. Rearing Habitat Suitability vs. Flow Functions for Steelhead and Coho used in Effects Analyses

4. Scenarios and Summary of Model Results

4.1. Scenarios Evaluated

The following scenarios have been examined:

- **Baseline:** Conditions at the time the City released the Notice of Preparation (NOP) for the EIR (2018). The minimum bypass flows for the Baseline reflect the 2018 interim bypass flow requirements[7].
- **Proposed Project:** All water rights modifications, including addition of Agreed Flows as the minimum bypass flows, and water supply augmentation components of the Proposed Project.
- **Alternative 1:** Agreed Flows only without other Proposed Project components.
- **Alternative 2:** Agreed Flows with all Proposed Project components except there is no place of use expansion, which means that there are no water transfers to neighboring agencies, and that aquifer storage and recovery (ASR) is possible only within the areas served by the City.
- **Alternative 3:** Agreed Flows with all Proposed Project components except ASR.

These scenarios are described in the Overview of Appendix D and are evaluated in the following sections. Each scenario was evaluated with historical hydrology. The Proposed Project was also evaluated with climate change hydrology, based on the CMIP-5 MOD climate model (see Appendix D-1). The HCP Base Hydrology developed by Balance Hydrologics uses a combination of measured and modeled mean daily streamflows to represent historical hydrologic conditions of the region from 1936-2015, as referenced above. The results for the historical hydrology are presented by water year type with individual model years assigned to year types based on total annual flow in the San Lorenzo River at Big Trees (see Appendix C).

4.2. CEQA Standards of Significance

Model results for each scenario are presented in the following sections together with identification of significant effects. The standards of significance used to evaluate the impacts of the Proposed Project related to fisheries are based on Appendix G of the CEQA Guidelines, as listed below. A significant impact would occur if the Proposed Project would:

[7] The interim bypass flow requirements are those flow requirements agreed to by CDFW and the City as part of an April 2018 agreement between CDFW and the City (see Appendix C). The City and CDFW have had numerous such agreements since 2007 during development of the ASHCP.

a) Have a substantial adverse effect, either directly or through habitat modifications, on any species identified as a candidate, sensitive, or special status species in local or regional plans, policies, or regulations, or by the California Department of Fish and Game or U.S. Fish and Wildlife Service

b) Have a substantial adverse effect on any riparian habitat or other sensitive natural community identified in local or regional plans, policies, regulations or by the California Department of Fish and Game or US Fish and Wildlife Service

c) Have a substantial adverse effect on federally protected wetlands as defined by Section 404 of the Clean Water Act (including, but not limited to, marsh, vernal pool, coastal, etc.) through direct removal, filling, hydrological interruption, or other means

d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites

e) Conflict with any local policies or ordinances protecting biological resources, such as a tree preservation policy or ordinance

f) Conflict with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved local, regional, or state habitat conservation plan

Additionally, CEQA sets forth mandatory findings of significance related to degradation of biological resources. Therefore, a significant impact to biological resources related to these mandatory findings would occur if the Proposed Project would:

g) Substantially reduce the habitat of a fish or wildlife species.

h) Cause a fish or wildlife population to drop below self-sustaining levels.

i) Threaten to eliminate a plant or animal community, or

j) Substantially reduce the number or restrict the range of a rare or endangered plant or animal.

The standards that apply to fisheries impacts of the Proposed Project related to project operations are standards of significance (a), (d), (g), (h), (i), and (j), which are the focus of the impact analysis included herein. Other standards of significance are evaluated in the EIR.

4.3. Baseline

The Baseline represents City water supply operations and environmental bypass flows that were in place at the time the City issued the Notice of Preparation (NOP) for the EIR in 2018. Bypass flows under the Baseline were defined by the interim bypass flow agreement between the City and CDFW (see Appendix C). The Proposed Project and each alternative are evaluated relative to the Baseline.

4.4. Proposed Project

The modeling for the Proposed Project includes implementation of the Agreed Flows and other water rights changes, all infrastructure components of the Proposed Project (i.e., ASR, water transfers and associated intertie improvements, and diversion improvements), and other planned infrastructure upgrades that are not part of the Proposed Project but would be a component of the future conditions that would exist with the Proposed Project (see Appendix D Overview). The Agreed Flows included in the Proposed Project were defined by the flows agreed to by the City, NMFS, and CDFW, as reflected in the City's pending ASHCP (see Appendix C). With respect to changes in habitat for anadromous species, the major difference between the Proposed Project and Baseline is the addition of adult migration flows in April and spawning flows in December in the North Coast streams with the Proposed Project; addition of adult migration flows in April in the San Lorenzo River below the Tait Diversion with the Proposed Project; and implementation of bypass flows for adult migration and spawning in the San Lorenzo River downstream of the Felton Diversion with the Project (Table 2). These provisions, which are not included in the interim bypass flows reflected in the Baseline, result in increases in habitat values in months with hydrologic conditions in the 0%-60% exceedance range,[8] which is generally in wetter year types, as described in Appendix C.

The Proposed Project also includes Standard Operational Practice #6 as follows:

6. At times when the Loch Lomond Reservoir is spilling during late spring and summer when surface temperatures in the reservoir are warmer and the cooler 1 cfs fish release below the dam (generally between 11°C and 14°C) may not be sufficient to maintain temperatures in Newell Creek below 21°C, which is within the suitable range for steelhead and coho, the City will release additional flow through the fish release to achieve a maximum instantaneous temperature of less than 21°C as measured in the anadromous reach of Newell Creek and verified at the City stream gage in Newell Creek below the dam.

[8] The Agreed Flows are specified on a month-by-month basis as determined by the hydrologic conditions for the water year to date. This approach tailors prescribed bypasses to the extreme range of seasonal and inter-annual flow variation (as described in Appendix C). These hydrologic conditions (HC) are based on the record of cumulative daily average flow by water year (October 1 - September 30) at the Big Trees gage on the San Lorenzo River (see Appendix C). The hydrologic condition types are developed by calculating the cumulative water-year flow for each month in the record (water-years 1936-2015) and sorting from lowest to highest. This record is split into five equal parts representing a range of hydrologic conditions from driest to wettest conditions (very dry, dry, normal, wet, and very wet as HC 5, 4, 3, 2, and 1, respectively). Hydrologic condition limits by month are shown in Appendix C. Operationally, the hydrologic condition is determined each month based on the cumulative water year flow at Big Trees gage for the preceding month.

Table 2: Comparison of Interim Bypass Flows and Agreed Flows.

Location/Life Stage	Interim Bypass Flows (Baseline)	Agreed Flows (Proposed Project and Alternatives)
Laguna Creek	No required adult migration bypass in April	Adult migration bypass required in April in 0-60% hydrologic exceedance conditions (HCs)
	No bypass for spawning in December	Bypass required for spawning in December
Liddell Creek	No required adult migration bypass in April	Adult migration bypass required in April in 0-60% HCs
	No bypass for spawning in December	Bypass for spawning required in December in 0-60% HCs
Majors Creek	No required adult migration bypass in April	Adult migration bypass required in April in 0-60% HCs
	No bypass for spawning in December	Bypass for spawning required in December in 0-60% HCs
San Lorenzo R @ Tait	No required adult migration bypass in April	Adult migration bypass required in April in 0-60% HCs
	Reduced rearing bypass flows to 3 cfs minimum in exceptionally dry years	8 cfs minimum bypass for rearing at all times
San Lorenzo R @ Felton	Minimum bypass 20 cfs Nov 1-May 31	Minimum bypass 20 cfs Nov 1-May 31 Minimum bypass for adult migration and spawning 40 cfs Dec-Apr when flow without diversion would occur at this level 40 cfs bypass for spawning for 14 days following potential migration event
	10 cfs September, 25 cfs October, No diversion July-Aug	10 cfs September, 25 cfs October, No diversion July-Aug
Newell Creek	1 cfs minimum bypass at all times	1 cfs minimum bypass, 0.25 cfs during low Loch Lomond Reservoir storage

4.4.1. Model Results – Proposed Project

Proposed Project with Historical Hydrology – Habitat Indices

Table 3 provides a summary of the habitat effects of the Proposed Project for steelhead and coho life stages in each of the stream reaches influenced by City diversions, using historical hydrology. Changes in habitat indices of less than 2% are well within the inherent statistical error in the habitat models and are not considered biologically significant or "substantial" under CEQA standards of significance. Changes greater than 2% may also be biologically insignificant or not significant under CEQA Standards but changes at this level are discussed in more detail. Conclusions of this analysis are described as follows.

The majority of effects of the Proposed Project involve an improvement in habitat conditions for steelhead and coho compared to the Baseline condition (Table 3). The only negative effect is a 2.7% decline in the rearing habitat index in wet years for coho in Laguna Creek (Table 3, Figure 12a). This decline is actually a result of higher flows in April provided for steelhead adult migration under the Proposed Project Agreed Flows. Coho rearing habitat is at optimum levels at lower flows than those provided for adult migration. Even with this effect, the wet year coho rearing index remains at 90% of the peak level in Laguna Creek (Figure 12a). This minor effect on rearing habitat is not likely to be biologically meaningful and would not be considered "substantial" under CEQA standards of significance or meet any of the thresholds for mandatory findings of significance under CEQA (Section 4.2). Specifically, a change of this magnitude in the rearing index would not substantially reduce the habitat of coho, interfere substantially with the movement or migration of coho, cause the coho population to drop below self-sustaining levels, threaten to eliminate coho in Laguna Creek or, substantially reduce the number or restrict the range of coho.

Habitat improvements for adult migration and spawning in normal and wet years in Laguna Creek and Liddell Creek (Table 3, Figures 6a, 7a, 6b, 7b) are consistent with the fact that bypass flows are provided for migration in April in 0-60% hydrologic exceedance conditions and for spawning in December under the Agreed Flows with the Proposed Project (see Appendix C), whereas they were not included in the interim bypass flow requirements in place in 2018 for the Baseline. Although April migration flows are also included in Majors Creek, we do not see the same benefits as in Laguna and Liddell Creeks. Winter diversions at Majors Creek are limited by pipeline capacity, particularly in wetter conditions, and are therefore not substantially different under the Baseline and Proposed Project.

Habitat indices are improved with the Proposed Project for adult migration and steelhead spawning in the San Lorenzo River downstream of the Felton Diversion, with the largest increases in dry and critical years (Table 3, Figures 6e, 7d, 10c). This is consistent with the ASHCP, which emphasizes improvements in Laguna Creek and the San Lorenzo River. It is a direct result of the 40 cfs bypass flow for adult migration and spawning provided in the Agreed Flows with the Proposed Project. The interim bypass flow requirements under the Baseline do not have this provision. Spawning suitability data for coho in the San Lorenzo River downstream of the Felton Diversion are not available but evaluation of change in flow shows a small increase (0.1%) or small decreases (-0.3% or less) during the coho spawning period, indicating that any effect on coho spawning would likely be insignificant.

Table 3: Habitat effects of the Proposed Project compared to Baseline Alternative as percent change from Baseline using historical hydrology.

Stream Reach		Steelhead: Adult migration (m)	Steelhead: Spawning/incubation (i)	Steelhead: Rearing (r)	Steelhead: Smolt migration (s)	Coho: Adult migration (cm)	Coho: Spawning/incubation (ci)	Coho: Rearing (cr)	Coho: Smolt migration (cs)
Laguna Anadromous	wet	8.5%	5.9%	o	o	o	+	-2.7%	o
	normal	o	3.3%	o	o	o	+	-	o
	dry	o	+	o	o	o	+	-	o
	critically dry	o	+	o	o	o	+	o	o
Liddell Anadromous	wet	4.1%	3.4%	o	o				
	normal	5.0%	3.4%	o	o				
	dry	o	-	-	o				
	critically dry	o	-	-	o				
Majors Anadromous	wet	o	+	o	o				
	normal	o	+	o	o				
	dry	o	-	-	o				
	critically dry	o	o	o	o				
San Lorenzo below Tait St	wet	o		-	o	o			o
	normal	o		-	o	o			o
	dry	o		-	o	o			o
	critically dry	o		-	o	o			o
San Lorenzo below Felton	wet	+	+	-	o	4.9%	-	-	o
	normal	+	+	-	o	4.6%	-	-	o
	dry	8.0%	2.6%	o	o	15.8%	***+***	***o***	o
	critically dry	22.0%	6.4%	o	o	15.3%	-	***o***	o
Newell Anadromous	wet	6.3%	4.5%	+	3.4%	15.9%	5.1%	-	3.4%
	normal	19.9%	10.1%	o	14.0%	19.8%	9.2%	-	14.0%
	dry	50.5%	27.1%	+	44.5%	o	29.6%	+	44.5%
	critically dry	o	26.3%	8.6%	o	o	50.0%	2.0%	o

"-" = <2% decrease in habitat index

"+" = <2% increase in habitat index

"o" = no change in habitat index, or change of 1 day or less in migration periods

Values for coho spawning and rearing below Felton (bold italic) based on change in flow rather than habitat indices

Differences in habitat index values in Newell Creek downstream of Newell Creek Dam/Loch Lomond Reservoir are the result of differing reservoir operations between the Baseline and Proposed Project. Bypass requirements for habitat are the same under the Baseline and Proposed Project in this location, but habitat provided by reservoir spill is altered by operation of the Proposed Project. Specifically, the increased capacity of the GHWTP, described in Appendix D-2, results in the ability to take more water at the Tait Diversion, offsetting water that would otherwise be withdrawn from Loch Lomond Reservoir. The effect is most pronounced in dry and critical year types, although, while the differences are large in percentage terms, they are not necessarily large in overall magnitude (Table 3, Figures 6f, 7e, 9f, 10d, 11c, 13d). For example, the 50.5% increase in the steelhead adult migration index in dry years amounts to only 3 additional days (from 7 days to 10 days) and therefore the improvement may not be biologically significant (Figure 6f). Habitat index values are low in dry and critical years even with no City diversion (i.e., Loch Lomond Reservoir operations and diversion not present, Figures 6f, 7e, 9f, 10d, 11c, 13d).

Proposed Project with Historical Hydrology – Water Temperature

The Proposed Project results in slightly higher reservoir elevations at Loch Lomond Reservoir and more frequent spill conditions. Hydrologic modeling indicates that the Proposed Project would result in increased spill mostly in the winter and spring and infrequently during the warmer months of July and August (less than 4% of the time) (see Draft EIR Chapter 8, Alternatives). Spill in June would occur 38% of the time with the Proposed Project compared to 19% under the Baseline. Increased spill during the winter could benefit steelhead and coho during the adult migration, spawning, and smolt migration life-stages. Increased frequency of spill in April and May with associated warmer temperatures may actually be beneficial for rearing steelhead (and coho if present) as long as the temperature is still within the suitable range. Salmonids grow faster at warmer temperatures within the suitable range with adequate food supply. Increased spill in June may also be beneficial as long as it does not result in temperature above the suitable level.

At times when the reservoir is spilling and the 1 cfs fish release is not sufficient to maintain temperature in Newell Creek below 21°C, Standard Operational Practice #6 requires the City to release additional flow through the fish release to achieve a maximum instantaneous temperature of less than 21°C as measured in the anadromous reach of Newell Creek and verified at the City stream gage in Newell Creek below the dam. With the implementation of this operational practice, potential adverse temperature effects in Newell Creek and the San Lorenzo River due to an increase in spill frequency with the Proposed Project would be avoided. Therefore, the Proposed Project would not substantially reduce the habitat of coho and steelhead, or otherwise substantially reduce the number or restrict the range of these species.

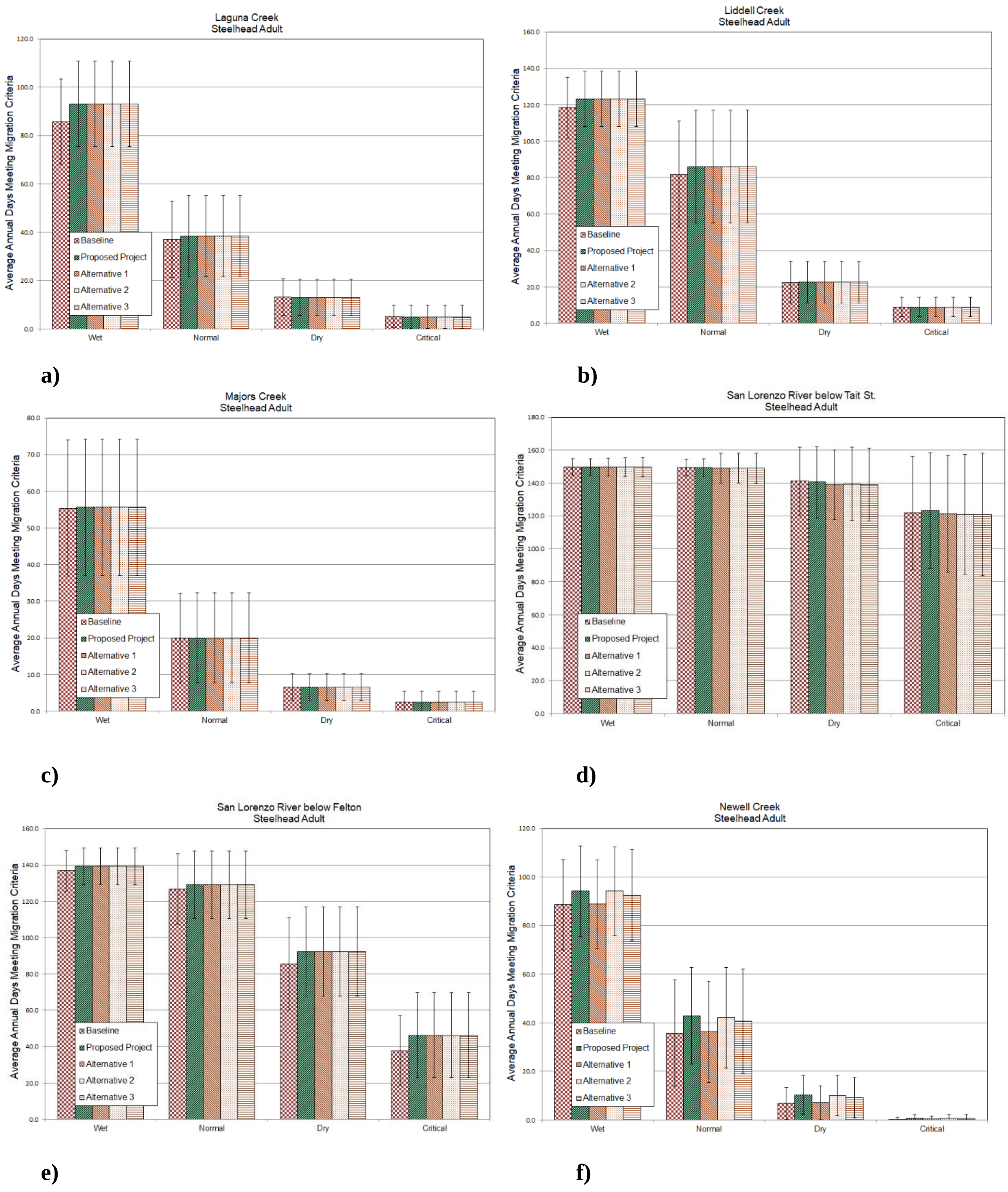
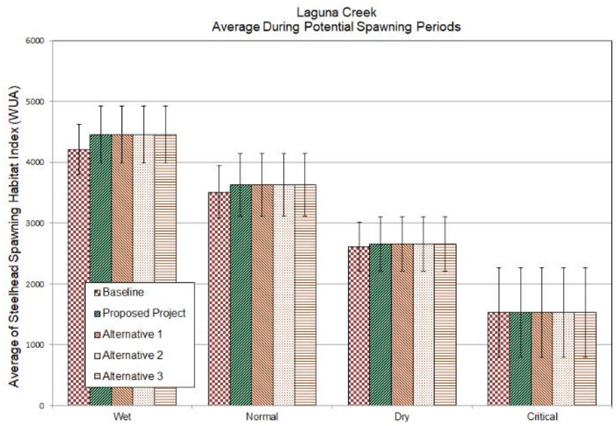


Figure 6: Modeled Adult Migration Index for Steelhead by Stream Reach with Historical Hydrology



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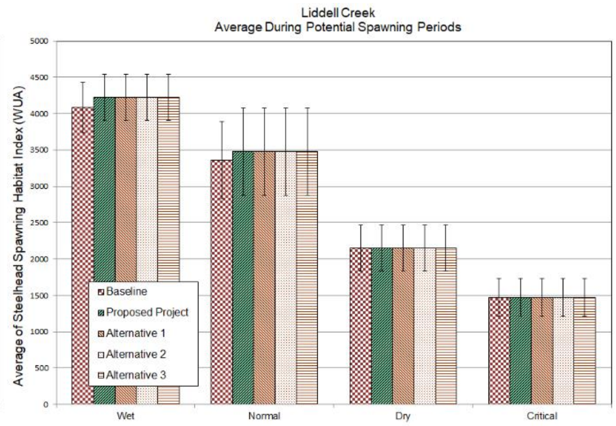

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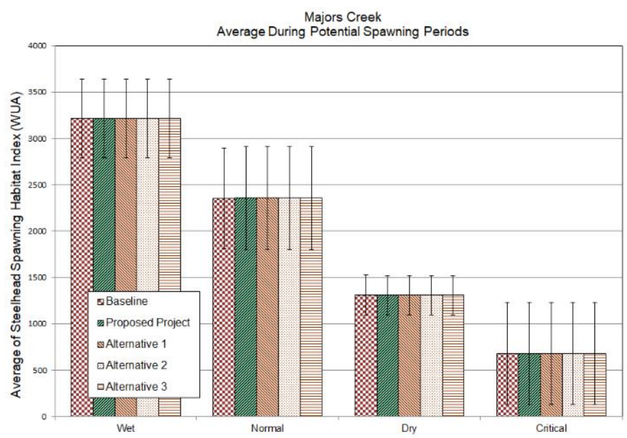

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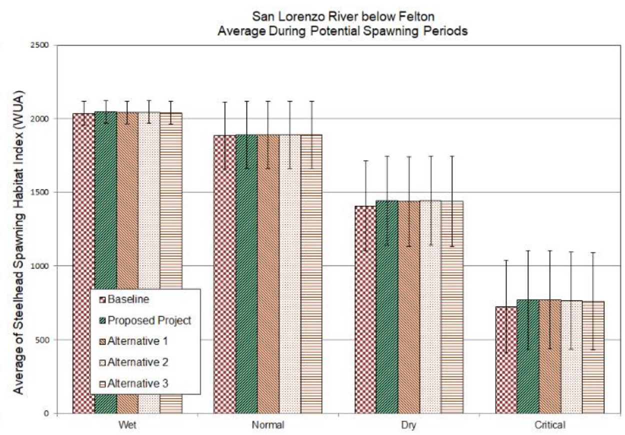

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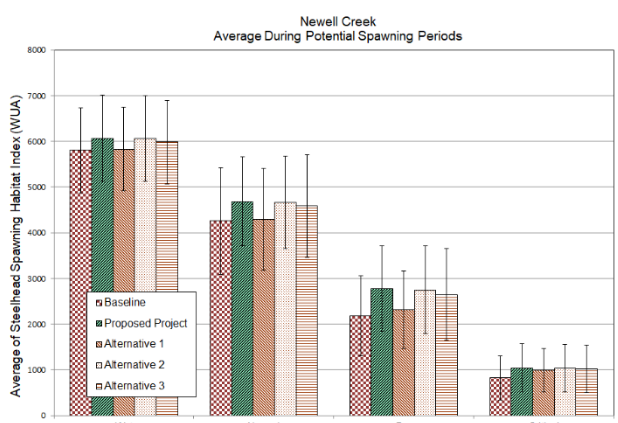

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Figure 7: Modeled Spawning Index for Steelhead by Stream Reach with Historical Hydrology

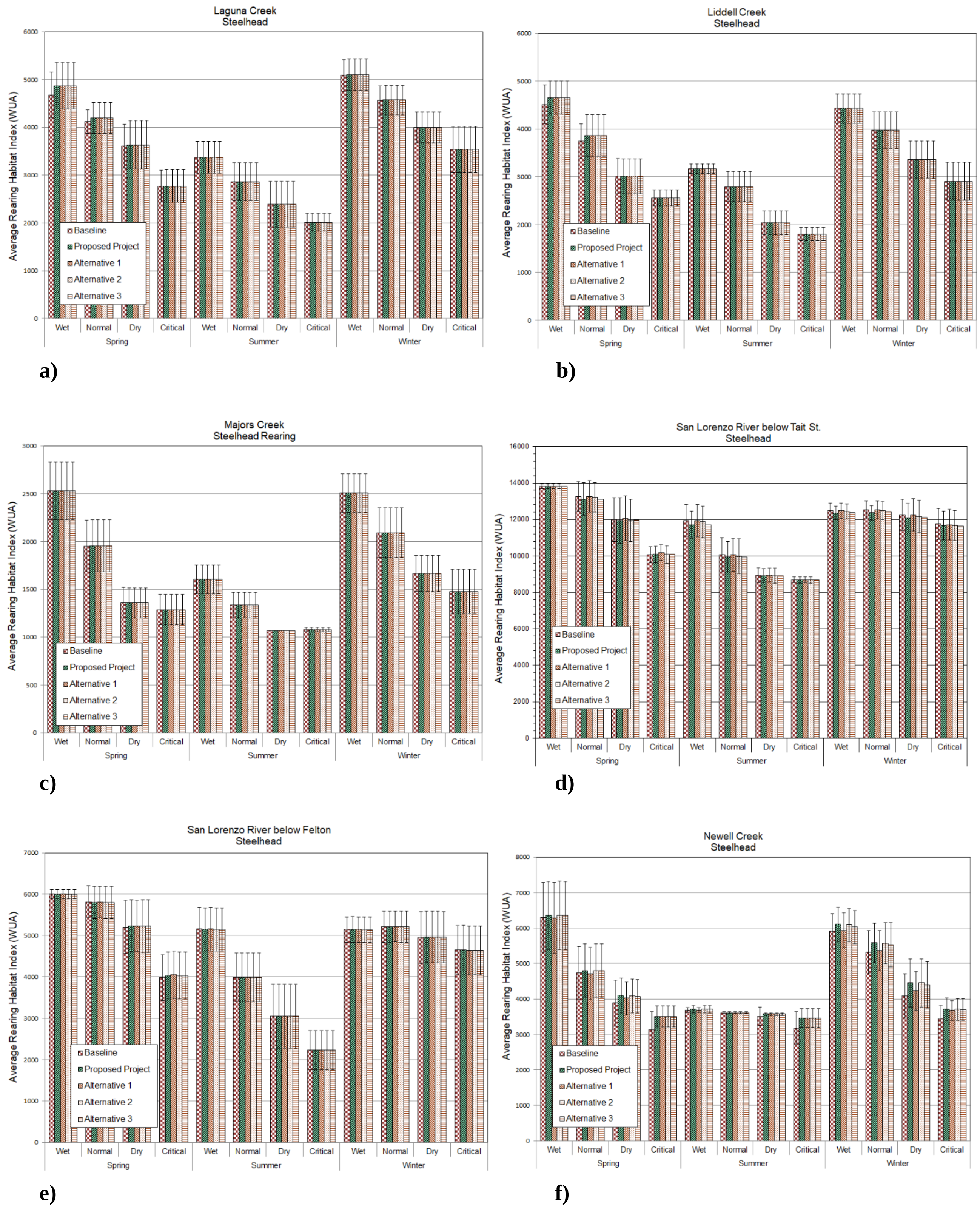


Figure 8: Modeled Juvenile Rearing Index for Steelhead by Stream Reach with Historical Hydrology

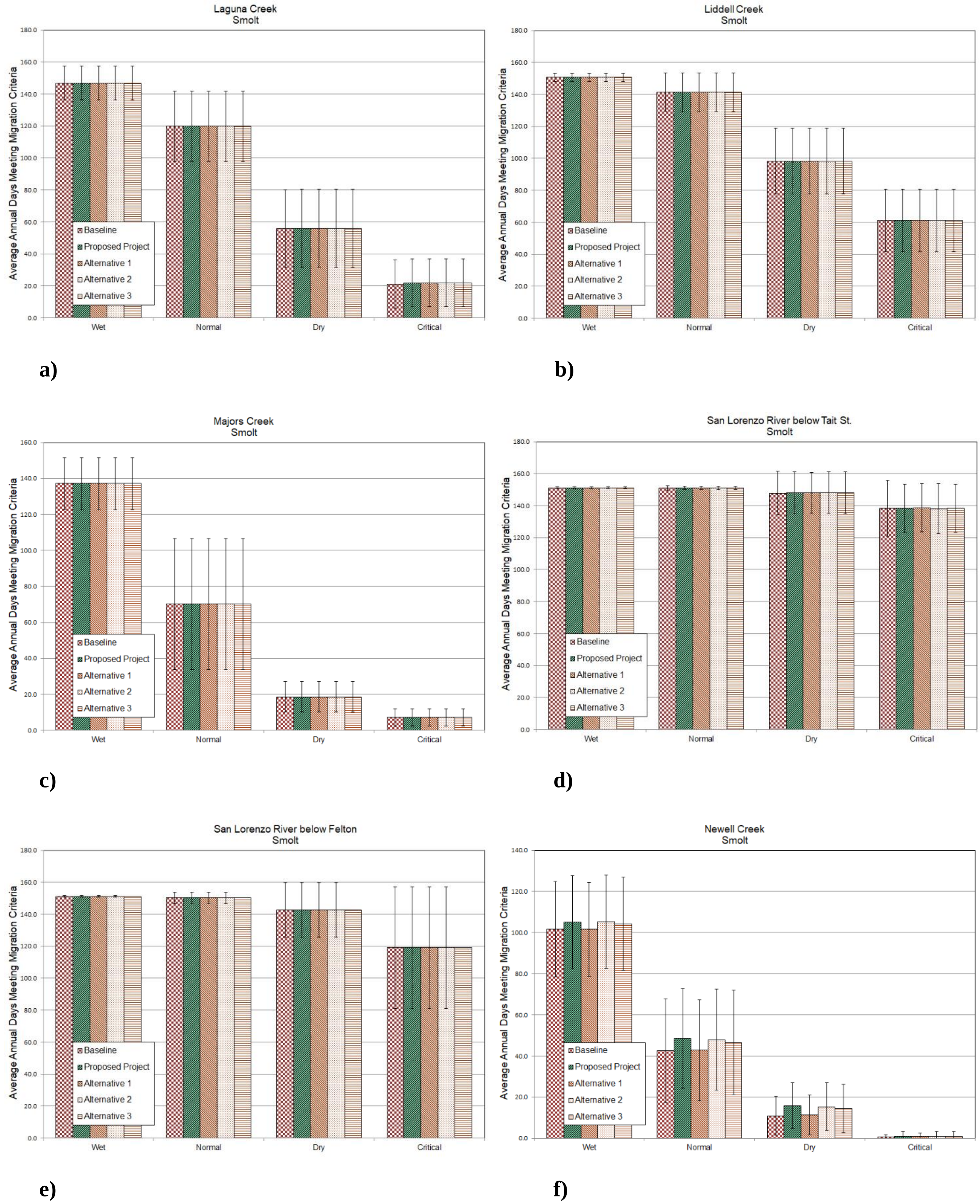
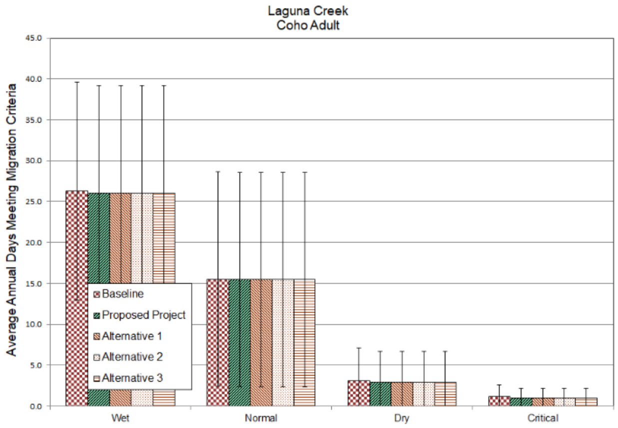


Figure 9: Modeled Smolt Migration Index for Steelhead by Stream Reach with Historical Hydrology



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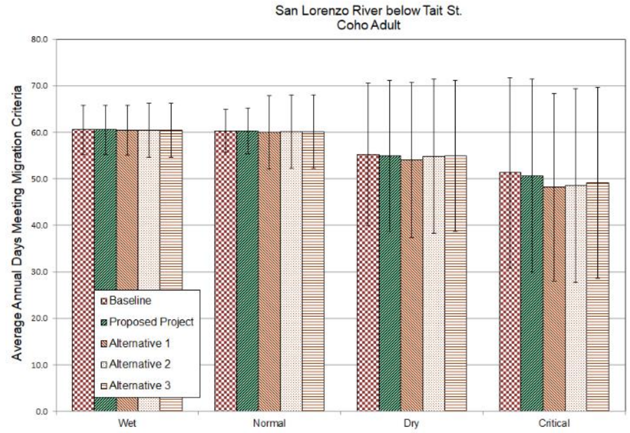

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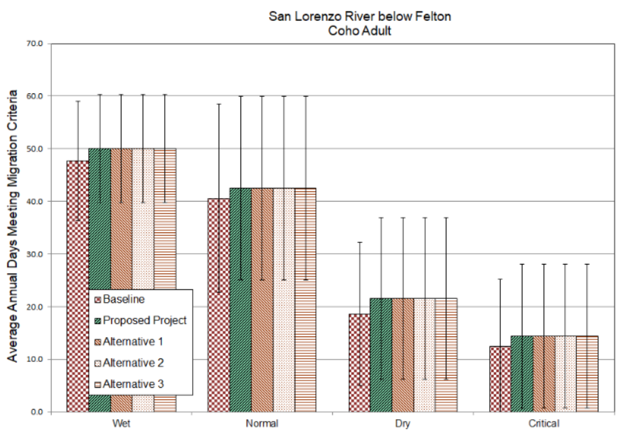

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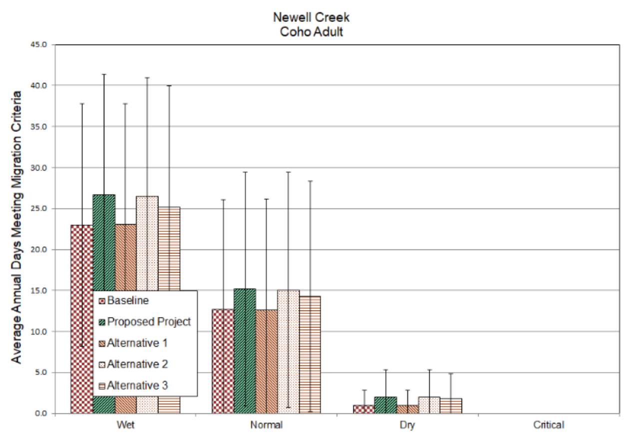

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Figure 10: Modeled Adult Migration Index for Coho by Stream Reach with Historical Hydrology

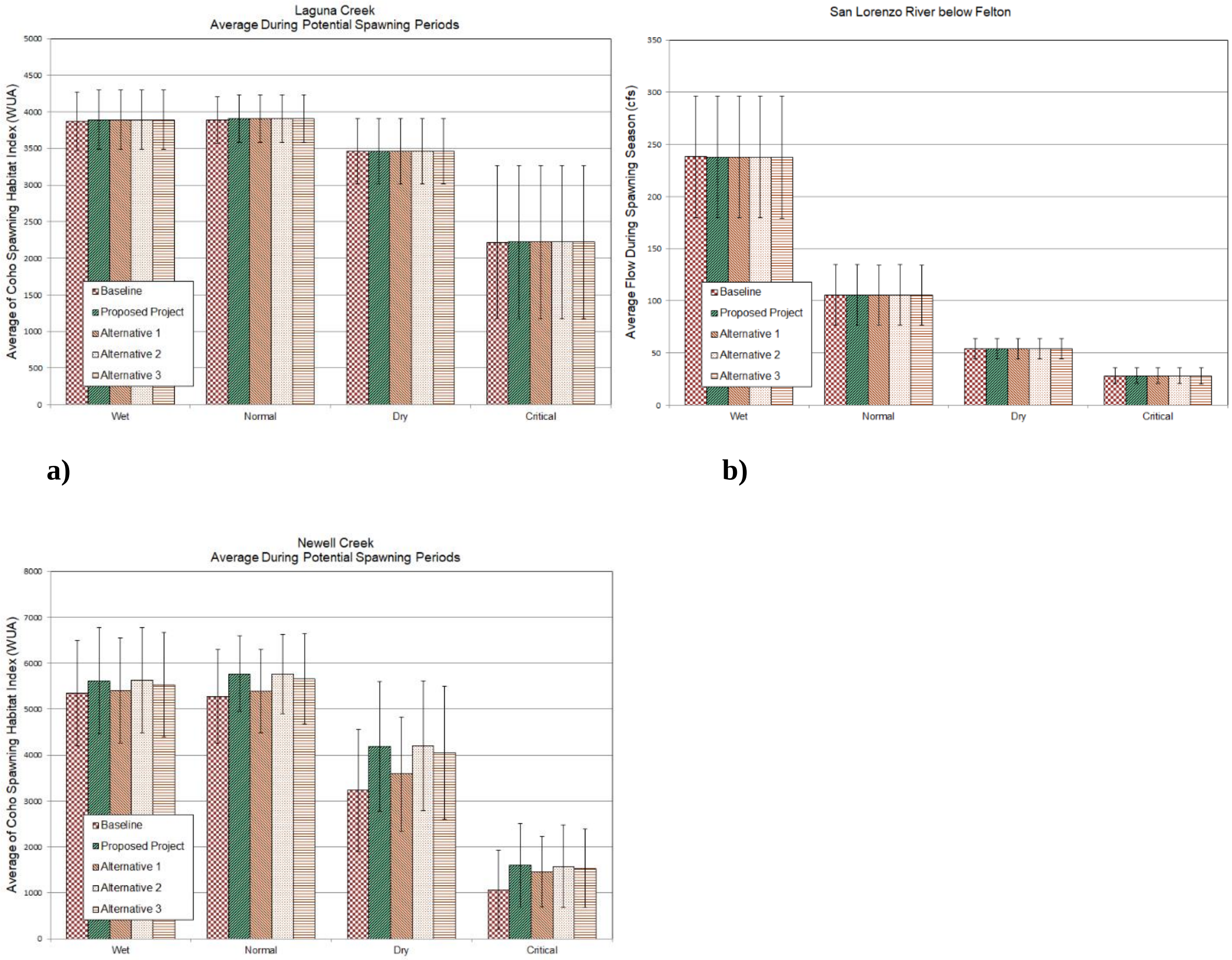
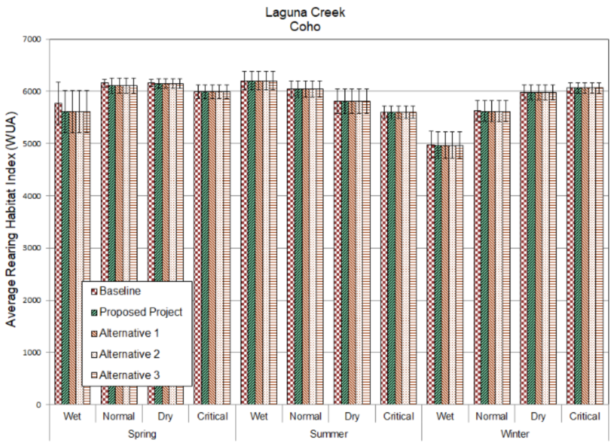


Figure 11: Modeled Spawning Index for Coho by Stream Reach with Historical Hydrology



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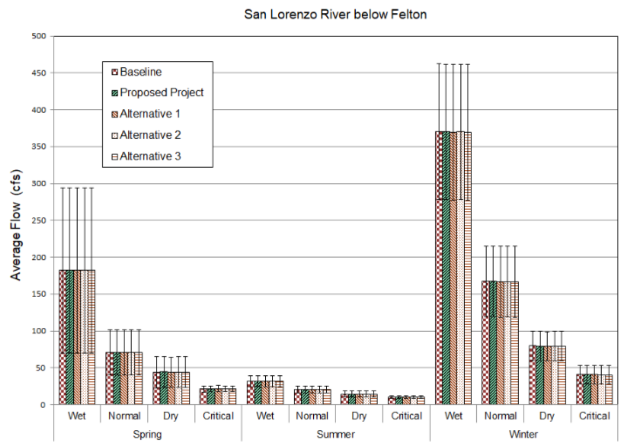

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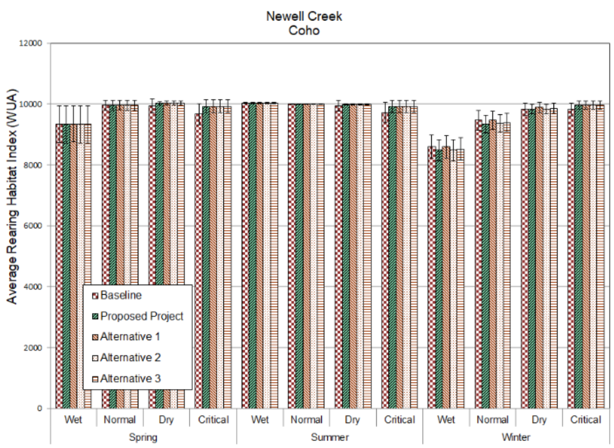

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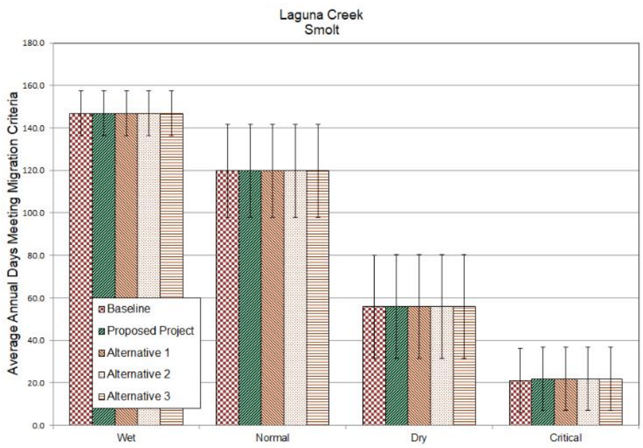
Figure 12: Modeled Juvenile Rearing Index for Coho by Stream Reach with Historical Hydrology



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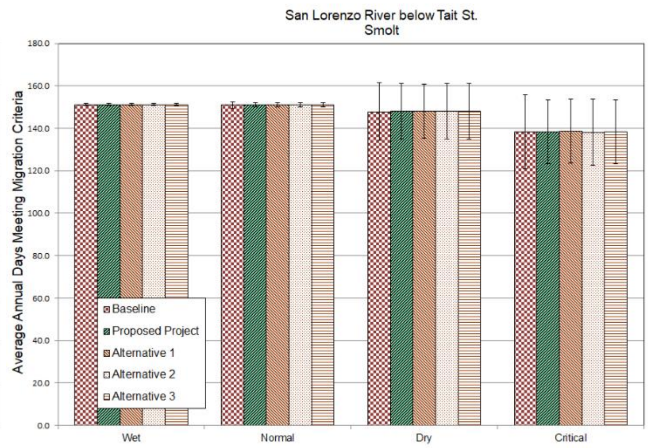

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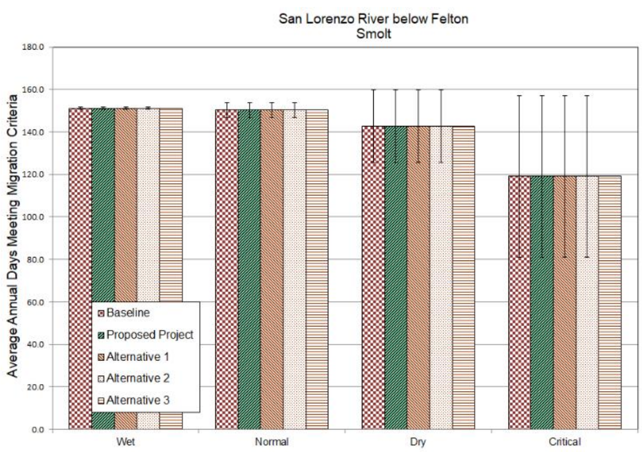

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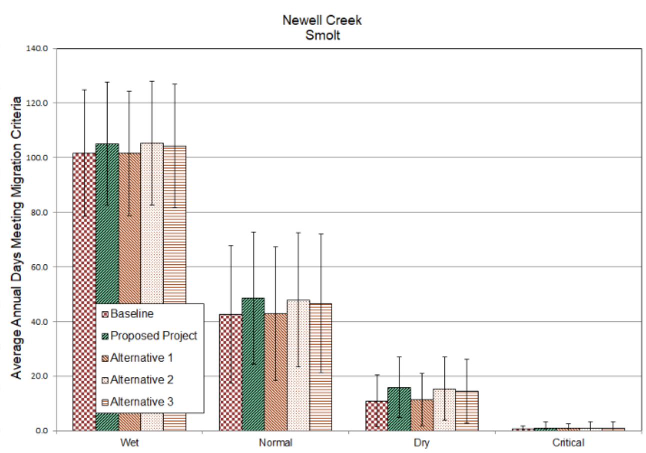

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Figure 13: Modeled Smolt Migration Index for Coho by Stream Reach with Historical Hydrology

Proposed Project with Climate Change Hydrology – Habitat Indices

Effects of the Proposed Project on habitat indices were also evaluated using hydrological conditions predicted to occur with climate change (see Appendix D-1 for a description of how climate change hydrology was developed). The results for climate change are presented by water year type with water year type determined by the frequency of water year total runoff in the climate change hydrology. The wettest one-third is designated as "wet", the next one-third are designated as "normal", and the driest one-third is split in half between "dry" and "critical". This is consistent with the presentation of results for the historical hydrology (see Appendix C).

A summary of the habitat effects of the Proposed Project with climate change hydrology is provided for steelhead and coho life stages in each of the stream reaches influenced by City diversions (Table 4). The results for climate change hydrology have similar patterns to the results for historical hydrology. The majority of effects of the Proposed Project involve an improvement in habitat conditions for steelhead and coho compared to the Baseline (Table 4). Negative effects are limited to coho rearing in Laguna Creek in normal and wet years and smolt migration in the San Lorenzo River downstream of the Tait Diversion in dry years. As described previously, the decline in the coho rearing habitat index is a result of higher flows in April provided for adult steelhead migration under the Proposed Project Agreed Flows. Coho rearing habitat is at optimum levels at lower flows than those provided for adult migration. Even with this effect, the wet year coho rearing index remains at 80% of the peak level in Laguna Creek (Figure 20a). This minor effect on rearing habitat is not likely to be biologically meaningful and would not be considered "substantial" under CEQA standards of significance or meet any of the thresholds for mandatory findings of significance under CEQA (Section 4.2). Specifically, a change of this magnitude in the rearing index would not substantially reduce the habitat of coho, interfere substantially with the movement or migration of coho, cause the coho population to drop below self-sustaining levels, threaten to eliminate coho in Laguna Creek or, substantially reduce the number or restrict the range of coho.

The smolt index downstream of the Tait Diversion is decreased in dry years with the Proposed Project due to modification of the smolt bypass flows during HC-5 conditions (see Appendix C). The increased capacity at the Tait Diversion under the Proposed Project results in more frequent flows below the smolt threshold on the four days per week when smolt bypass flows are not required. There are still a relatively large number of days (about 120 out of 150 possible) when conditions are suitable for smolt migration (Figure 17d) under the Proposed Project. This is a minor effect on smolt migration that is unlikely to have biological significance. It would not be considered a "substantial effect" under CEQA standards of significance or meet any of the thresholds for mandatory findings of significance under CEQA (Section 4.2). Specifically, a change of this magnitude in the smolt index would not substantially reduce the habitat of coho, interfere substantially with the movement or migration of coho, cause the coho population to drop below self-sustaining levels, threaten to eliminate coho in Laguna Creek or, substantially reduce the number or restrict the range of coho.

Extremely low habitat indices with climate change hydrology in dry and critical years in some locations (Newell Creek, Laguna Creek, and downstream of the Felton Diversion to some degree), even with no City diversions, could be problematic, particularly for viability of coho (Figures 18a, 18d, 21a, 21d). These conditions occur in one-third of modeled water years and, due to lack of life-history variability in coho, lost year classes are not easily re-established. This is a feature of the altered hydrology and not related to implementation of the Proposed Project.

Table 4: Habitat effects of the Proposed Project compared to Baseline Alternative as percent change from Baseline using projected hydrology with climate change.

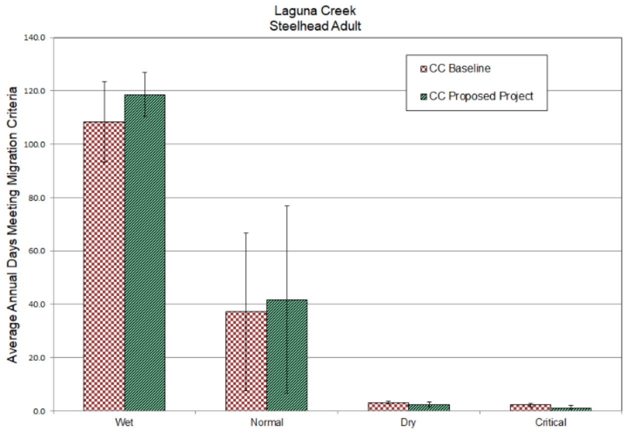
Stream Reach		Steelhead: Adult migration (m)	Steelhead: Spawning/incubation (i)	Steelhead: Rearing (r)	Steelhead: Smolt migration (s)		Coho: Adult migration (cm)	Coho: Spawning/incubation (ci)	Coho: Rearing (cr)	Coho: Smolt migration (cs)
Laguna Anadromous	wet	9.4%	3.3%	o	o		o	+	-2.9%	o
	normal	12.3%	6.5%	o	o		o	+	-2.0%	o
	dry	o	-	o	o		o	+	o	o
	critically dry	o	-	o	o		o	+	o	o
Liddell Anadromous	wet	8.2%	4.7%	-	o					
	normal	8.0%	2.0%	o	o					
	dry	o	o	-	o					
	critically dry	o	o	-	o					
Majors Anadromous	wet	o	+	-	o					
	normal	o	+	o	o					
	dry	o	o	o	o					
	critically dry	o	o	o	o					
San Lorenzo below Tait St	wet	o		-	o		o			o
	normal	o		-	o		o			o
	dry	4.0%		-	-4.0%		o			-4.0%
	critically dry	7.1%		-	o		3.2%			o
San Lorenzo below Felton	wet	+	2.5%	o	o		4.3%	-	-	o
	normal	7.4%	5.9%	-	o		13.0%	***+***	-	o
	dry	42.5%	28.6%	o	o		29.4%	***2.7%***	***o***	o
	critically dry	48.4%	22.5%	o	o		32.0%	***2.5%***	***o***	o
Newell Anadromous	wet	4.9%	2.1%	o	2.9%		24.5%	+	-	2.9%
	normal	7.3%	6.2%	+	6.2%		o	9.5%	+	6.2%
	dry	o	17.2%	7.6%	o		o	35.7%	+	o
	critically dry	o	10.7%	8.3%	o		o	18.1%	+	o

"-" = <2% decrease in habitat index

"+" = <2% increase in habitat index

"o" = no change in habitat index, or change of 1 day or less in migration periods

Values for coho spawning and rearing below Felton (bold italic) based on change in flow rather than habitat indices



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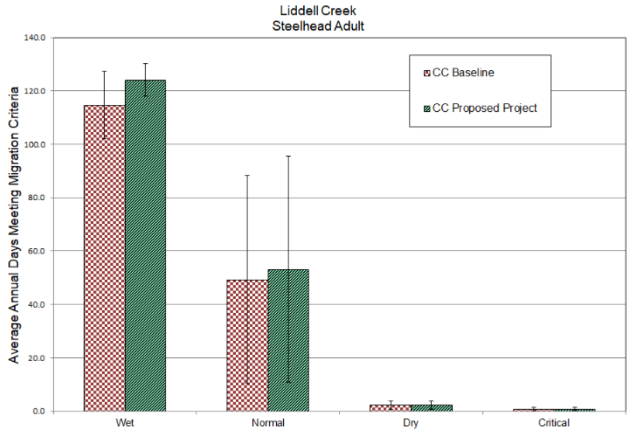

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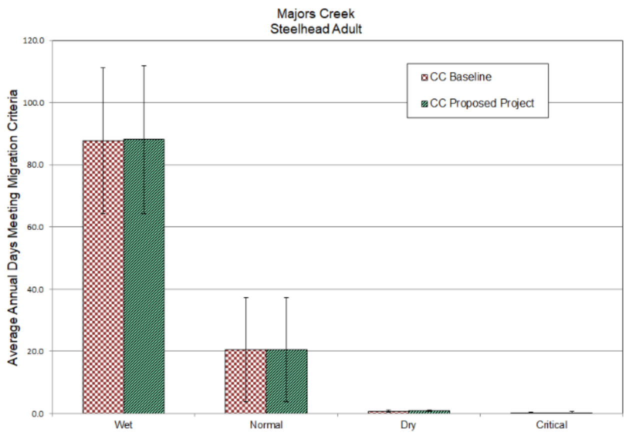

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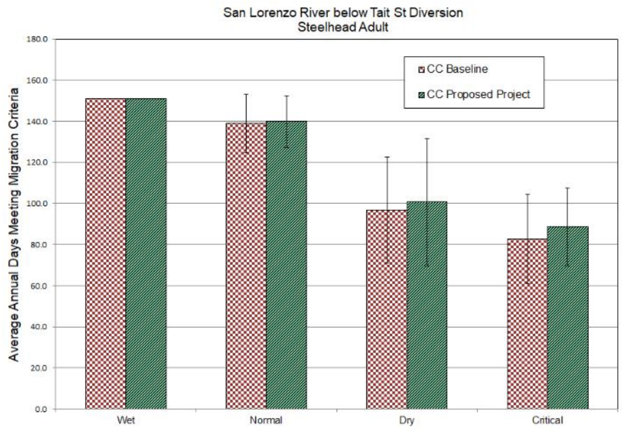

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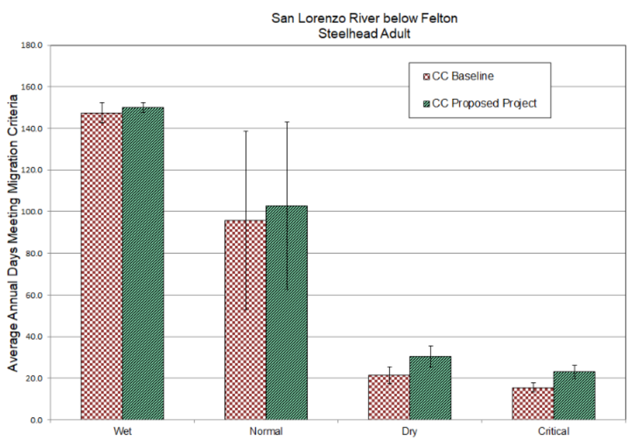

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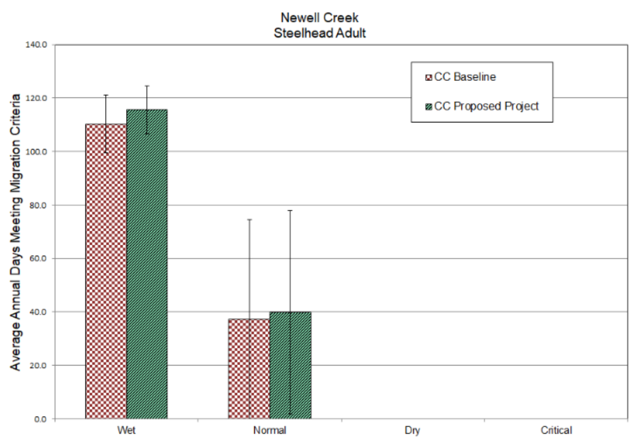

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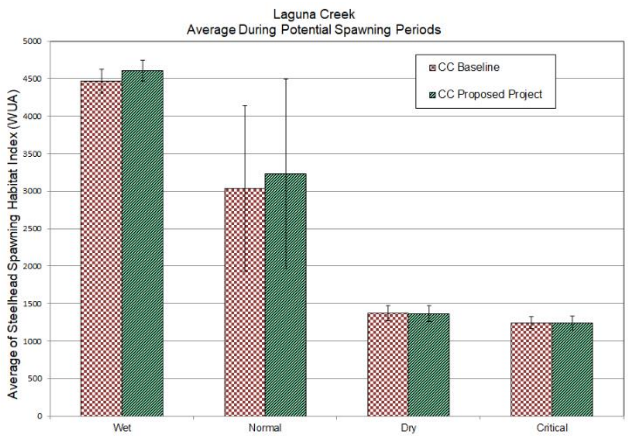
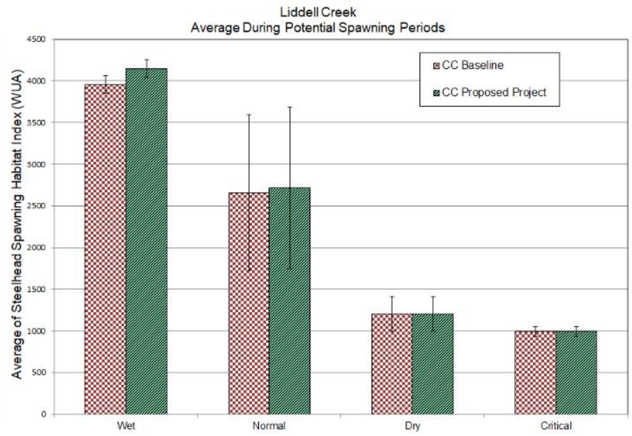
Figure 14: Modeled Adult Migration Index for Steelhead by Stream Reach with Climate Change Hydrology



a)



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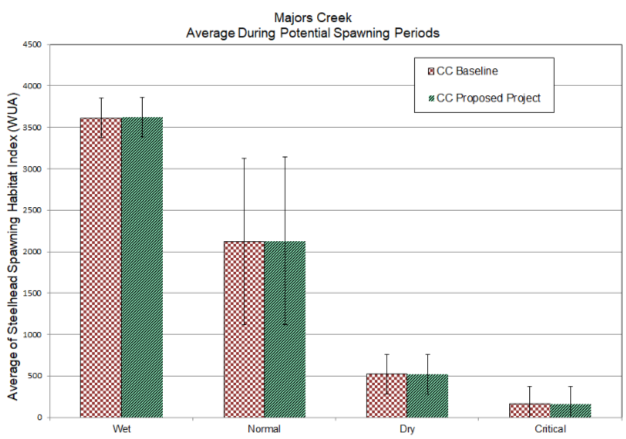
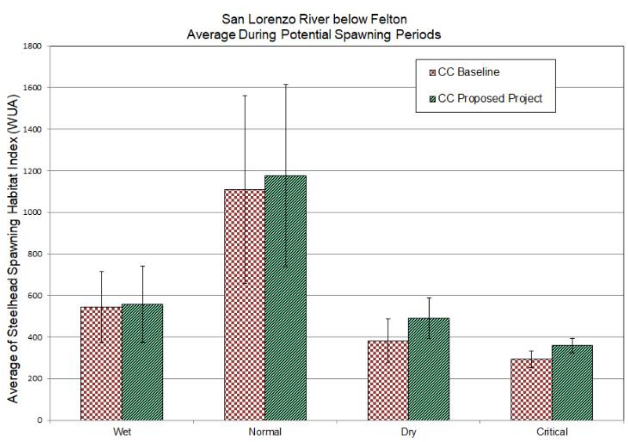
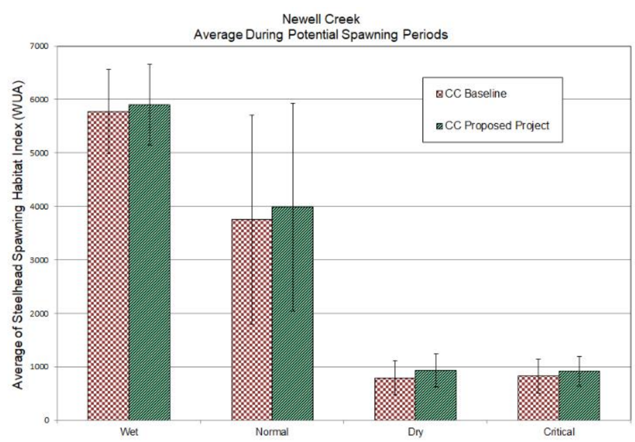


c)

d)



e)



f)

Figure 15: Modeled Spawning Index for Steelhead by Stream Reach with Climate Change Hydrology

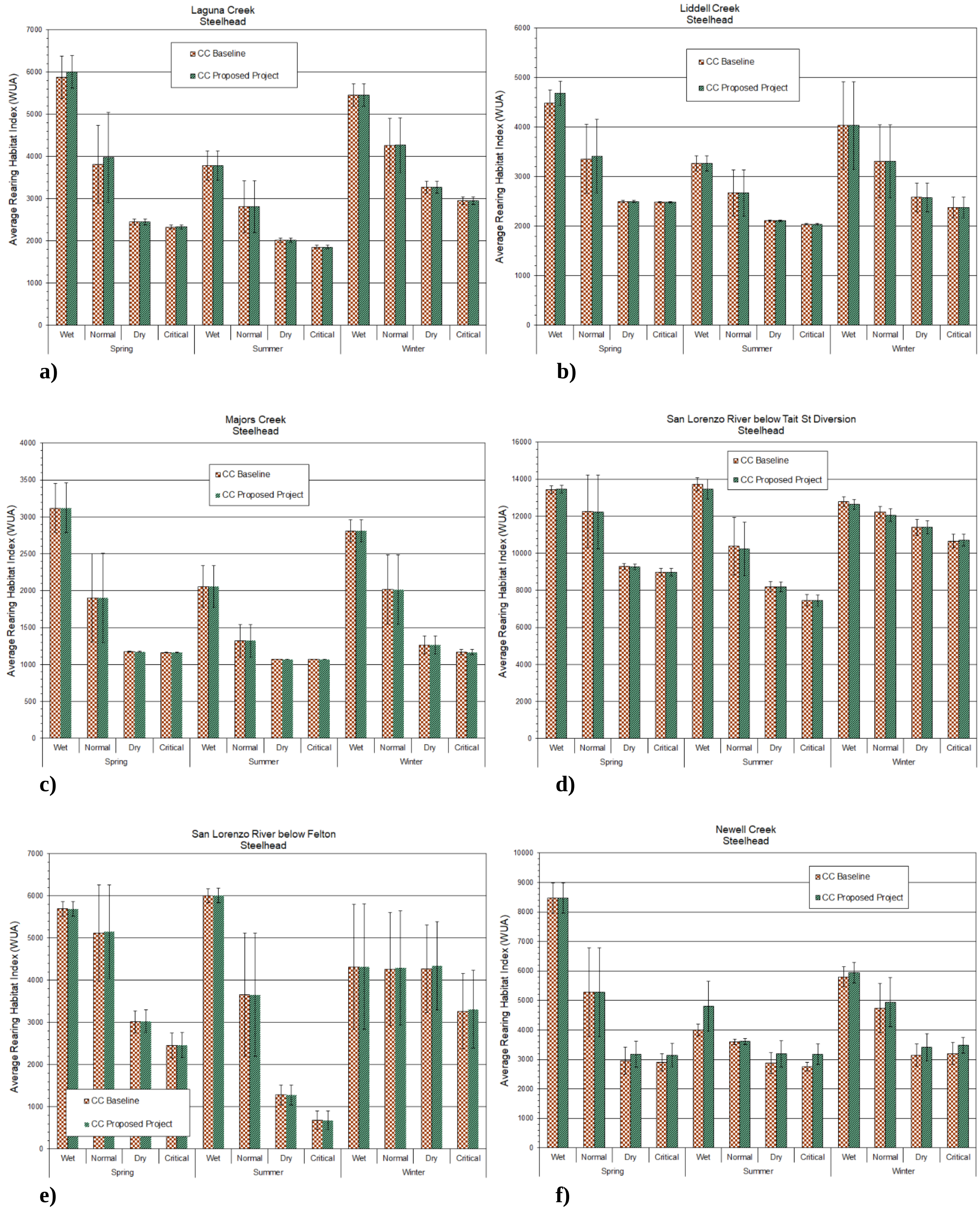


Figure 16: Modeled Juvenile Rearing Index for Steelhead by Stream Reach with Climate Change Hydrology

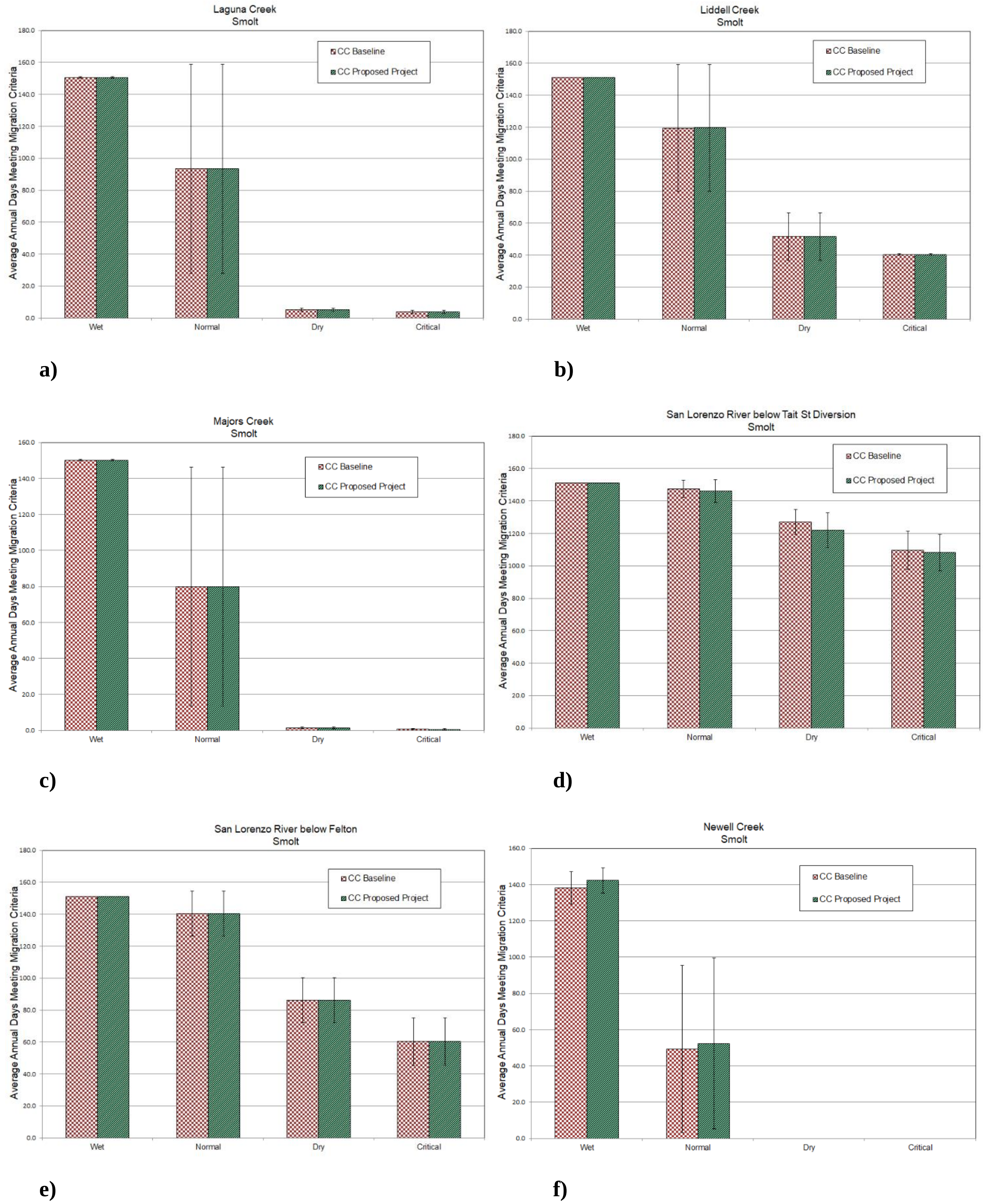
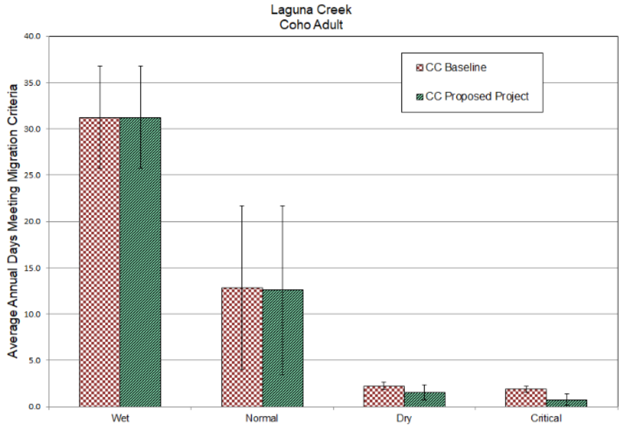
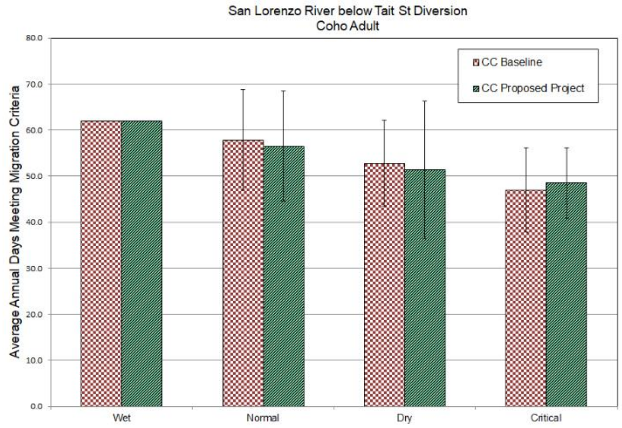


Figure 17: Modeled Smolt Migration Index for Steelhead by Stream Reach with Climate Change Hydrology



a)



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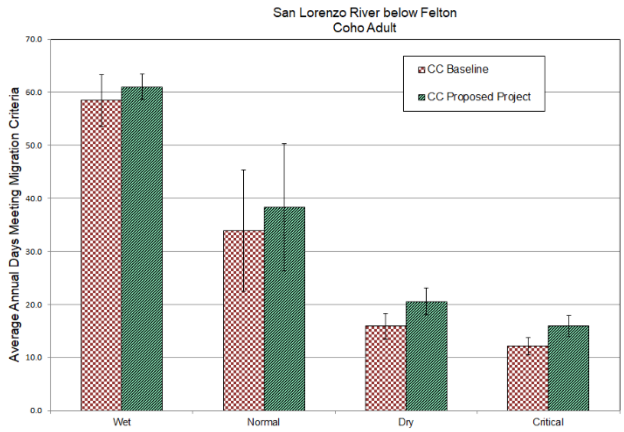
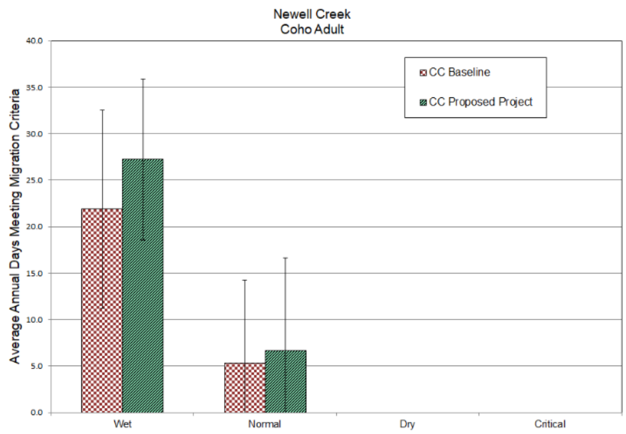
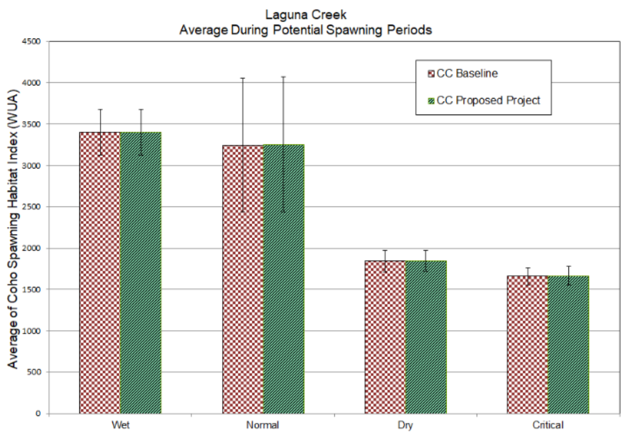


c)

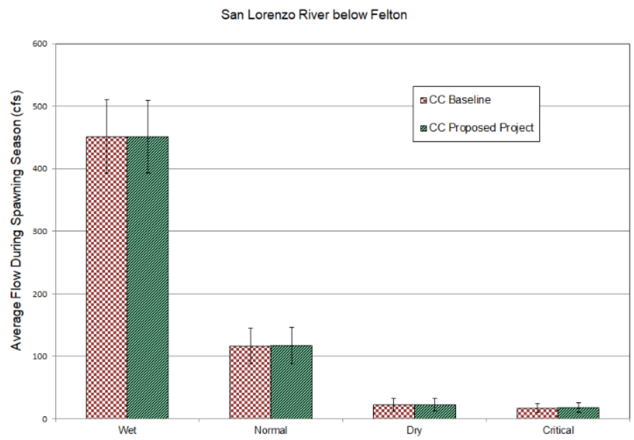


d)

Figure 18: Modeled Adult Migration Index for Coho by Stream Reach with Climate Change Hydrology



a)



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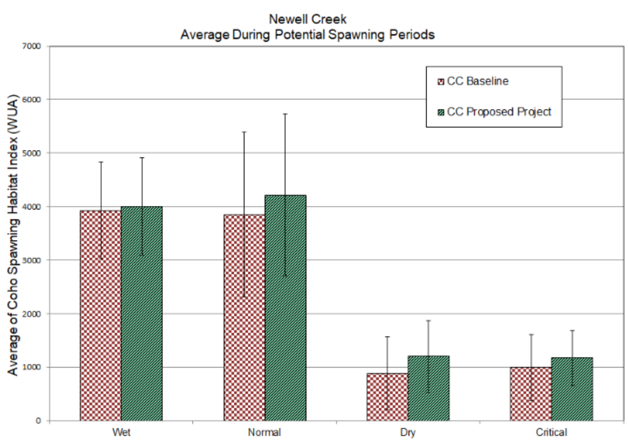


c)

Figure 19: Modeled Spawning Index for Coho by Stream Reach with Climate Change Hydrology

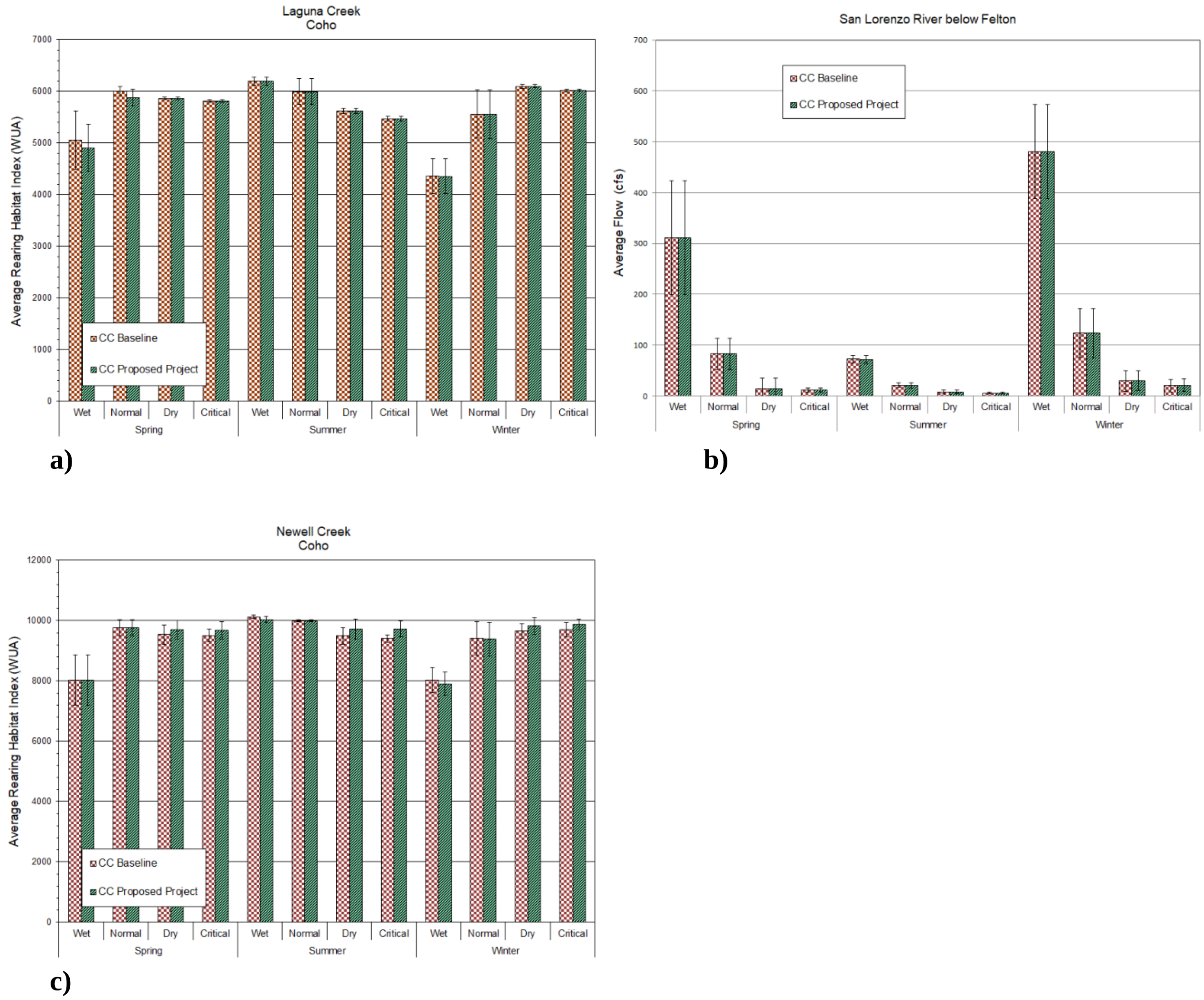
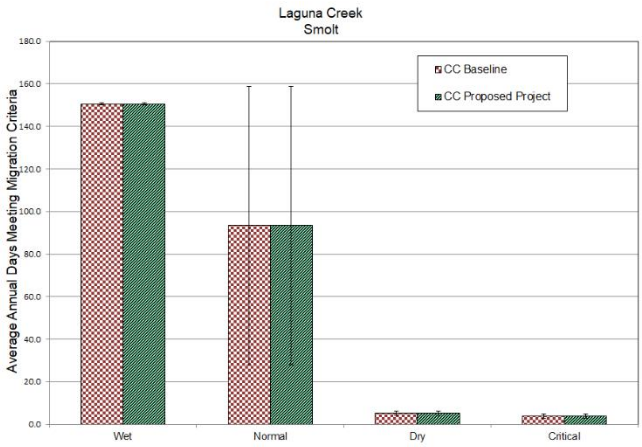
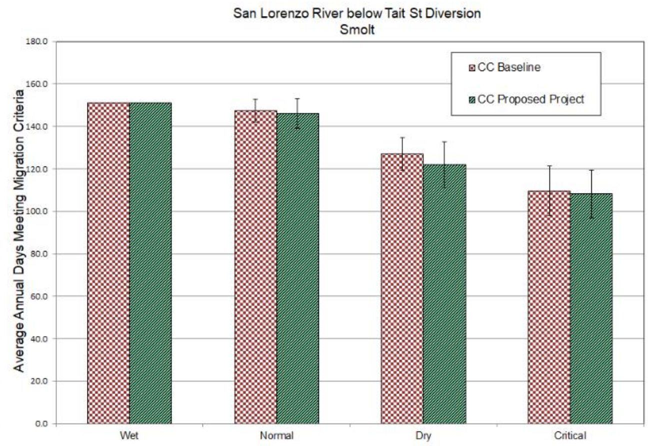


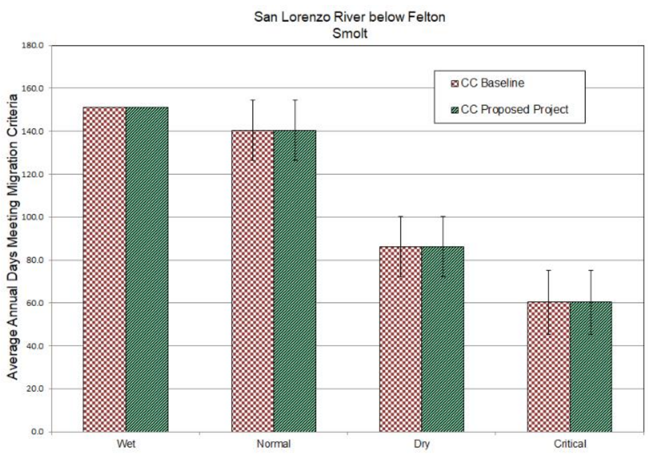
Figure 20: Modeled Juvenile Rearing Index for Coho by Stream Reach with Climate Change Hydrology



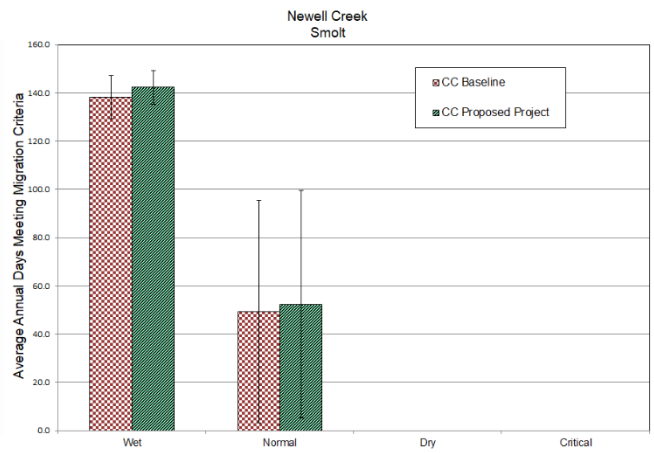
a)



b)



c)



d)

Figure 21: Modeled Smolt Migration Index for Coho by Stream Reach with Climate Change Hydrology

Proposed Project with Climate Change Hydrology – Water Temperature

Average annual air temperature in California has increased through the 20^{th} century with the rate of increase accelerating since the 1980s (OEHHA 2018). Air temperature projections for the 21st century show continued increases from 2 to 4°C in the San Francisco Bay Area (Flint and Flint 2012). The increase in minimum (nighttime) temperatures have increased at a faster rate than maximum (daytime) temperatures. Since air temperature is the major determining factor for water temperature, temperature of aquatic systems is likely to show similar trends. The ability of aquatic species to persist in presently occupied habitats will depend on the rate of increase and the ability of the species to adapt to changing conditions.

The Santa Cruz mountains currently represent the southern margin for the range of coho with temperature and associated habitat features (redwood forest) being a major determinant, if not the major determining factor, in the extent of their range. Coho do not presently maintain viable populations in the San Lorenzo River and its tributaries in the southern part of Santa Cruz County where the City has its water supply operations. Water temperature in many of the streams in Santa Cruz County is presently at or near the level limiting coho persistence (City of Santa Cruz 2021) and may explain why coho are no longer present. Increasing temperatures will only exacerbate these effects. Steelhead have slightly greater tolerance of high temperature than coho but they are also near the southern edge of their present range and, at least in the San Lorenzo River, near their upper thermal tolerance range.

These effects are unrelated to and will occur regardless of the Proposed Project. However, there may be synergies between aspects of the Proposed Project and climate change that have an effect on steelhead or coho. With the Proposed Project, storage in Loch Lomond Reservoir is predicted to be high with greater frequency than under the Baseline, with the result that spill from the reservoir will be more frequent with the Project (see Draft EIR Section 7, Climate Change Considerations). This could benefit steelhead and coho during the adult migration, spawning, and smolt migration life-stages, though the increase in spill frequency is relatively small.

At times when the reservoir is spilling and the 1 cfs fish release is not sufficient to maintain temperature in Newell Creek below 21°C, Standard Operational Practice #6 requires the City to release additional flow through the fish release to achieve a maximum instantaneous temperature of less than 21°C as measured in the anadromous reach of Newell Creek and verified at the City stream gage in Newell Creek below the dam. With the implementation of this operational practice, potential adverse temperature effects in Newell Creek and the San Lorenzo River due to an increase in spill frequency with the Proposed Project would be avoided. Therefore, the Proposed Project would not substantially reduce the habitat of coho and steelhead, or otherwise substantially reduce the number or restrict the range of these species.

4.4.2. Evaluation of Any Significant Effects

The Proposed Project incorporates Agreed Flows and some conservation and mitigation measures from the ASHCP (see EIR Chapter 3 and Appendix C), including improvements to fish screening at the Tait and Felton Diversions and improving fish passage at the Felton Diversion and as needed at the Tait Diversion. Habitat modeling indicates that, although there are isolated instances of minor effects to some life stages in some reaches relative to the Baseline, the Proposed Project would result in a net beneficial effect on both species (Table 4). Based on historic hydrology and projected climate change hydrology, the Proposed Project would not have a substantial adverse effect on habitat indices for steelhead or coho in the project area. The habitat models also indicate that the Proposed Project would not interfere substantially with migration of steelhead or coho. Additionally, with the implementation of Standard Operational Practice #6 as part of the Proposed Project, potential adverse water temperature effects due to an increase in reservoir spill frequency would be avoided. Based on CEQA standards of significance and thresholds for mandatory findings of significance (Section 4.2), the Proposed Project is expected to have a less-than-significant impact on steelhead and coho, based on both the historical hydrology and projected climate change hydrology.

4.5. **Alternative 1:** Agreed Flows only without other Proposed Project components

Alternative 1 implements the Agreed Flows as in the Proposed Project, without any of the operational flexibility enabled by the Proposed Project. In terms of habitat for anadromous species, the major difference between Alternative 1 and the Baseline is the addition of adult migration flows in April and spawning flows in December in the North Coast streams with the Agreed Flows in Alternative 1; addition of adult migration flows in April in the San Lorenzo River below Tait Street; and implementation of bypass flows for adult migration and spawning in the San Lorenzo River downstream of the Felton Diversion (Table 1). Provision of the Agreed Flows, which are not included in the interim bypass flow requirements reflected in the Baseline, result in increases in habitat values in months with hydrologic exceedance conditions in the 0%-60% range, which is generally in wetter year types (see Appendix C), and improvements in the adult migration and spawning indices in the San Lorenzo River downstream of the Felton Diversion.

4.5.1. Model Results – Alternative 1

Alternative 1 with Historic Hydrology – Habitat Indices

Alternative 1 was modeled using historical hydrology but not with climate change hydrology. The majority of Alternative 1 effects involve an improvement in habitat conditions for steelhead and coho compared to the Baseline condition (Table 5). Effects are nearly identical to the Proposed Project at all locations except Newell Creek. Improvement in habitat effects in Newell Creek downstream of Newell Creek Dam is less under Alternative 1 than under the Proposed Project or Alternatives 2 and 3. Elements of the Proposed Project add operational flexibility, which results in higher storage levels in Loch Lomond Reservoir and increased frequency and/or duration of spill (Appendix D-2). As a result of less frequent reservoir spills under Alternative 1, habitat values in Newell Creek show less improvement over the Baseline compared to the Proposed Project and Alternatives 2 and 3.

The only negative effects of Alternative 1 (relative to the Baseline) are a 2.7% decline in the rearing habitat index in wet years for coho in Laguna Creek (Figure 12a) and a 6.2% decline in the adult migration index for coho downstream of the Tait Diversion in critically dry years (Figure 10b). The decline in Laguna Creek coho rearing habitat is a result of higher flows in April provided for adult migration under the Agreed Flows compared to no provision of migration flows in April under the interim bypass flows in the Baseline. Coho rearing habitat is at optimum levels at lower flows than those provided for adult migration. Even with this effect, the wet year coho rearing index remains at 80% of the peak level in Laguna Creek (Figure 12a). This minor effect on rearing habitat is not likely to be biologically meaningful and would not be considered “substantial” under CEQA standards of significance or meet any of the significance thresholds under CEQA (Section 4.2). Specifically, a change of this magnitude in the rearing index would not substantially reduce the habitat of coho, interfere substantially with the movement or migration of coho, cause the coho population to drop below self-sustaining levels, threaten to eliminate coho in Laguna Creek or, substantially reduce the number or restrict the range of coho.

Table 5: Habitat effects of Alternative 1 compared to Baseline as percent change from Baseline using historical hydrology.

Stream Reach		Steelhead: Adult migration (m)	Steelhead: Spawning/incubation (i)	Steelhead: Rearing (r)	Steelhead: Smolt migration (s)	Coho: Adult migration (cm)	Coho: Spawning/incubation (ci)	Coho: Rearing (cr)	Coho: Smolt migration (cs)
Laguna Anadromous	wet	8.5%	5.9%	o	o	o	+	-2.7%	o
	normal	o	3.3%	o	o	o	+	-	o
	dry	o	+	o	o	o	+	-	o
	critically dry	o	+	o	o	o	+	o	o
Liddell Anadromous	wet	4.1%	3.4%	o	o				
	normal	5.0%	3.4%	o	o				
	dry	o	-	-	o				
	critically dry	o	-	-	o				
Majors Anadromous	wet	o	+	o	o				
	normal	o	+	o	o				
	dry	o	-	-	o				
	critically dry	o	o	o	o				
San Lorenzo below Tait St	wet	o		-	o	o			o
	normal	o		o	o	o			o
	dry	-		o	o	o			o
	critically dry	o		o	o	-6.2%			o
San Lorenzo below Felton	wet	+	+	-	o	4.9%	-	-	o
	normal	+	+	-	o	4.6%	-	-	o
	dry	8.0%	2.0%	o	o	15.8%	-	***o***	o
	critically dry	22.0%	6.4%	o	o	15.3%	***+***	***o***	o
Newell Anadromous	wet	o	+	-	o	o	+	o	o
	normal	o	+	-	o	o	2.2%	o	o
	dry	o	6.0%	+	o	o	11.0%	+	o
	critically dry	o	19.9%	8.6%	o	o	36.8%	2.0%	o

"-" = <2% decrease in habitat index

"+" = <2% increase in habitat index

"o" = no change in habitat index, or change of 1 day or less in migration periods

Values for coho spawning and rearing below Felton (bold italic) based on change in flow rather than habitat indices

The decline in the adult migration index for coho downstream of the Tait Diversion in Alternative 1 likely results from more frequent restrictions on migration bypass flows due to lower storage levels in Loch Lomond Reservoir under Alternative 1 in a limited number of years. Under both the Agreed Flows and the interim bypass flows (Baseline), requirements for adult migration bypass flows at the Tait Diversion can be relaxed under low storage levels in Loch Lomond Reservoir from December through March. If Alternative 1 results in more frequent Loch Lomond Reservoir storage levels below the trigger for lower migration bypass flows, bypass flows below the Tait Diversion would be modified more often (see Appendix D-2). The reason the adult migration index for coho can be reduced while the index for steelhead is not is that migration opportunities lost in December can be compensated for by gains in April for steelhead but not for coho, which migrate primarily before March. Provision of adult migration bypass flows in April under the Agreed Flows may also contribute to lower storage levels in Loch Lomond Reservoir in the early winter with Alternative 1 compared to the Baseline. The 6.2% decline in the adult coho migration index is not likely to be biologically significant since migration conditions are still suitable 80% of the time during the coho migration period in critically dry years. Migration typically takes place during higher flow periods associated with winter storms. For comparison, conditions for migration are met only about 20% of the time in the San Lorenzo River downstream of the Felton Diversion even under unimpaired conditions (i.e. no diversion at Felton). This minor effect on adult migration index is not likely to be biologically meaningful and would not be considered “substantial” under CEQA standards of significance or meet any of the thresholds for mandatory findings of significance under CEQA (Section 4.2). Specifically, the decline in the migration index would not interfere substantially with the movement of coho, substantially reduce the habitat of coho, cause the coho population to drop below self-sustaining levels, threaten to eliminate coho in the San Lorenzo River or, substantially reduce the number or restrict the range of coho.

Effects on habitat in Laguna Creek, Liddell Creek, and Majors Creek with Alternative 1 are the same as the Proposed Project and Alternatives 2 and 3 and result from the provision of bypass flows for migration in April and spawning in December under the Agreed Flows. Habitat effects downstream of the Tait Diversion are also similar for Alternative 1, as compared to the Proposed Project and Alternatives 2 and 3 except that Alternative 1 results in a negative effect on coho adult migration in critically dry years whereas the Proposed Project does not (Table 5, Figure 10b). This is likely due to lower storage levels in Loch Lomond Reservoir in the early winter under Alternative 1 compared with the Proposed Project and resulting restrictions on migration flows under the Agreed Flows (Appendix D-2).

Habitat effects in the San Lorenzo River downstream of the Felton Diversion are similar for all Alternatives and the Proposed Project with improvements over the Baseline for adult migration and spawning, primarily in dry and critically dry years (Figure 6e, 7d, 10c). This is the result of higher bypass flows for migration and spawning under the Agreed Flows compared with the interim bypass flow requirements under the Baseline.

Alternative 1 with Historic Hydrology – Water Temperature

Reservoir spill under Alternative 1 is nearly identical to the Baseline. Hydrologic modeling indicates that the Alternative 1 would result in minor increase in spill from November through March and minor decrease in spill in April and May (less than 3% difference). There would be no difference between Alternative 1 and Baseline in June and no spill under either Alternative 1 or the Baseline from July through October (see Draft EIR Chapter 8, Alternatives). Increase in spill during the winter may be beneficial for migration, spawning, and smolt migration of steelhead and coho although the difference in this case is not likely to be biologically significant. Decrease in spill during April and May may slightly reduce water temperature but is not likely to be biologically significant at the level of change involved.

At times when the reservoir is in spill and the 1 cfs fish release is not sufficient to maintain temperature in Newell Creek below 21°C, Standard Operational Practice #6 requires the City to release additional flow through the fish release to achieve a maximum instantaneous temperature of less than 21°C as measured in the anadromous reach of Newell Creek and verified at the City stream gage in Newell Creek below the dam. With the implementation of this operational practice, potential adverse water temperature effects in Newell Creek and the San Lorenzo River due to an increase in reservoir spill frequency with Alternative 1 would be avoided. Therefore, Alternative 1 would not substantially reduce the habitat of coho and steelhead, or otherwise substantially reduce the number or restrict the range of these species.

4.5.2. Evaluation for Any Significant Effects – Alternative 1

Alternative 1 has effects that are similar to those of the Proposed Project. As with the Proposed Project, Alternative 1 incorporates Agreed Flows. Habitat modeling indicates that, although there are isolated instances of minor effects to some life stages in some reaches relative to the Baseline, Alternative 1 would result in a net beneficial effect on both species (Table 5). Alternative 1 does not have a substantial adverse effect on habitat indices for steelhead or coho in the project area. The habitat modeling effects also indicate that Alternative 1 will not interfere substantially with migration of steelhead or coho. Additionally, with the implementation of Standard Operational Practice #6 as part of Alternative 1, potential adverse water temperature effects due to an increase in reservoir spill frequency would be avoided. Based on CEQA standards of significance and thresholds for mandatory findings of significance (Section 4.2), Alternative 1 is expected to have a less-than-significant impact on steelhead and coho under historic hydrologic conditions.

4.6. **Alternative 2:** Agreed Flows with all Proposed Project components except changes to place of use

Alternative 2 implements the Agreed Flows similar to the Proposed Project and portions of the Proposed Project without changes to the place of use authorizing transfers to neighboring agencies or ASR outside of the area of service for the City. In terms of habitat for anadromous species, the major difference between Alternative 2 and the Baseline is the addition of adult migration flows in April and spawning flows in December in the North Coast streams with the Agreed Flows in Alternative 2; addition of adult migration flows in April in the San Lorenzo River below Tait Street; and implementation of bypass flows for adult migration and spawning in the San Lorenzo River downstream of the Felton Diversion (Table 1). These provisions of the Agreed Flows, which are not included in the interim bypass flow requirements reflected in the Baseline, result in increases in habitat values in months with hydrologic exceedance conditions in the 0%-60% range, which is generally in wetter year types (see Appendix C), and improvements in the adult migration and spawning indices in the San Lorenzo River downstream of the Felton Diversion.

4.6.1. Model Results – Alternative 2

Alternative 2 with Historic Hydrology – Habitat Indices

Alternative 2 was modeled using historical hydrology but not with climate change hydrology. As for the Proposed Project and other Alternatives, the majority of Alternative 2 effects involve an improvement in habitat conditions for steelhead and coho compared to the Baseline condition (Table 6). Effects are nearly identical to the Proposed Project at all locations except for a slight decline in the adult migration index for coho downstream of the Tait Diversion in critically dry years (Table 6, Figure 10b). This is most likely a result of more frequent restrictions on migration bypass flows due to lower storage levels in Loch Lomond Reservoir under Alternative 2 in early winter in a limited number of years compared to the Proposed Project (Appendix D-2, as discussed in Section 4.5.1 for Alternative 1). The 5.5% decline in the adult coho migration index is not likely to be biologically significant since migration conditions are still suitable 80% of the time during the coho migration period in dry years. Migration typically takes place during higher flow periods associated with winter storms. For comparison, conditions for migration are met only about 20% of the time in the San Lorenzo River downstream of Felton, even under unimpaired conditions (i.e. no diversion at Felton). This minor effect on adult coho migration habitat is not likely to be biologically meaningful and would not be considered "substantial" under CEQA standards of significance or meet any of the significance thresholds under CEQA (Section 4.2). Specifically, the decline in the migration index cannot be considered to interfere substantially with the movement of coho or to substantially reduce the habitat of coho, cause the coho population to drop below self-sustaining levels, threaten to eliminate coho in the San Lorenzo River or, substantially reduce the number or restrict the range of coho.

The only other negative effect is a 2.7% decline in the rearing habitat index in wet years for coho in Laguna Creek (Table 6, Figure 12a). The decline in Laguna Creek coho rearing habitat is a result of higher flows in April provided for adult migration under the Agreed Flows compared to no provision of migration flows in April under the interim bypass flow requirements in the Baseline. Coho rearing habitat is at optimum levels at lower flows than those provided for adult migration. Even with this effect, the wet year coho rearing index remains at 80% of the peak level in Laguna Creek (Figure 12a). This minor effect on rearing habitat is not likely to be biologically meaningful and would not be considered "substantial" under CEQA standards of significance or meet any of the significance thresholds under CEQA (Section 4.2). Specifically, a change of this magnitude in the rearing index would not substantially reduce the habitat of coho, interfere substantially with the movement or migration of coho, cause the coho population to drop below self-sustaining levels, threaten to eliminate coho in Laguna Creek or, substantially reduce the number or restrict the range of coho.

Effects on habitat in Laguna Creek, Liddell Creek, and Majors Creek are the same with Alternative 2 as the Proposed Project and Alternatives 1 and 3 and result from the provision of bypass flows for migration in April and spawning flows in December under the Agreed Flows (Table 6, Figures 6a, 6b, 6c, 7a, 7b, 7c). Habitat effects in the San Lorenzo River downstream of the Felton Diversion are similar for all Alternatives and the Proposed Project with improvements over the Baseline for adult migration and spawning, primarily in dry and critically dry years (Figures 6e, 7d, 10c). This is the result of higher bypass flows for migration and spawning under the Agreed Flows compared with the interim bypass flow requirements under the Baseline.

Table 6: Habitat effects of Alternative 2 compared to Baseline as percent change from Baseline using historical hydrology.

Stream Reach		Steelhead: Adult migration (m)	Steelhead: Spawning/incubation (i)	Steelhead: Rearing (r)	Steelhead: Smolt migration (s)	Coho: Adult migration (cm)	Coho: Spawning/incubation (ci)	Coho: Rearing (cr)	Coho: Smolt migration (cs)
Laguna Anadromous	wet	8.5%	5.9%	o	o	o	+	-2.7%	o
	normal	o	3.3%	o	o	o	+	-	o
	dry	o	+	o	o	o	+	-	o
	critically dry	o	+	o	o	o	+	o	o
Liddell Anadromous	wet	4.1%	3.4%	o	o				
	normal	5.0%	3.4%	o	o				
	dry	o	-	-	o				
	critically dry	o	-	-	o				
Majors Anadromous	wet	o	+	o	o				
	normal	o	+	o	o				
	dry	o	-	-	o				
	critically dry	o	o	o	o				
San Lorenzo below Tait St	wet	o		-	o	o			o
	normal	o		-	o	o			o
	dry	-		-	o	o			o
	critically dry	o		-	o	-5.5%			o
San Lorenzo below Felton	wet	+	+	-	o	4.9%	-	-	o
	normal	+	+	-	o	4.6%	-	-	o
	dry	8.0%	2.5%	o	o	15.8%	***+***	***o***	o
	critically dry	22.0%	5.6%	o	o	15.3%	-	***o***	o
Newell Anadromous	wet	6.3%	4.5%	+	3.5%	15.4%	5.3%	-	3.5%
	normal	17.8%	9.6%	o	12.4%	18.8%	9.1%	-	12.4%
	dry	46.6%	25.7%	+	40.2%	o	30.1%	+	40.2%
	critically dry	o	25.3%	8.6%	o	o	48.0%	2.0%	o

"-" = <2% decrease in habitat index

"+" = <2% increase in habitat index

"o" = no change in habitat index, or change of 1 day or less in migration periods

Values for coho spawning and rearing below Felton (bold italic) based on change in flow rather than habitat indices

Improvement in habitat effects in Newell Creek downstream of Newell Creek Dam under Alternative 2 (Table 6) is comparable to the Proposed Project (Table 3) and Alternative 3 (Table 7) and results from higher storage levels in Loch Lomond Reservoir than Baseline conditions, particularly in drier years (Appendix D-2).

Alternative 2 with Historic Hydrology – Water Temperature

Alternative 2 results in slightly higher reservoir elevations and more frequent spill conditions, similar to the Proposed Project. Hydrologic modeling indicates that the Alternative 2 would result in increased spill mostly in the winter and spring and infrequently during the warmer months of July and August (less than 4% of the time) (see Draft EIR Chapter 8, Alternatives). Spill in June would occur 38% of the time with the Alternative 2 compared to 19% under the Baseline. Increased spill during the winter could benefit steelhead and coho during the adult migration, spawning, and smolt migration life-stages. Increased frequency of spill in April and May with associated warmer temperatures may actually be beneficial for rearing steelhead (and coho if present) as long as the temperature is still within the suitable range. Salmonids grow faster at warmer temperatures within the suitable range with adequate food supply. Increased spill in June may also be beneficial as long as it does not result in temperature above the suitable level.

At times when the reservoir is spilling and the 1 cfs fish release is not sufficient to maintain temperature in Newell Creek below 21°C, Standard Operational Practice #6 requires the City to release additional flow through the fish release to achieve a maximum instantaneous temperature of less than 21°C as measured in the anadromous reach of Newell Creek and verified at the City stream gage in Newell Creek below the dam. With the implementation of this operational practice, potential adverse water temperature effects in Newell Creek and the San Lorenzo River due to an increase in reservoir spill frequency with the Alternative 2 would be avoided. Therefore, Alternative 2 would not substantially reduce the habitat of coho and steelhead, or otherwise substantially reduce the number or restrict the range of these species.

4.6.2. Evaluation for Any Significant Effects – Alternative 2

Alternative 2 has effects that are similar to the Proposed Project. As with the Proposed Project, Alternative 2 incorporates Agreed Flows and includes improvements to fish screening at the Tait and Felton Diversions and improving fish passage at the Felton Diversion and as needed at the Tait Diversion. Habitat modeling indicates that, although there are isolated instances of minor effects to some life stages in some reaches relative to the Baseline, Alternative 2 would result in a net beneficial effect on both species (Table 6). Alternative 2 does not have a substantial adverse effect on habitat indices for steelhead or coho in the project area. The habitat models also indicate that Alternative 2 would not interfere substantially with migration of steelhead or coho. Additionally, with the implementation of Standard Operational Practice #6 as part of Alternative 2, potential adverse water temperature effects due to an increase in frequency of reservoir spills would be avoided. Based on CEQA standards of significance and thresholds for mandatory findings of significance (Section 4.2), Alternative 2 is expected to have a less-than-significant impact on steelhead and coho under historical hydrologic conditions.

4.7. **Alternative 3:** Agreed Flows with all Proposed Project components except aquifer storage and recovery

Alternative 3 implements the Agreed Flows and portions of the Proposed Project except the ASR component. In terms of habitat for anadromous species, the major difference between Alternative 2 and the Baseline is the addition of adult migration flows in April and spawning flows in December in the North Coast streams with the Agreed Flows in Alternative 2; addition of adult migration flows in April in the San Lorenzo River below Tait Street; and implementation of bypass flows for adult migration and spawning in the San Lorenzo River downstream of the Felton Diversion (Table 1). These provisions of the Agreed Flows, which are not included in the interim bypass flow requirements reflected in the Baseline, result in increases in habitat values in months with hydrologic exceedance conditions in the 0%-60% range, which is generally in wetter year types (see Appendix C). There is also improvement in adult migration and spawning habitat indices in the San Lorenzo River downstream of the Felton Diversion.

4.7.1. Model Results – Alternative 3

Alternative 3 with Historic Hydrology – Habitat Indices

Alternative 3 was modeled using historical hydrology but not with climate change hydrology. As with the Proposed Project and other Alternatives, the majority of effects of Alternative 3 involve an improvement in habitat conditions for steelhead and coho compared to the Baseline condition (Table 7). Effects are nearly identical to the Proposed Project at all locations except for a slight decline in the adult migration index for coho downstream of the Tait Diversion in critically dry years (Table 7, Figure 10b). This is most likely a result of more frequent restrictions on migration bypass flows due to lower storage levels in Loch Lomond Reservoir under Alternative 3 in early winter in a limited number of years compared to the Proposed Project (Appendix D-2). The 4.2% decline in the adult coho migration index is not likely to be biologically significant since migration conditions are still suitable 80% of the time during the coho migration period in dry years. Migration typically takes place during higher flow periods associated with winter storms. For comparison, conditions for migration are met only about 20% of the time in the San Lorenzo River downstream of Felton, even under unimpaired conditions (i.e. no diversion at Felton). This minor effect on adult coho migration habitat is not likely to be biologically meaningful and would not be considered “substantial” under CEQA standards of significance or meet any of the significance thresholds under CEQA (Section 4.2). Specifically, the decline in the migration index cannot be considered to interfere substantially with the movement of coho or to substantially reduce the habitat of coho, cause the coho population to drop below self-sustaining levels, threaten to eliminate coho in the San Lorenzo River or, substantially reduce the number or restrict the range of coho.

The only other negative effect is a 2.7% decline in the rearing habitat index in wet years for coho in Laguna Creek (Table 7, Figure 12a). The decline in Laguna Creek coho rearing habitat is a result of higher flows in April provided for adult migration under the Agreed Flows compared to no provision of migration flows in April under the tolling flows in the Baseline. Coho rearing habitat is at optimum levels at lower flows than those provided for adult migration. Even with this effect, the wet year coho rearing index remains at 80% of the peak level in Laguna Creek (Figure 12a). This minor effect on rearing habitat is not likely to be biologically meaningful and would not be considered “substantial” under CEQA standards of significance or meet any of the thresholds for mandatory findings of significance under CEQA (Section 4.2). Specifically, a change of this magnitude in the rearing index would not substantially reduce the habitat of coho, interfere substantially with the movement or migration of coho, cause the coho population to drop below self-sustaining levels, threaten to eliminate coho in Laguna Creek or, substantially reduce the number or restrict the range of coho.

Table 7: Habitat effects of Alternative 3 compared to Baseline as percent change from Baseline using historical hydrology.

		Steelhead				Coho			
Stream Reach		Adult migration (m)	Spawning/incubation (i)	Rearing (r)	Smolt migration (s)	Adult migration (cm)	Spawning/incubation (ci)	Rearing (cr)	Smolt migration (cs)
Laguna Anadromous	wet	8.5%	5.9%	o	o	o	+	-2.7%	o
	normal	o	3.3%	o	o	o	+	-	o
	dry	o	+	o	o	o	+	-	o
	critically dry	o	+	o	o	o	+	o	o
Liddell Anadromous	wet	4.1%	3.4%	o	o				
	normal	5.0%	3.4%	o	o				
	dry	o	-	-	o				
	critically dry	o	-	-	o				
Majors Anadromous	wet	o	+	o	o				
	normal	o	+	o	o				
	dry	o	-	-	o				
	critically dry	o	o	o	o				
San Lorenzo below Tait St	wet	o		-	o	o			o
	normal	o		-	o	o			o
	dry	-		-	o	o			o
	critically dry	o		-	o	-4.2%			o
San Lorenzo below Felton	wet	+	+	-	o	4.9%	-	-	o
	normal	+	+	-	o	4.6%	-	-	o
	dry	8.0%	2.2%	o	o	15.8%	-	***o***	o
	critically dry	22.0%	5.1%	o	o	15.3%	-	***o***	o
Newell Anadromous	wet	4.3%	3.1%	+	2.5%	9.4%	3.4%	-	2.5%
	normal	13.7%	7.7%	o	9.4%	12.8%	7.2%	-	9.4%
	dry	34.0%	21.1%	+	31.7%	o	25.4%	+	31.7%
	critically dry	o	24.0%	8.6%	o	o	44.0%	2.0%	o

"-" = <2% decrease in habitat index
"+" = <2% increase in habitat index
"o" = no change in habitat index, or change of 1 day or less in migration periods
Values for coho spawning and rearing below Felton (bold italic) based on change in flow rather than habitat indices

Effects on habitat in Laguna Creek, Liddell Creek, and Majors Creek with Alternative 3 are the same as the Proposed Project and Alternatives 1 and 2 and result from the provision of bypass flows for migration in April and spawning flows in December under the Agreed Flows (Table 7, Figures 6a, 6b, 6c, 7a, 7b, 7c). Habitat effects in the San Lorenzo River downstream of the Felton Diversion are similar for all Alternatives and the Proposed Project with improvements over the Baseline for adult migration and spawning, primarily in dry and critically dry years (Table 7, Figures 6e, 7d, 10c). This is the result of higher bypass flows for migration and spawning under the Agreed Flows compared with the interim bypass flow requirements under the Baseline.

Improvement in habitat effects in Newell Creek downstream of Newell Creek Dam under Alternative 3 (Table 7) is comparable to the Proposed Project (Table 3) and Alternative 2 (Table 6) and results from higher storage levels in Loch Lomond Reservoir than Baseline conditions, particularly in drier years (Appendix D-2).

Alternative 3 with Historic Hydrology – Water Temperature

Alternative 3 is similar to the Proposed Project and Alternative 2 in that it results in slightly higher reservoir elevations and more frequent spill conditions. Hydrologic modeling indicates that the Alternative 3 would result in increased spill mostly in the winter and spring and infrequently during the warmer months of July and August (less than 4% of the time) (see Chapter 8, Alternatives). Spill in June would occur 38% of the time with the Alternative 3 compared to 19% under the Baseline. Increased spill during the winter could benefit steelhead and coho during the adult migration, spawning, and smolt migration life-stages. Increased frequency of spill in April and May with associated warmer temperatures may actually be beneficial for rearing steelhead (and coho if present) as long as the temperature is still within the suitable range. Salmonids grow faster at warmer temperatures within the suitable range with adequate food supply. Increased spill in June may also be beneficial as long as it does not result in temperature above the suitable level.

At times when the reservoir is spilling and the 1 cfs fish release is not sufficient to maintain temperature in Newell Creek below 21°C, Operational Practice #6 requires the City to release additional flow through the fish release to achieve a maximum instantaneous temperature of less than 21°C as measured in the anadromous reach of Newell Creek and verified at the City stream gage in Newell Creek below the dam. With the implementation of this operational practice, potential adverse water temperature effects in Newell Creek and San Lorenzo River due to an increase in reservoir spill frequency with Alternative 3 would be avoided. Therefore, Alternative 3 would not substantially reduce the habitat of coho and steelhead, or otherwise substantially reduce the number or restrict the range of these species.

4.7.2. Evaluation for Any Significant Effects – Alternative 3

Alternative 3 has effects that are similar to those of the Proposed Project. As with the Proposed Project, Alternative 3 incorporates Agreed Flows and includes improvements to fish screening at the Tait and Felton Diversions and improving fish passage at the Felton Diversion and as needed at the Tait Diversion. Habitat modeling indicates that, although there are isolated instances of minor effects to some life stages in some reaches relative to the Baseline, Alternative 3 would result in a net beneficial effect on both species (Table 7). Alternative 3 does not have a substantial adverse effect on habitat indices for steelhead or coho in the project area. The habitat modeling effects also indicate that Alternative 3 will not interfere substantially with migration of steelhead or coho under historical hydrology. Additionally, with the implementation of Standard Operational Practice #6 as part of Alternative 3, potential adverse water temperature effects due to an increase in reservoir spill frequency would be avoided. Based on CEQA standards of significance and thresholds for mandatory findings of significance (Section 4.2), Alternative 3 is expected to have a less-than-significant impact on steelhead and coho under historic hydrologic conditions.

5. References

Berry, C. 2016. Subject: City of Santa Cruz Anadromous Salmonid Habitat Conservation Plan Felton Diversion Downstream Passage Issues – December 2016. City of Santa Cruz, Water Department.

Bjornn, T. C. and Reiser, D. W. 1991. Habitat Requirements of Salmonids in Streams. In Influences of Rangeland Management on Salmonid Fishes and Their Habitats (Meehan), Ed., American Fisheries Society, Bethesda, MD.

Bovee, K.D. 1978. Probability-of-use criteria for the family Salmonidae. Instream Flow Information Paper 4. United States Fish and Wildlife Service FWS/OBS-78/07. 79pp.

CDFW. 1998. Memorandum of Agreement the California Department of Fish and Game and The City of Santa Cruz Regarding the Operation of The Felton Water Diversion. August 18, 1998.

CDFW. 2013. Standard Operating Procedure for Critical Riffle Analysis for Fish Passage in California. California Department of Fish and Game Instream Flow Program Standard Operating Procedure DFG-IFP-001. 24 p. Available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=57462

City of Santa Cruz 2021. *Draft City of Santa Cruz Anadromous Salmonid Habitat Conservation Plan for the Issuance of an Incidental Take Permit under Section 10(a)(1)(B) of the Endangered Species Act*. Prepared by City of Santa Cruz Water Department, Ebbin Moser + Skaggs LLP, Hagar Environmental Science, Gary Fiske and Associates, Balance Hydrologics, Inc., and Alnus Ecological. April.

ENTRIX. 2004. Additional Habitat Studies: Liddell, Laguna, and Majors Creeks. Prepared for the City of Santa Cruz. March 10, 2004.

ENTRIX. 2006. Draft Mitigated Negative Declaration Santa Cruz Water Rights Conformance and Extension Project. Prepared for: City of Santa Cruz Water Department 715 Graham Hill Road Santa Cruz, CA, 95060. December 18, 2006.

Flint, L.E., and Flint, A.L., 2012, Simulation of climate change in San Francisco Bay Basins, California: Case studies in the Russian River Valley and Santa Cruz Mountains: U.S. Geological Survey Scientific Investigations Report 2012–5132, 55 p.

Gray, C. 2016. “Re: HCP tech team 2” Received by C. Berry, R. Adair, J. Jankovitz, D. Howe, W. Stevens, J. Hagar, Z. Bean, M. Miletich, and G. Fiske. 27 October 2016. Email with attachment.

Hampton, M. 1997. Microhabitat suitability criteria for anadromous salmonids of the Trinity River. T.R. Payne and J.A. Thomas, contributing editors. U.S. Fish and Wildlife Service, Coastal California Fish and Wildlife Office, Arcata, CA, December 15, 1997. 10pp + figs and apps.

HES. 2007. Newell Creek Habitat and Fish Population Survey 2007. Technical Memorandum Prepared for: Ebbin Moser + Skaggs LLP. J-133. December 13, 2007.

HES. 2014. Assessment of Stream flow Effects on Migration, Spawning, and Rearing Habitat for Anadromous Salmonids in Streams Influenced by City of Santa Cruz Water Diversions Including Newell Creek. Prepared for City of Santa Cruz Water Department. Prepared by Hagar Environmental Science, Richmond, California. December 1, 2014.

Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, 2018. Indicators of Climate Change in California.

Payne, T.R. 1994. RHABSIM: User-friendly computer model to calculate river hydraulics and aquatic habitat. Pages 254-260 in Proceedings of the First International Symposium on Habitat Hydraulics, Trondheim, Norway, August 18-20, 1994.

Powers, P.D. and J.F. Orsborn. 1985. Analysis of Barriers to Upstream Fish Migration; An Investigation of the Physical and Biological Conditions Affecting Fish Passage Success at Culverts and Waterfalls. Albrook Hydraulics Laboratory Department of Civil and Environmental Engineering Washington State University Pullman, Washington. Submitted to Bonneville Power Administration Part of a BPA Fisheries Project on the DEVELOPMENT OF NEW CONCEPTS IN FISHLADDER DESIGN Contract DE-A179-82BP36523 Project No. 82-14.

R2 Resource Consultants. 2008. North Coast Instream Flow Policy: Scientific Basis and Development of Alternatives Protecting Anadromous Salmonids Task 3 Report Administrative Draft, Appendix E Development of Policy Element Alternatives Defining a Range of Protective Levels of Minimum Bypass Flow for Application at the Regional Scale: Upper MBF and Lower MBF Alternatives. Prepared for: California State Water Resources Control Board Division of Water Rights. Updated March 14, 2008.

Thompson, K. 1972. Determining stream flows for fish life. Pages 31-50 in Proceedings, instream flow requirements workshop. Pacific Northwest River Basins Commission, Vancouver, Washington.