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Assessment of Streamflow Effects on Migration, Spawning, and Rearing Habitat for Anadromous Salmonids in Streams Influenced by City of Santa Cruz Water Diversions including Newell Creek

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Notes for the 2014 Revised Report

In early January 2013 the City of Santa Cruz discovered an error in stage observations resulting from an error in measurement of the angle of the staff plate installed at the Lower Newell Creek stream gaging station below Newell Dam. The error resulted in recalculation of flow estimates during the period when instream flow studies were being conducted in Newell Creek. Since the flow data in question were used in development of stage-discharge relationships used in the PHABSIM modeling and passage assessments the habitat modeling and other analyses have been corrected to be consistent with the revised flow data. The revised data result in small changes to the minimum passage estimates (Table i) and to the shape of WUA vs. discharge relationships for spawning and rearing (Figures i and ii). The revisions also affect data on the Newell Creek extreme critical riffle presented in Appendices F; WUA vs. discharge data for Newell Creek presented in Appendix G; and WUA vs. discharge for individual transects in Newell Creek presented in Appendix H.

Table i. Changes to passage flow estimates for Newell Creek.

Transect Name	Adult Steelhead and Coho		Steelhead and Coho Smolts	
	Previous	Revised	Previous	Revised
N P-1 (below Rancho Rio)	**21.7**	**24.4**	**6.2**	**8.3**
N P-2 (below Rancho Rio)	20.0	22.7	4.6	6.4
N P-A1 (below Glen Arbor)	12.3	11.4	3.9	3.9
N P-A2 (above Glen Arbor)	19.7	21.3	2.8	3.2

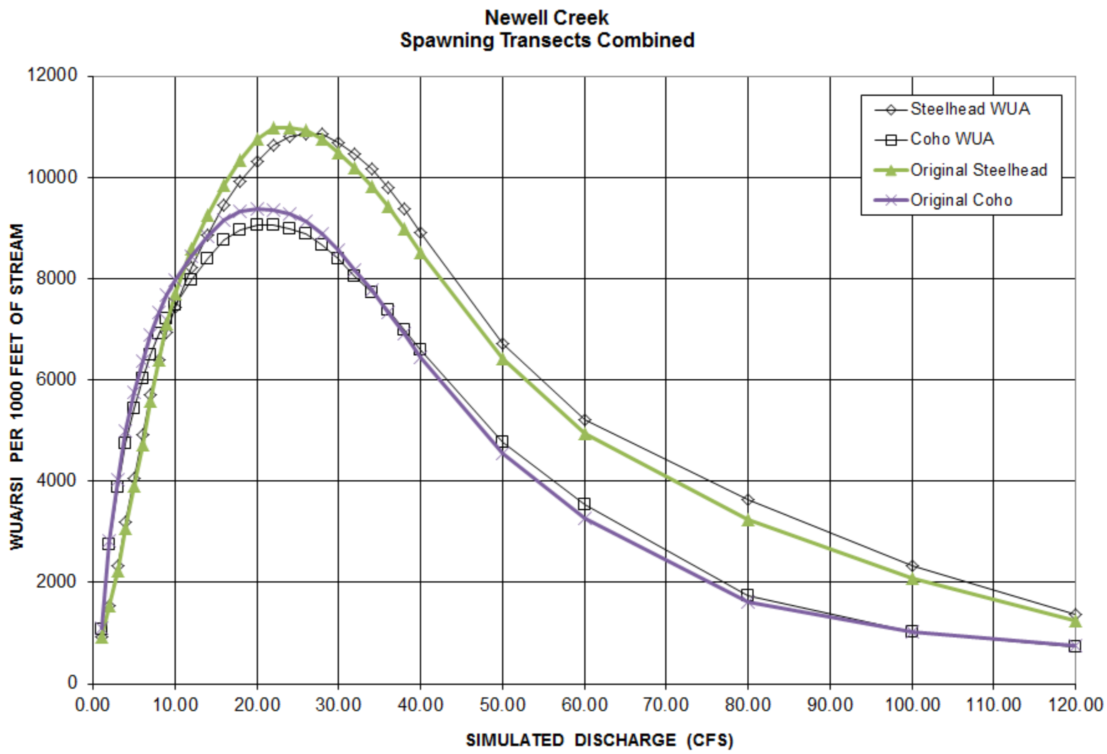

Figure i. Spawning habitat suitability for steelhead and coho salmon as a function of flow in Newell Creek.

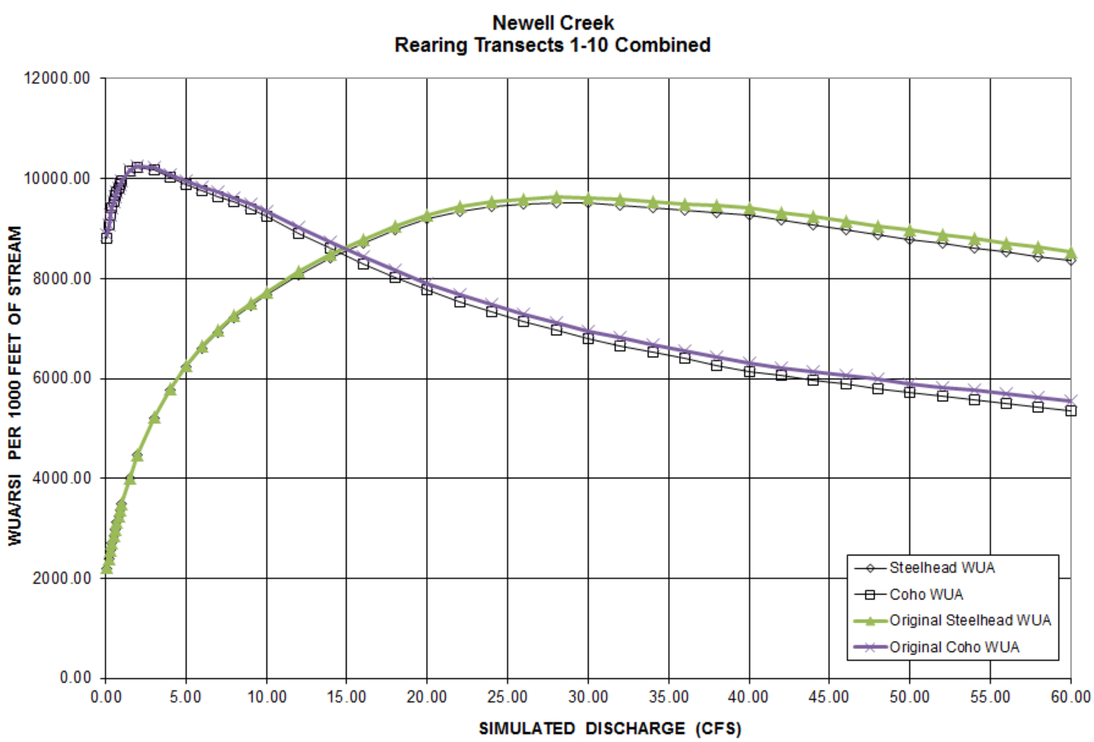

Figure ii. Rearing habitat suitability for steelhead and coho salmon as a function of flow in Newell Creek.

1 Introduction

Development of the City of Santa Cruz Habitat Conservation Plan (HCP) has resulted in the need to explore changes in operation of City diversions from the San Lorenzo River and North Coast streams to provide better conditions for steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*) populations in those streams (San Lorenzo River, Newell Creek, Liddell Creek, Laguna Creek, and Majors Creek). This may include limitations on diversions during certain periods to bypass flows to provide migration, spawning and rearing habitat. There is a limited amount of capacity within the City's water supply system for augmenting streamflow, and any augmentation of streamflow needs to be directed at achieving incremental improvement in habitat conditions that has the greatest potential for increasing the stability and productivity of target steelhead and coho salmon populations. The analysis described here is intended to support development of an HCP that makes the best use of available water supply to protect these species within the constraints of maintaining a reliable level of water supply for the City of Santa Cruz.

The study described in this report was conducted to develop data that quantify changes in habitat features as a function of streamflow. The study addresses flow-related habitat features during key life-history periods of anadromous salmonids including: adult migration between the stream mouth and spawning areas; migration of juvenile salmonids as smolts and during the rearing period; spawning and egg incubation; and juvenile rearing during low flow periods. The methodology involved selection of study sites (transects) to represent each of the life-history phases of interest and development of computer models to simulate changes in habitat metrics (depth, velocity, and substrate) as a function of streamflow. This information can be used, together with other existing information on limiting factors, hydrology, geomorphology, population characteristics, and so on, to develop operational and flow management options to improve habitat conditions for steelhead and coho salmon.

The City diversions on each of the North Coast streams (Liddell, Laguna, and Majors Creeks) are located upstream of the anadromous reaches of these streams and operate year round, potentially influencing migration, spawning, and rearing of both steelhead and coho salmon. This study therefore addresses each life stage for both species in the North Coast streams. Diversion at Tait Street also occurs year round and potentially influences migration passage opportunities for both smolts and adult steelhead and coho salmon and at critical passage locations in the 1.4 mile section between the diversion and the lagoon. Diversion at Tait Street also potentially influences habitat conditions for steelhead rearing in this reach. No spawning of either steelhead or coho salmon is known to occur downstream of Tait Street and coho salmon are not expected to rear there, primarily due to warm temperature during the summer (see Appendix A). Operation of Newell Reservoir has the potential to influence migration and spawning. The existing instream flow requirement of 1 cubic feet per second (cfs) augments rearing flows above levels that would occur naturally so the relationship between streamflow and juvenile rearing was not evaluated in Newell Creek. The Felton Diversion is also subject to existing agreements to avoid and minimize flow related effects on salmonid lifestages downstream of the diversion so this study does not address flow/habitat relationships in the San Lorenzo River between Felton and Tait Street (HES 2009).

1.1 Study Objectives

The objective of this assessment is to quantitatively determine the relationship between streamflow and potential migration, spawning, and rearing habitat for steelhead and coho salmon in each of the streams that feed the City of Santa Cruz water supply. Flow/habitat relationships were assessed for four distinct life stages of steelhead and coho salmon including, adult upstream migration passage, spawning and egg incubation, smolt downstream migration passage, and juvenile rearing.

Assessment of migration habitat was completed using the Thompson methodology (Bjornn and Reiser 1991, Thompson 1972). The spawning and rearing habitat assessments were completed using the Physical Habitat Simulation (PHABSIM) model of the Instream Flow Incremental Methodology (Bovee et al. 1998). PHABSIM consists of three principal components: a hydraulic model, habitat suitability criteria, and a habitat simulation. The hydraulic modeling component is used to simulate the transect depths and velocities that would occur over a range of simulated flows. The Habitat Suitability Criteria (HSC's) describe the suitability of different values of depth, velocity, and substrate to different species and lifestages. The habitat simulation component uses the HSC component to interpret the results of the hydraulic modeling to develop an index of habitat quality. This index is commonly termed Weighted Usable Area (WUA), although it is more accurately termed a Relative Suitability Index (RSI) (Payne 2003) or Physical Habitat Index (Payne 2007). Methods for each life stage are summarized in Section 3.0.

This is a habitat-based approach and changes in hydrology are related to predicted changes in habitat conditions. Change in habitat condition is not directly predictive of change in population status. The methods used are subject to potential error in measurement of parameters in the field, inadequacies of hydraulic modeling techniques, and errors due to invalid assumptions.

1.2 Target Species

This assessment includes steelhead and coho salmon. The North Coast watersheds and the San Lorenzo River watershed are part of the Central California Coast Distinct Population Segment (DPS). Steelhead composing this DPS are listed as threatened under the Federal Endangered Species Act (FESA) (NOAA Fisheries 1997). The Central California Coast DPS consists entirely of winter-run steelhead and extends from the Russian River south to, but not including, the Pajaro River at the southern border of Santa Cruz County. The HCP area is located in the southern part of the Central California Coast DPS (Busby et al. 1996). Steelhead are known to be present in all streams influenced by City water diversions.

Coho salmon in the HCP area are part of the Central California Coast DPS which is listed as threatened under the FESA and endangered under the California Endangered Species Act (CESA). Under FESA, the Central California Coast ESU extends from Punta Gorda in Humboldt County south to, and including, the San Lorenzo River (NOAA Fisheries 1996). Central California represents the southern margin of the species natural distribution, and coastal streams of Santa Cruz County constitute the southernmost extent of current coho distribution. In Santa Cruz County, historically coho salmon are believed to have used Gazos, Waddell, Scott, San Vicente, Soquel, and Aptos Creeks and the San Lorenzo River (CDFG 2003a). During recent surveys (2000-2002) coho salmon were found in Gazos, Waddell and Scott Creeks. No juvenile coho salmon were captured during electrofishing surveys conducted throughout the San Lorenzo River watershed (including both mainstem and tributary locations) between 1994 and 2002 (H.T. Harvey 2003; DWA 2000, 2002). Four juvenile coho salmon were observed in Bean Creek (tributary to Zayante Creek) in the fall of 2005 (DW Alley and Associates 2007) and two young-of-year coho were captured in September 2005 in Zayante Creek just upstream of the Bean Creek confluence (HES 2005). Some investigators contend that much of the former coho production in the San Lorenzo River was the result of stocking from the 1950s throughout the mid-1970s (DWA 2000, ENTRIX, Inc. 2004a, Kaczynski and Alvarado 2006). Others argue against this position (Adams et al. 2007).

No coho salmon have been observed in Liddell, Laguna, or Majors Creeks during electrofishing surveys of Santa Cruz County streams in the fall of 1981 (Harvey & Stanley Associates, Inc. 1982) or in recent visual surveys completed by the City of Santa Cruz in 2006 and 2007. Smolt-sized and young-of-year coho were captured in the Laguna Creek lagoon in 2005 (2nd Nature 2006) indicating that coho spawned successfully in Laguna Creek both during the winter of 2003-2004 and the winter of 2004-2005.

Habitat was evaluated for migration, spawning, and rearing of steelhead in all three of the North Coast streams and for coho salmon in Laguna Creek. Habitat conditions for migration and rearing of steelhead and coho were evaluated for the San Lorenzo River downstream of Tait Street although coho are not expected to rear in this area. There is no spawning of either species known to occur or expected there. Habitat conditions for migration, spawning, and rearing of both species were evaluated in Newell Creek. Coho salmon are not known to have ever occurred in Newell Creek but were included in the assessment since Newell Creek is included in the coho recovery plan (NMFS 2010).

O. mykiss exhibit the capacity for remarkable adaptability in life history strategies, with the ability to complete their life cycle completely in freshwater (rainbow trout) or as sea-run (anadromous) steelhead. Many streams in central California support both anadromous and resident forms with no distinguishable genetic differentiation (Moyle 2002, Nielsen 2003). Both forms can interbreed and the progeny of either life history trait may adopt the alternate life history pattern. In some streams, the non-migratory form may exist upstream of an impassible barrier while the anadromous form persists downstream. Unless they have been stocked in a stream, resident rainbow trout populations are believed to have derived, whether recently or at some point in the past, from steelhead.

ENTRIX, Inc. (2004b) identified barriers to anadromous runs in each of the North Coast streams within approximately 1.6 miles or less of the stream mouths. Therefore, this assessment of streamflow effects on habitat were limited to the identified anadromous reaches and considered only the anadromous life-history. Newell Creek likely supports anadromous populations downstream of migration obstacles downstream of Newell Dam and resident populations upstream of these obstacles (Hagar Environmental Science (HES) 2007). Assessment sites for migration and spawning in Newell Creek were therefore placed downstream of the migration obstacles. Assessment sites for migration and rearing in the San Lorenzo River were placed between Water Street (the upper limit of lagoon influence) and Tait Street, where the City diversion is located.

2 Background and Life History Considerations

2.1 Adult Migration Passage

Steelhead and coho salmon along the central California coast enter freshwater to spawn when winter rains have been sufficient to raise streamflows and breach the sandbars that form at the mouths of many streams during the summer. Increased streamflow during runoff events also appears to provide cues that stimulate migration and allows better conditions for fish to pass obstructions and shallow areas on their way upstream. The season for upstream migration and spawning of steelhead adults lasts from late October through the end of May but typically the bulk of migration (over 95% in Waddell Creek) occurs between mid-December and mid-April (Shapovalov and Taft 1954). Coho salmon have a more abbreviated spawning season that occurs earlier in the winter. In California, coho spawning migrations occur between late October and early March with more southern populations typically spawning slightly later. Between 1933 and 1942, the coho migration in Waddell Creek occurred between early December and early March with 90% of the run completed by early February (Shapovalov and Taft 1954). This relatively early spawning period for coho salmon increases the probability that their embryos will be exposed to severe conditions during high flow episodes and has resulted in very weak year classes in some of the remaining runs south of San Francisco Bay (Anderson 1995).

Steelhead have strong swimming and leaping abilities that allow them to ascend streams into small tributary and headwater reaches. Steelhead can swim at rates of up to 4.5 feet per second (fps) for extended periods of time and can achieve burst speeds of 14 to 26 fps during passage through difficult areas (Bell 1986). Leaping ability is dependent on the size and condition of fish and hydraulic conditions at the jump. Given satisfactory conditions, a conservative estimate of steelhead leaping ability is a height of 6 to 9 feet (Bjornn and Reiser 1991), although other estimates range from 11 feet (Bell 1986) to as high as 15 feet (McEwan 1999). Coho have slightly lower swimming and leaping ability than steelhead, with cruising speeds up to 3.5 fps and burst speed of 10 to 21 fps (Bell 1986). Maximum jumping height for coho is reported by Bell (1986) at just over 7 feet. These differences in swimming ability may limit coho to relatively lower gradient reaches of coastal streams. In Waddell Creek, Shapovalov and Taft (1954) found that coho consistently spawned lower in the creek.

Diversion during the winter (December through March) may potentially reduce passage opportunities for adult steelhead and coho salmon 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 standard procedures commonly referred to as the Thompson method (Bjornn and Reiser 1991, Thompson 1972). Using this method, critical riffles or other sites that are exceptionally wide and shallow or otherwise hinder fish passage can be identified. The objective of this method is to estimate the stream flow level that meets accepted criteria for depth of flow and flow velocity that facilitate passage of a fish species and life-stage of interest, in this case steelhead and coho salmon.

Streamflow can also influence opening and closing of the lagoons at the mouths of coastal streams. In the Santa Cruz County streams in this study, the lagoons are relatively small and tend to open in the fall with small increases in streamflow (HES 2009). Generally, initial precipitation events in the fall are associated with conditions favoring lagoon opening including increased streamflow and wave energy. Flow levels at which suitable migration conditions exist at critical riffles appear sufficient to open or maintain the lagoons in an open state in these streams (HES 2009). In addition, the magnitude of City Diversions is relatively small compared to flows during migration periods so the potential effect of City Diversions on lagoon opening and closing is minimized. City Diversions are usually curtailed during runoff events due to concerns with excessive sediment and turbidity.

2.2 Spawning and Egg Incubation

Both steelhead and coho salmon select spawning sites with gravel substrate and with sufficient water velocity to maintain circulation through the gravel and provide a clean, well-oxygenated environment for incubating eggs. Flowing water also enables the female to clean spawning gravels of fine sediment when constructing the nest site (redd). Preferred flow velocity is in the range of 1 to 3 fps for steelhead (Raleigh et.al 1984) and 0.7 to 2.3 fps for coho (McMahon 1983). Moyle (2002) states that water velocity over steelhead redds (spawning nests) is typically 0.5 to 5 fps and depth is 0.3 to 5 feet. Preferred gravel substrate is in the range of 0.25 to 4 inches in diameter for steelhead and 0.5 to 4 inches for coho (Bjornn and Reiser 1991).

Typically, sites with preferred features for spawning occur most frequently in the pool tail/riffle head areas where flow accelerates out of the pool into the higher gradient section below. In such an area, the female will create a pit, or redd, by undulating her tail and body against the substrate. This process also disturbs fine sediment in the substrate and lifts it into the current to be carried downstream, cleaning the nest area. Incubation and emergence success are influenced by accumulation of fine sediments (generally less than 3.3 mm) in the substrate. Embryo survival for steelhead decreases when the percentage of substrate particles less than 6.4 mm reaches 25 to 30% and is extremely low when fines are 60% or more. Emergence of steelhead and coho fry is generally high when fine sediments are less than 5% of substrate volume but drops sharply with fine sediment volume of 15% or more.

Steelhead eggs hatch in 3 to 4 weeks at temperatures of 10 to 15°C, and fry emerge from the gravel 2 to 3 weeks later (Moyle 2002). Coho embryos hatch after 8 to 12 weeks of incubation with timing highly dependent on temperature conditions. Hatchlings remain in the gravel another 4 to 10 weeks until their yolk sacs have been absorbed (Moyle 2002). In central California, near the southern edge of their range and presumably where temperature conditions are highest, the time between spawning and emergence from the gravel would be expected to be closer to 12 weeks. Survival of fertilized eggs through hatching and emergence from the gravel are often limited by severe changes in flow that can dislodge eggs from the substrate, result in sedimentation, or de-water incubation sites.

Diversion of flow during the winter has the potential to alter habitat conditions for spawning of salmonids in the study streams. The relationship between flow and spawning habitat quality was assessed in the anadromous reaches of study streams by collecting data to calibrate a

Physical Habitat Simulation Model (PHABSIM). 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.

2.3 Rearing

In Central California streams coho typically rear for one year in freshwater and steelhead typically rear one or two years. Habitat selection and use by juvenile salmonids is complex and variable. After emergence from the gravel, fry inhabit low velocity areas along the stream margins. As they feed and grow they gradually move to deeper and faster water. Steelhead juveniles (parr) of 4 to 6 inches (generally in their second year of life) may be found in a variety of habitat types including pools, runs, and riffles. Parr larger than 6 inches are more often found in deeper waters where low velocity areas are in close proximity to higher velocity areas and cover is provided by boulders, undercut banks, logs, or other objects. Heads of pools generally provide classic conditions for older trout. Coho parr are most abundant in large, deep pools (greater than 1 foot) with abundant cover in the form of logs, roots, woody debris, undercut banks, and overhanging vegetation (McMahon 1983). Some studies have shown positive correlations between coho standing crop and pool volume (McMahon 1983). Trout and juvenile coho can inhabit quite small streams, particularly in coastal streams. Often habitat may be far more limiting for older juveniles than habitat for younger fish. The critical period is during base flow conditions that generally occur between May and October in Central California. Streamflow can drop to very low levels with loss of depth and velocity in riffle and run habitats, or in the extreme, only isolated pools with intervening dry sections of stream. Winter high flows may also be limiting, particularly for coho salmon, if backwater refuge areas are not available.

Food and cover are key factors for rearing steelhead and coho (Mason and Chapman 1965; Shapovalov and Taft 1954). Food availability, in terms of production of aquatic and terrestrial insects, is influenced by substrate composition, extent of riffles, riparian vegetation, and flow. The highest production of aquatic invertebrates is in gravel and cobble substrate with low amounts of fine sediments, often occurring in riffle type habitats. Production of coho has been shown to be higher in pools with larger riffles upstream (Pearson et al. 1970). Coho production decreases with high levels of fine sediments and high embeddedness of cobble substrate (Crouse et al. 1981). Bjornn et al. (1977) found that the density of rearing steelhead and chinook salmon in artificial channels was reduced in nearly direct proportion to increased cobble embeddedness. Response to increased embeddedness was even greater during the winter. During the high flows, reduced food abundance, and lower temperatures occurring in winter, both coho and steelhead may move into the substrate or other cover. Backwater habitat, small tributaries, or other low velocity areas may also be important winter habitat. The influence of flow on food production or availability or on sediment transport was not a component of this study.

Temperature is an important factor for steelhead/rainbow trout and coho, particularly during the over-summer rearing period. In many Central California streams growth slows or ceases in conjunction with warm, low flow conditions in late summer. Temperature monitoring in the North Coast streams indicates that temperature is well within the suitable ranges for both steelhead and coho salmon juveniles and cooler than in many streams that support steelhead in the region (HES 2009). The existing temperature monitoring data were collected during periods when the diversions were operational. The diversions are not expected to negatively influence temperature conditions and temperature was not a factor considered in this analysis.

Steelhead/rainbow trout populations in Central California can occur in streams with relatively low baseflow and in streams varying widely in terms of standard evaluation parameters such as pool:riffle ratio and mean depth. Often, local populations thrive under conditions that may depart widely from species norms (Behnke 1992). The anadromous life history of both steelhead and coho salmon is an adaptation that allows them to avoid the limited rearing potential in the relatively unproductive streams of their birth in favor of the much richer potential provided by the marine environment. This life history is a tradeoff between remaining in the relative safety of their freshwater rearing environment long enough to achieve a size that provides relatively greater protection from the abundant potential predators in marine waters.

Diversions throughout the year have the potential to alter habitat conditions for rearing salmonids in the study streams. Given the complexity and variability of habitat selection and use by juvenile salmonids and that hydraulic conditions in good rearing habitat are generally complex and difficult to model effectively, predicting change in habitat quality for rearing juveniles based only on change in flow is exceedingly problematic. Nevertheless, the relationship between flow and two components of rearing habitat quality, i.e., depth and velocity, was described in study streams through application of the PHABSIM model. This information, while not necessarily useful in isolation, may be combined with other information sources to provide some basis for assessing the effect of flow on rearing habitat.

2.4 Smolt Migration

Shapovalov and Taft (1954) conducted an extensive study of steelhead and coho salmon migration in Waddell Creek. Behavior of steelhead/rainbow trout in Waddell Creek is probably typical for most Central California populations. Trout of various ages migrated out of Waddell Creek in all months of the year but the majority migrated in April, May and June. Downstream migration of young-of-year fish (less than a year old) extended from late-April through the following spring; however this movement may have been just dispersal to downstream rearing areas and not a true seaward migration. Downstream migration of 1-year old steelhead was from April through late June and 2-year old fish from March through late May. Coho in Waddell Creek migrated almost exclusively as one-year old fish and 96% of all migration occurred between April 1 and June 15.

Temperature and flow conditions may influence smolt migration and in addition, smolts are subject to predation, primarily by birds including cormorants, mergansers, and herons. Although predation by fish can be high in certain situations, large predatory fish are generally not present in smaller coastal streams. Predation by birds can increase under conditions where smolts have to traverse shallow sections of streams without cover. With clear water, birds can be particularly effective predators. Conditions favoring predation by birds occur in channel reaches modified for flood control where the channel is maintained in a wide, shallow configuration and is largely devoid of in-stream large woody debris and riparian vegetation.

Diversion during the spring, particularly during April and May, may potentially reduce passage opportunities for steelhead and coho salmon 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 Thompson method as described in greater detail in Section 3. Migration passage for rearing juveniles at these locations can also be evaluated with the data collected although depth criteria may be different.

3 Methodology

3.1 Flow Measurements

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 of Santa Cruz in the anadromous reach of each stream. In some cases where there was significant distance between the study site and the stream gage and the potential for flow accretion, regression equations were developed from site measured flow to relate flow at the study sites to flow at the stream gage.

One of the passage sites in Liddell Creek was located upstream of the West Branch confluence and flow at the anadromous gage, downstream of the West Branch confluence, was higher due to the contribution of the West Branch. Flow at the upstream passage site was estimated from flow measurements made near the site or by linear regression of measured flows above the West Branch with corresponding flow from the anadromous gage record (Section 3.3.2). In Laguna Creek, two of the passage transects were in the vicinity of the anadromous gage and two were further upstream, near the confluence with Y Creek. Flows at the upper sites were also estimated from flow measurements made near the site or by linear regression of measured flows in the upper study site with corresponding flow from the anadromous gage record to account for accretion of flows between the two sites, particularly during runoff periods. In Majors Creek there was a diversion a short distance upstream from Highway 1 that influenced flows at the anadromous gage location. One passage site was located upstream from the diversion and flow at this site was estimated from flow measurements made near the site or by linear regression of measured flows in the upper study site with corresponding flow from the anadromous gage. In both Newell Creek and the San Lorenzo River downstream of Tait Street the respective reference gages were the gage maintained by the City of Santa Cruz below the outlet of Newell Reservoir and the USGS San Lorenzo River at Santa Cruz Gage located immediately downstream of the City's Tait Street Diversion. In Newell Creek, many transects were located near Glen Arbor Road, about 1.5 miles downstream of the gage. Flow measurements made by the City of Santa Cruz were used to develop an equation for estimating flows at these study sites from flow at the City gage.

3.2 Passage at Critical Riffles

Passage at critical riffles was analyzed using 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 both at least 25% of the total channel width and a contiguous minimum width of 10% of the channel. Thompson then recommends averaging the results for all the study transects, and the averaged value is the passage flow recommendation for the stream segment. 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. For example, some recent studies have adopted a specified width (e.g., 10 feet) for attainment of minimum depth criteria rather than a percentage of the channel width.

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 Tait Street were identified during a habitat survey conducted in October 2005 (Appendix B) and critical passage locations were identified in Newell Creek downstream of the reservoir during the fall of 2007 and during the winter of 2009-2010. A single transect was placed along the shallowest cross-section of each riffle. Transects were marked with head pins at each critical riffle by driving a section of rebar into the bank above the bankfull channel. Transects incorporated the shallowest portion on the probable route a migrating salmonid would follow. A fiberglass survey tape was stretched between rebar head pins with the zero point of the tape on the west side of the channel. Streambed elevations were measured at regular intervals along the tape using an autolevel and leveling rod. The reference elevation for each cross-section was the west head pin. 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. Water surface elevation was measured relative to the west headpin at each transect. 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 of Santa Cruz in the anadromous reach of the North Coast streams and below Loch Lomond Dam in Newell Creek.

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 (e.g., 0.6 feet) 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.

Critical flow levels for passage at each cross-section were determined in the data analysis stage using standard passage criteria values for adult steelhead and coho salmon (i.e., minimum depths and widths). For adults migrating upstream, the minimum passage flow is that flow providing a depth of 0.6 feet or greater across 25% of the wetted channel width and a contiguous minimum width of 10% of the wetted channel. 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 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, Inc. 2004b, 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. The benefit of meeting a higher value (e.g., 0.8 or 1.0 feet) should be weighed against the potential benefits of using limited supplies for flow augmentation during other life history stages. In this study, the standard passage criteria were judged to be applicable. Given swimming speeds cited previously, high velocity was not a factor at any of the identified passage sites.

The transect data were also used to assess conditions for smolt migration passage and for juvenile in-stream migration during the rearing period. The channel cross-section and hydraulic data are all identical to the adult passage assessment, only the depth criteria are altered (a depth of 0.3 feet or greater across 25% of the wetted channel width and a contiguous minimum width of 10% of the wetted channel. Velocity was not considered to be a factor in downstream migration success. Downstream migration of both steelhead and coho salmon smolts is expected to occur in April, May and June (Section 2.4), although the stream mouths may close at varying points during this period in any given year.

The analysis can also be applied to downstream migration passage of adult steelhead. Steelhead that survive spawning return downstream to re-enter the ocean. All coho die following spawning. As many as 20% of adult steelhead spawners may be repeat spawners and some fish may return to spawn up to 3 or 4 times (Shapovalov and Taft 1954). In some streams fish return downstream immediately after spawning while in others they may remain for a period up to several months. After spawning, these fish do not typically resume feeding while in freshwater. In Waddell Creek the bulk of adults returned downstream from April through June. Fish that remain in the stream for any period of time generally reside in deeper pools. Adequate cover and cool temperature are critical habitat variables for adults that hold over for the entire summer.

3.3 Passage at Bedrock Sheets in Newell Creek

Two bedrock sheet passage obstacles upstream of Rancho Rio Bridge in Newell Creek were more complex than the critical riffles and were assessed using a 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. The cross-section for N P-3a was about a third of the way from the top of the chute and for N-P4a it was at the top of the chute. 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 Mannings Equation. The Mannings equation predicts mean velocity from wetted width, cross-sectional area, bed slope, and an empirical roughness coefficient (the Mannings 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 choice of roughness coefficient, minimum and maximum velocity (and corresponding flow estimates) were calculated. For this analysis we used Mannings coefficients 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 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 salmon 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.

3.4 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 water depth and velocity with discharge. The model output includes an index representing habitat suitability in terms of depth and velocity conditions. For spawning, the suitability index also incorporates substrate size characteristics.

There are many important components of salmonid rearing habitat that are not included in the analysis such as food availability, cover, and inter-species interactions. In addition, there are limitations on the ability of the models to accurately represent depth and velocity conditions and fish response to those conditions. Fish response to these conditions is assumed to be related to observations of habitat use either in the study streams or in other studies. In this study, it was impractical to develop site-specific data and the observations come from studies in the Trinity River in Northern California (Hampton 1997). Observations made in studies of steelhead and coho in the Trinity River may not be completely applicable to these species in the San Lorenzo River and other relatively small coastal drainages in Central California. Nevertheless, this type of study provides some indication of how rearing habitat changes in response to flow and can provide a gross measure of habitat quality when used in conjunction with other information.

3.4.1 STUDY SITES

In general, study sites were selected by walking the stream and identifying locations where, in the professional opinion of an experienced fisheries biologist, conditions were generally favorable for either spawning or rearing of steelhead or coho salmon. 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, Inc. 2004b for North Coast Streams; HES 2007 for Newell Creek; and a 2005 HES survey of the Lower San Lorenzo River (Appendix B). 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. Information on individual transects is provided in Table 1.

North Coast Streams

The study areas included the anadromous reaches of the three North Coast streams influenced by City diversions. There are three main branches of Liddell Creek including the mainstem (also referred to as the Middle Branch), the West Branch which joins the mainstem about 0.25 miles upstream from Highway 1, and the East Branch which joins the mainstem about 0.9 miles upstream from the West Branch. The East Branch is not accessible to steelhead due to a migration barrier in the mainstem about 0.75 miles upstream from the West Branch confluence. Although the West Branch likely supports steelhead, at least in the lower part of the stream, only the East Branch and mainstem are influenced by the City diversion, thus all PHABSIM study sites were located in the mainstem downstream of the East Branch. Transects were distributed in two study areas in Liddell Creek, one downstream of the West Branch confluence and one between the West Branch confluence and the East Branch confluence (Figure 1). Each study area in Liddell Creek had two spawning transects and three rearing transects. PHABSIM study sites were dispersed within two discreet areas in the anadromous reach of Laguna Creek: a lower area was in the reach just upstream of Highway 1 and an upper area was near the upper end of the anadromous reach about 0.5 miles downstream of the Y Creek confluence (Figure 2). There were two spawning transects and three rearing transects in each of the two study areas in Laguna Creek (Table 1). In both Liddell and Laguna Creeks the area downstream of Highway 1 is influenced by the summer lagoon and these areas are not appropriate for PHABSIM modeling. In Majors Creek, study sites were divided between the reach downstream of Highway 1 and the reach upstream of Highway 1 (Figure 3). The lower study area in Majors Creek had two spawning transects, and three rearing transects; the upper study area had two spawning transects, and four rearing transects (Table 1).

San Lorenzo River Downstream of Tait Street

This study is specific to the reach downstream of the City's Tait Street diversion and is not applicable to reaches upstream of Tait Street. The relationship between streamflow and rearing habitat quality was investigated in the fall of 2005 by measuring habitat characteristics in this reach under different flow conditions. An initial habitat assessment using the CDFG Salmonid Stream Restoration Manual was conducted to quantify the number and extent of different habitat types in the study reach (Appendix B). Flow during the habitat survey, measured at Tait Street (USGS gage 11161000 San Lorenzo River at Santa Cruz), was approximately 17 to 18 cfs. Flow in Pogonip Creek, entering the San Lorenzo River between Tait Street and Highway 1, was approximately 0.5 cfs (Chris Berry, personal communication, October 2005). At this relatively high level of flow it was difficult to distinguish some of the boundaries between habitat types. Several units were first categorized as deep run type habitat since there was significant velocity throughout the unit but they were later re-categorized as pools based on depth characteristics and subsequent observations at lower flow levels.

Representatives of each habitat type that are likely to support rearing steelhead were selected for study. A total of 9 transects were selected to represent the range of conditions for rearing juvenile steelhead in each of the habitat types identified in the survey reach (Figure 4) Four of the transects were in pool habitat, four were in run habitat, and one was in a riffle. Information on individual transects is provided in Table 2.

Newell Creek

The relationship between streamflow and spawning habitat quality was investigated during the winters of 2007-2008 and 2009-2010. Potential spawning areas for the 2007-2008 study were identified during habitat assessment in August 2007 using the CDFG Salmonid Stream

Restoration Manual (Appendix C). The PHABSIM study focused on the reach of Newell Creek downstream of bedrock outcrops beginning just upstream of Rancho Rio bridge, since they likely limit or preclude the anadromous life history in upstream areas (Figure 5). In 2007-2008, there was sufficient flow to complete the study during a single storm event in late February that resulted in sufficient runoff to fill the reservoir and result in spill to the lower portion of the Creek. Significant spill began on February 23 and flow peaked at about 80 cfs on the night of February 24 and fell to less than 20 cfs on the morning of February 26. Due to limited access to the creek and the extremely short duration of higher flows necessary for the study, only 2 transects in spawning habitat were evaluated. Both transects were located in glide type habitat in the transition from a pool-tail to a riffle head (Table 2). Evidence of redds had been observed at this location during previous surveys and it appeared to be one of the better spawning sites in the entire reach of Newell Creek downstream of the dam. During the winter of 2009-2010, spawning habitat was evaluated at two additional sites and rearing habitat was evaluated at ten sites. PHABSIM transects for spawning and rearing were selected in a walk-through of the project reach with David Hines of NOAA Fisheries using the same approach described at the beginning of this section.

3.4.2 DATA COLLECTION AND PRE-PROCESSING

The study required collection of channel geometry and hydraulic data including an elevation profile, depth and velocity cross-sections, and water surface elevation (stage) across a range of flows that bracketed the suitable range for a given lifestage. 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. At each cross-section, a transect was located across the stream channel perpendicular to the predominant flow direction. Transects were marked at each end by a 0.5 inch by 3 foot length of rebar driven into the streambank. These headpins served as the site benchmarks to reference water stage. The right bank headpin was used as the zero point for all stationing. 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. Measurements were made at intervals of 1.5 feet or less, depending on the width of the channel and the distribution of flow across the transect. Water stage data were collected at each cross-section to serve as the low-flow point for stage/discharge relationships. One transect was selected for flow estimation in each study area 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. Rearing transects were often in pools where flow measurement is imprecise and problematic due to low velocities and more complex flow direction due to eddies and potentially large differences between surface and bottom flow velocity. Flow measurements were supplemental to the City's 15-minute gage data for each stream.

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 to include (at a minimum) a high flow, a low flow, and an intermediate flow. These data were collected during storm runoff periods.

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.

In Liddell Creek, the City gage is located downstream of the West Branch. All sites in the lower study area were also below the West Branch and were well-represented by the City gage. Sites in the upper study area were upstream of the West Branch and therefore, flow at cross-sections in the upper study area would be lower than simultaneous flow at the City gage, particularly during periods of storm runoff. Therefore an equation was developed using flow measurements at upper study area sites and simultaneous City gage readings. The observed relationship can be expressed by a simple linear regression of the form: $Q_u = 0.1694 + 0.6616Q_c$, where Q_u is flow in the upper study reach, upstream of the West Branch and Q_c is flow at the anadromous gage (Appendix D).

In Laguna Creek, the lower study transects were all close to the City gage and gage data was used as the best estimate of flows for these transects. There are no significant tributaries between the upper and lower study areas; however they are far enough apart for significant accretion, particularly during stormflows. Therefore, development of stage/discharge relationships for the upper study transects used site measured flows or correlation with the City gage.

In Majors Creek, there is a diversion within the upper study area that potentially influences the City gage as well as transects located downstream, particularly during lower flows. Flows for the four sites upstream of the diversion location were either measured independently or estimated by regression with the City gage data.

In the lower San Lorenzo River, the City's Tait Street gage is located at the upper end of the study reach. Pogonip Creek contributes flow in the upper part of the study reach, upstream from Highway 1. At the time of the study flow in Pogonip Creek was about 0.5 cfs and no modification to the flow estimates was made for transects downstream of Pogonip Creek.

The City's Newell Creek stream gage measures flow downstream of Newell Creek dam. There are no major tributaries between the dam and the San Lorenzo River; however, flows measured at the study sites were consistently higher than simultaneous gage data indicating significant accretion of flows downstream of the dam. For sites measured in 2007, gage data were adjusted by a factor of 1.17 based on the additional watershed area contributing to the study site downstream of the gage. This gave better agreement with study site measured flows and also provided stage/discharge relationships with low mean error. For sites measured in 2009-2010, flows were measured independently or estimated by regression with the City gage data.

Multiple stage measurements were restricted to a maximum of five data pairs per transect due to limitations in the modeling software. These stage and discharge data were utilized for calibration of the hydraulic model in the analysis. At some of the North Coast cross-sections, high flows in February 2007 resulted in changes in the channel profile. Data collected after these changes were not used for developing stage discharge relationships. All data used to develop stage/discharge relationships are provided in Tables 3 through 7.

Substrate observations were collected at each interval across the transects at the lowest calibration flow when visibility and access were the greatest. Substrate particle size classes and relative abundance were characterized at each measurement point (along the study transect) using the Bovee substrate coding system (see Table 8). This method of substrate coding (Bovee 1978) uses a single digit (corresponding to particle size) and a decimal (corresponding to abundance). The two-digit code describes the mixture of the two adjacent-sized particle classes which dominate a particular cell by assigning the number (1 through 8 as in Table 8) of the smaller-diameter size class to the digit place and the volumetric percentage (0 through 9 for 0% to 90%) of the larger-diameter size class to the decimal place. Suitability curves for substrate size classes for steelhead and coho salmon spawning using the Bovee system are depicted in Figure 6.

3.4.3 HYDRAULIC MODEL DEVELOPMENT AND CALIBRATION

The purpose of hydraulic simulation under the PHABSIM framework is to simulate depths and velocities in streams under varying stream flow conditions. Simulated depth and velocity data are then used to calculate the physical habitat index, either with or without substrate and/or cover information. Depths are not directly determined, but are calculated from water surface elevations and bottom contours. The calibration flows commonly enable the hydraulic and habitat models to reliably simulate depths and velocities from 40% of the low measured flow to 250% of the high measured flow. Calibration flows and flow ranges for WUA/RSI estimates are shown in Table 9.

3.4.3.1 Water Surface Elevation Prediction

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 in Tables 3 through 7. The stage-discharge relationships are used to determine water surface elevations across a series of simulation flows. Each cross section is treated independently of all others in the data set. A minimum of three stage-discharge measurement pairs is used to calibrate the stage-discharge relationship.

3.4.3.2 Water Velocity Prediction and Calibration

Water velocity predictions can be made in several ways. These include predicting velocities from a template of measured velocities from a single flow (one-flow method), regressing measured velocities against discharge for two or more flows (three-flow regression method), or deriving velocities from flow apportioned into cells based on cell depth (no-velocity method). Velocity regression is rarely used in instream flow studies and is no longer recommended (Milhous & Schneider 1985).

The “one-flow” technique was used for predicting water velocities on study cross-sections in this study. This technique uses a single set of measured velocities and depths, and using Manning’s formula, the Manning’s n is solved 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. In this sense, the one set of velocities is used as a template to predict the simulated velocities at other discharges. Simulated velocities are inspected during hydraulic calibration.

The purpose of velocity calibration is to determine, through examination of the simulated velocity adjustment factors (VAF’s) and velocity patterns, the adequacy of velocity simulations up to a given flow level. It is also important to preserve as closely as possible the measured velocities. Generally, few cells require adjustment during velocity calibration. In those cases when adjustments are needed, individual cell calibration modifications are limited to minor velocity changes in shallow edge cells or to cells that either significantly deviated from surrounding patterns or contributed to substantial errors in discharge calculations. Calibration is generally accomplished by specifying an adjacent cell’s Manning’s n roughness value and applying it to the target cell. A second technique is to average Manning’s n values or velocities from adjacent cells, then substitute a new Manning’s n in the target cell.

Other calibration adjustments involve changing negative velocities to positive, or not applying observed angles to velocities, especially for cases when a transect under-calculates discharge. These situations usually occur in edge cells, or in cells where an upstream obstruction creates a negative or angular velocity that is likely to change or turn positive at higher levels of flow. This method has little effect on habitat index simulations because the program uses absolute values of the velocities for habitat suitability.

3.4.3.3 Habitat Suitability Criteria

An important component of an instream flow study is the habitat suitability criteria (HSC) that describe the relative suitability of water depth, water velocity, stream substrate, and cover types to the fish species being evaluated. For the current study, HSC are required for spawning and rearing of both steelhead and coho salmon. The preferred method for developing HSC is to make numerous site-specific observations of the target species in the study streams or suitable surrogates (Category II and III HSC). Such observations involve a large expenditure of effort and more commonly, existing HSC from other studies are used. HSC may also be developed using professional judgment (Category I HSC). No site-specific observations of either steelhead or coho life stages are available for the study streams. Due to relatively low numbers of these species in the study streams, particularly coho salmon, and other limitations of the HCP process, collection of site specific data was not feasible for this study. Therefore, existing HSC from similar streams were used.

For spawning adult steelhead and coho salmon and rearing juvenile steelhead and coho salmon, HSC depth and velocity criteria were developed for sea-run steelhead and coho salmon in the Trinity River by the U.S. Fish and Wildlife Service (Hampton 1997). While the Trinity River is a significantly larger stream and is located some distance to the north of Santa Cruz County, these HSC were judged to be most compatible with steelhead in the study streams given other alternatives. The Trinity River HSC are more likely to be applicable to these streams than HSC developed in larger, more northerly streams in Oregon and Washington. The Trinity River HSC are Category II or Category III curves (developed from actual observations), while many of the HSC available from other studies are Category I (developed using professional judgment). HSC for spawning steelhead are available from the Carmel River; however, these curves were developed by measuring conditions at existing redds and flow conditions may have varied from those at the time of spawning. Suitability criteria for spawning substrates were taken from Bovee (1978) due to a lack of data from Hampton (1997). Figure 6 illustrates the HSC for spawning steelhead and coho salmon including velocity (in feet per second), depth (in feet), and substrate (Bovee code). Figures 7 and 8 show a comparison of all the HSC curves available for spawning steelhead and coho salmon. Figure 9 illustrates the HSC for rearing steelhead and coho salmon and Figures 10 and 11 show a comparison of all HSC curves available for rearing steelhead and coho salmon.

3.4.3.4 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 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).

3.4.3.5 Hydraulic Simulation and Calibration

All transect water surface elevations were simulated using log-log stage-discharge regression (IFG4). Sources of error in the stage-discharge regressions include stage measurement error, flow measurement error, changes in stage and flow during the period when the measurements are being made, and change in the channel cross-section elevations or stage of zero flow due to bed mobilization or deposition during high flows. Stage measurements are generally quite precise and are expected to be in error by no more than +/- 0.02 feet. Flow measurements can be more variable, generally within +/- 5% of the actual flow. In some cases, field data were adjusted within these ranges when there was a reasonable basis for doing so (i.e., evidence of stage or flow changes during the measurement period) in order to minimize the mean error in the stage-discharge regressions. Stage and flow estimates used in this analysis are shown in Tables 3 through 7.

The mean errors for the log-stage/log-discharge regressions for most transects are below five percent (Tables 10 and 11). In some cases, the mean error is slightly greater than 5% and could not be reduced further by adjusting stage or flow estimates within reasonable limits. In these cases the slope of the regression and intercepts are comparable to the other transects in the respective study areas. Transect R1 in Liddell Creek had exceptionally high error, possibly due to changes in the channel cross-section at this location during the study period. The altered cross-section may have been due to movement of a large tree trunk under high flow conditions. This transect was omitted from the analysis. Results of the rearing WUA vs. discharge analysis in Liddell Creek are comparable with and without inclusion of transect R1. The slopes for these regressions are within the range of 2 to 4.5 as recommended by the Instream Flow Group (1995), and, in general, the Y-intercept values for the transects in each study area are also consistent. These characteristics meet the established quality control standards for PHABSIM hydraulic simulation.

Standard procedures were followed in making velocity calibration adjustments to account for "edge effect", excessive velocity prediction, and over- or under-calculation of discharge. After calibration, the velocity adjustment factors (VAF) were within the recommended 0.1 to 10 over the range of simulated flows (Instream Flow Group 1995). The VAFs for transects in each study area are illustrated in Figures 12 through 16. The VAFs for most transects generally transition through 1.0 in the vicinity of their velocity calibration flow.

3.4.3.6 Transect Weighting

Each of the PHABSIM transects can be given a weighting to ensure its contribution to the habitat index simulation is indicative of its relative proportional representation in the total habitat character of the study area being modeled. In this study, all spawning transects were placed across likely spawnable run/riffle habitat. Therefore, the spawning transects in each study stream were weighted equally. Similarly, rearing transects were selected primarily in pool and flatwater habitat, consistent with the results of habitat surveys conducted as part of this study and previously conducted by ENTRIX, Inc. (2004b) in the North Coast streams. Pool and deeper flatwater habitat is also most critical to rearing steelhead and coho salmon to smolt size and is most limiting in these small coastal streams. Transects were placed to represent the range of suitable rearing habitat in each study stream and all transects were weighted equally in initial model runs.

4 Results and Discussion

4.1 Adult and Smolt Migration Passage

4.1.1 LIDDELL CREEK

Three critical riffles were selected for analysis in Liddell Creek, including the concrete apron at the upper end of the culvert under Highway 1 (LD P-3), a shallow riffle downstream of the West Branch confluence (LD P-1), and a shallow riffle in the upper study area, upstream of the West Branch confluence (LD P-2). The culvert outlet at the beach downstream of Highway 1 is also a potential passage issue but was not included in this study since improvement of passage at this location is the subject of mitigation plans being prepared by CEMEX. Channel cross-sections and critical water surface stages are shown in Appendix E. Stage/discharge data for each transect are presented in Table 12, and the regression equations for log stage and log discharge are shown in Table 14. Minimum passage flow estimates for adult migration ranged from 4.9 cfs to 11.3 cfs (Table 15). The site with the highest flow requirement for adult migration was near the anadromous gage, downstream of the West Branch confluence (LD P-1). Channel cross-section, stage-discharge data, and analytical results for this site are in Appendix F. Minimum passage flow estimates for smolt migration ranged from 0.8 to 2.0 cfs with the most critical location for smolt passage being the apron at the upper end of the Highway 1 culvert (LD P-3)[1].

4.1.2 LAGUNA CREEK

Four critical riffles were selected for analysis in Laguna Creek including the concrete apron at the upper end of the culvert under Highway 1 (LG P-1), a shallow riffle just upstream of the anadromous gage site (LG P-2), and two critical riffles in the upper study area near the City of Santa Cruz aqueduct crossing (LG- P-3 and LG P-4). Channel cross-sections and critical water surface stages are shown in Appendix E. Stage/discharge data for each transect are presented in Table 12, and the regression equations for log stage and log discharge are shown in Table 14. Minimum passage flow estimates for adult migration ranged from 10.6 cfs to 15.5 cfs (Table 15). The site with the highest flow requirement (most critical riffle) for adult passage was in the lower study area, just upstream of the anadromous gage (LG P-2). Channel cross-section, stage-discharge data, and analytical results for this site are in Appendix F. Minimum passage flow estimates for smolt migration ranged from 1.7 cfs to 3.8 cfs with the most critical location being the apron at the upper end of the Highway 1 culvert (LG P-1).

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[1] Since the depth criteria is different for adults and smolts, the most critical riffle for adults may be different than the most critical riffle for smolts. This is due to the irregular nature of the cross-sections and the "percentage of wetted width" calculation.

4.1.3 MAJORS CREEK

Three critical riffles were selected for analysis in Majors Creek including a wide, shallow riffle between Highway 1 and Scaroni Road (M P-1), a reinforced section immediately upstream of the Highway 1 culvert (M P-2), and a wide, shallow riffle upstream from Highway 1 just upstream of a diversion (M P-3). Channel cross-sections and critical water surface stages are shown in Appendix E. Stage/discharge data for each transect are presented in Table 12, and the regression equations for log stage and log discharge are shown in Table 14. Minimum passage flow estimates for adult migration ranged from 9.0 cfs to 16.0 cfs (Table 15). The site with the highest flow requirement for adult passage was M P-1 in the lower study area, downstream of Highway 1. Channel cross-section, stage-discharge data, and analytical results for this site are in Appendix F. Minimum passage flow estimates for smolt migration ranged from 2.0 cfs to 3.4 cfs with the most critical location being M P-3, the shallow riffle upstream of the diversion.

4.1.4 SAN LORENZO RIVER DOWNSTREAM OF TAIT STREET

Downstream of Highway 1, habitat consisted primarily of relatively deep pools and runs with a small amount of relatively short riffles (Table 16). Upstream of Highway 1, habitat consisted of one long shallow glide and a long, relatively shallow run. There were shorter sections within the run that had pool-like characteristics but these were not distinct enough to break out as separate units. The glide had a deeper channel along one bank but this was generally very narrow and constituted a minor part of the habitat. The substrate upstream of Highway 1 was dominated by sand (90%) and silt (5%).

A total of six low-gradient riffles were classified between Water Street and Highway 1. In addition, there were two shallow riffle sections within larger habitat units that were too short to break out as individual habitat units (including one that was evaluated as a passage site). The riffles were all relatively short, ranging from 27 to 54 feet in length and averaging 38 feet. Upstream of Highway 1 there were no riffles classified although there were short riffle-like sections located at transverse sand bars. Four transects were placed in potentially critical riffles identified between Water Street and the Tait Street Diversion.

Transect P-1 was placed about 120 feet downstream from the Tait Street diversion. The sand bed channel was exceptionally wide and shallow forming a bar at this location (Figure 17). Downstream, the thalweg followed the east bank closely, in association with aquatic plants and overhanging riparian vegetation, forming an ideal migration route for adult steelhead and coho salmon. This migration channel was pinched out by the sandbar at the east end of the transect and the thalweg moved toward the center of the channel as it passed over the bar. Transect P-1 was placed to intersect the thalweg at its shallowest location on the bar.

Transect P-2 was placed behind the tannery, about 0.4 miles downstream of the Tait Street diversion and about 600 feet upstream from the Highway 1 Bridge. This was also an exceptionally wide, shallow sand bar (Figure 18). The channel between Highway 1 and transect P-2 was characterized as a wide, shallow, sandy glide with average depth of 0.9 feet. As at transect P-1, the thalweg downstream from P-2 closely followed the east bank in association with aquatic plants and overhanging riparian vegetation. This migration channel was pinched out by the sandbar at the east end of the transect. Migrating fish would have to follow the thalweg over the sandbar and continue to the west bank where the channel became deeper again in association with aquatic vegetation and overhanging riparian vegetation. The analysis was configured to require that depth criteria be met in only the center cells adjacent to the thalweg. The deeper cells at each end of the transect were omitted from the analysis since they were not actually on the migration pathway and were closed out by the bar either upstream (east bank) or downstream (west bank) of the cross-section (Appendix E).

Transect P-3 was a short but shallow gravel/cobble transverse riffle about 900 feet downstream of Highway 1, in the river adjacent to Petsmart in the Gateway Mall. A well-developed pool was located immediately downstream of the riffle and the riffle formed the tail of another pool immediately upstream (Figure 19). The transect followed the shallowest portion of the riffle including slightly deeper portions at each end. Fish could move across the riffle at virtually any point.

Transect P-4 was placed in a riffle under the Water Street Bridge (Figure 20). There was a relatively well-defined thalweg along the west bank that would serve as the main migration route for fish passing this location. The substrate was dominated by cobbles and boulders.

In the reach between Water Street and Tait Street the riffle sections are generally short and relatively low gradient (HES 2007). Downstream of Highway 1, the riffles are generally within close proximity to deep pool habitat and there is a substantial amount of cover from aquatic plants and dense overhanging riparian vegetation. The study reach is immediately upstream of the lagoon and migrating adults are likely to be in good condition passing through this reach. The 0.6 foot depth criterion applied to a contiguous width of 10% of the wetted width is likely to result in minimum difficulty for steelhead and coho salmon migrating in the San Lorenzo River downstream of Tait Street. Similarly, a 0.3 foot depth criterion applied to 10% of the wetted width is likely to provide suitable conditions for downstream migrating smolts and would be achieved at a flow of 6 to 12 cfs.

Channel cross-sections and critical water surface stages are shown in Appendix E. Stage/discharge data for each transect are presented in Table 13, and the regression equations for log stage and log discharge are shown in Table 14. Minimum passage flow estimates for adult migration ranged from 17 cfs to 25 cfs (Table 15). The site with the highest flow requirement for adult passage was SL P-1, just below the Tait Street diversion. Channel cross-section, stage-discharge data, and analytical results for this site are in Appendix F. Minimum passage flow estimates for smolt migration ranged from 3.8 cfs to 10 cfs with the most critical location being SL P-2, the shallow riffle upstream of Highway 1, near the tannery.

4.1.5 NEWELL CREEK

A total of four critical riffles were selected for analysis in Newell Creek. Two were located downstream of Rancho Rio Bridge, one was a short distance upstream of Glen Arbor Road, and one was a short distance downstream of Glen Arbor Road. Channel cross-sections and critical water surface stages are shown in Appendix E. Stage/discharge data for each transect are presented in Table 13, and the regression equations for log stage and log discharge are shown in Table 14. Minimum passage flow estimates for adult migration ranged from 11.4 cfs to 24.4 cfs. Channel cross-section, stage-discharge data, and analytical results for the most critical site, P-1, are in Appendix F. Minimum passage flow estimates for smolt migration ranged from 3.2 cfs to 8.3 cfs.

Two obstacles at bedrock sheets in Newell Creek were also selected for analysis. The first bedrock obstacle (N-P3) was located about 0.3 miles upstream of Rancho Rio Bridge and about 0.95 miles upstream from the San Lorenzo River (Figure 5). It consisted of a sloped bedrock ledge rising a total of about 2 feet over a distance of about 17 feet (Figure 21). The Mannings equation was used to generate velocity predictions and flow predictions for a range of passage depths (Table 17). Depending on the value of Mannings coefficient used, the estimated flow at which depth becomes sufficient for passage (0.6 feet) is between 145 and 275 cfs. Velocity, depth, and channel measurements from February 25, 2008 indicate that this is a suitable range for the Mannings coefficient suggested by Powers and Orsborn (1985) for smooth rock. Using equation 1 to determine the length a fish could swim and assuming a critical passage depth of 0.6 feet and a length of 17 feet for the ledge, a steelhead in good condition or better (c = 75% or more) swimming for 5 seconds at maximum burst speed of 25.6 fps would be able to swim far enough to ascend the bedrock ledge at this flow level (145 to 275 cfs) but would have difficulty if able to sustain only average or minimum burst speed (Table 17). A coho salmon would also be able to ascend the ledge at this flow level if swimming at maximum burst speed and assuming the higher Mannings coefficient of 0.040 (Table 17). However, at the lower Mannings coefficient of 0.25, velocity estimates indicate that a coho salmon would not be able to pass the obstacle unless swimming at top burst speed. Since the downstream water surface rises with increasing flow the length of ledge to be passed would be somewhat less at higher flows. For example, the length would be approximately 9 feet at a flow of 145 cfs, approximately 6 feet at a flow of 197 cfs, and only about 4 feet at a flow of 275 cfs.

The second bedrock obstacle (N-P4) was located about 0.1 miles upstream of N-P3. It consisted of a sloped bedrock ledge that rises a total of about 4.9 feet over a distance of about 27 feet (Figure 22). Even if a steelhead could leap from the relatively shallow pool at the base of the ledge, data presented in Powers and Orsborn (1985) indicates that the horizontal distance (27 feet) is too great for even a steelhead in prime condition (condition coefficient of 100%). This obstacle is more complex than N P-3 with 3 distinct potential migration pathways. The center of the bedrock ledge is a relatively uniform chute with relatively constant slope and laminar flow, similar to N-P3. On the right side there is an overflow channel with two drops of 1.5 to 2 feet and shallow flow over relatively steep bedrock only in the lower part. On February 25, 2008 at a flow of approximately 43 to 49 cfs, this channel was too shallow and had insufficient depth in the plunge pools to be passable. At higher flows this side may be passable. On the left side, the bedrock is more stepped forming a turbulent cascade with two small, shallow plunge pools. Although the plunge pools are quite small (about 2-3 feet in diameter) and have depths of only 1 to 1.5 feet, they may offer enough velocity reduction to allow fish to ascend this side of the ledge. On February 25, 2008 at a flow of 46 cfs the depth of flow along this pathway was too shallow in places to meet passage criteria. In addition, there was significant air entrainment in the highly turbulent flow along this pathway, reducing the fluid density and the propulsive force of a fishes swimming movements. 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). Using this equation, velocity in the steepest part of the cascade would be approximately 11 fps. While this is within the burst speed range for both steelhead and coho salmon, the turbulence in this cascade presents difficulty by deflecting the fish from its course and causing excessive expenditure of energy to resist upwellings, eddies, entrained air, and vortices. Most of the fish's energy is utilized simply to maintain position and direction (Powers and Orsborn 1985).

The central chute in this obstacle is comparable to N P-3 but has a slightly steeper slope (17% compared to 12% at N P-3). The uneven face of this ledge is more difficult to survey for cross-sectional area, wetted perimeter, or mean depth. Due to the steeper slope, it is likely that higher levels of flow are required to meet a 0.6 foot depth criteria than the estimated 230 cfs required at N P-3. Assuming other channel variables are similar to N P-3 the increased slope at N P-4 alone would result in suitable passage depth (0.6 feet) at a flow of 204 to 327 cfs. This flow range would correspond to mean velocity estimates of 10 to 16 fps. Only a steelhead in top condition would be capable of ascending at the upper end of the velocity range. A coho salmon would likely be incapable of passing this obstacle, even at the lower velocity estimate. However, these are extrapolations from conditions at N P-3 and more detailed information should be collected at N P-4 before accepting these conclusions.

4.2 Spawning and Egg Incubation

The relationship between flow and spawning habitat suitability is expressed as a habitat suitability index (WUA/RSI). These relationships generally show an increase in habitat suitability to some level, a peak, and then a gradual decline as flows continue to increase. WUA/RSI values that are 80% to 100% of the maximum values represent highly suitable or optimum conditions. Flows higher or lower than these levels result in increased frequency of depth, velocity, and substrate conditions that are outside the suitable range as defined by habitat suitability criteria used for steelhead and coho salmon spawning. Tabular values of the WUA/RSI verses streamflow relationship are presented in Appendix G.

Flows which provide higher WUA/RSI are more likely to support greater numbers of spawning fish, although the exact numbers and the specific relationships are influenced by too many other factors to be quantitative. Higher levels of WUA for spawning will only benefit the population if spawning habitat is limiting. If other factors, such as poor ocean conditions for production of returning adults, poor summer rearing habitat, or poor embryo survival due to high winter flows are limiting a population, then simply increasing the amount of suitable spawning habitat will have little or no benefit.

The relationships between flow and spawning habitat suitability can be used with hydrologic data to explore the effects of different flow conditions on spawning habitat quality. This information has been used in the City of Santa Cruz HCP to evaluate existing conditions for steelhead and coho salmon in streams influenced by City diversions and determine the extent to which spawning habitat may be limiting these populations. The information is also used in the HCP to evaluate the potential effects of flow augmentation on spawning habitat quality and the implications for viability of steelhead and coho salmon populations in these streams.

4.2.1 NORTH COAST STREAMS

The form of the relationships between stream flow and the index of spawning habitat suitability (WUA/RSI) for steelhead and coho salmon is relatively similar in each of the three study streams (Figures 23, 24, and 25). The suitability index is expressed in dimensionless units per 1,000 feet of stream and represents the extent of match to the habitat suitability criteria of depth, velocity, and substrate. Generally, the rate of increase in the suitability index is relatively high at the lower simulated flows, reaches a peak at more moderate flow levels, and then declines gradually at higher flows. The spawning suitability index for coho salmon tends to peak at slightly lower flows than for steelhead and does not reach peak values as high as those for steelhead. In Liddell Creek, the peak of the suitability index curve for coho salmon occurs at a flow of about 9 cfs and is highest between 4.4 and 17.3 cfs (80% of the peak value). For steelhead in Liddell Creek the spawning suitability index is high (at least 80% of the peak value) across a very broad range of flow between 7.4 and 24.6 cfs with a peak at about 13.7 cfs (Figure 23). In Laguna Creek, the spawning suitability index for coho salmon is highest between 5.4 and 29.8 cfs and is highest for steelhead between 9.3 and 34.9 cfs (Figure 24). In Majors Creek the spawning suitability index peaks between 8.9 and 23.7 cfs for coho salmon and between 12.1 and 32.6 cfs for steelhead (Figure25). Individual WUA vs. discharge curves for each spawning transect in the study streams is in Appendix H.

4.2.2 NEWELL CREEK

The WUA vs. discharge relationships for steelhead and coho spawning in Newell Creek increase at relatively high rates up to 10 and 16 cfs, respectively, peak at flows around 20 and 26 cfs, respectively, and decline gradually at higher flows (Figure 26). The spawning suitability index for coho salmon tends to peak at slightly lower flows than for steelhead. In Newell Creek, the peak of the suitability index curve for coho salmon occurs at a flow of about 20 cfs and is highest between 9 and 37 cfs (80% of the peak value). For steelhead in Newell Creek the spawning suitability index is high (at least 80% of the peak value) across a very broad range of flow between 13 and 41 cfs with a peak at about 26 cfs (Figure 26). Individual WUA vs. discharge curves for each spawning transect in the study streams is in Appendix H.

4.3 Juvenile Rearing

Stream flows with higher rearing suitability index values have a greater frequency of depth and velocity conditions associated with observed utilization by rearing steelhead or coho salmon. In this study, it is important to remember that the observations of rearing juvenile steelhead and coho salmon were made in the Trinity River and not in the study streams. Although depth and velocity are key factors, habitat selection by steelhead and coho salmon juveniles is likely the result of many factors in addition to these two. Other important factors likely include the presence or proximity of hiding cover from potential predators, diet preferences, food availability and distribution, the presence of potential competitors, and thermal regulation. An important assumption of this study is that, all other factors being equal, flows which provide higher levels of WUA/RSI are more likely to support greater numbers of rearing juveniles. This would only be true if the abundance of rearing juveniles were limited by the availability of suitable depth and velocity conditions. Other factors may limit abundance of rearing juveniles such as low numbers of adult spawners, poor survival of eggs and fry, low food abundance, or high rates of predation. Although these factors may also be influenced by flow, there is no practical, generally accepted methodology for assessing them and they have not been considered in the present analysis. Cover is likely a very important factor determining potential juvenile salmonid rearing density. Some habitat preference data incorporating cover has been developed in other studies (Smith and Aceituno (1987) although the applicability of these data to the study streams is questionable. In any case, the objective of this study is to address the effects of changes in flow *under the existing levels of cover.* Cover is not influenced by the City diversions but depth and velocity certainly are. Never the less, changing cover conditions through habitat improvement projects is a way to potentially get higher habitat value for any given level of flow. This will be explored further in development of a conservation strategy.

The relationships between streamflow and rearing habitat suitability developed here are most appropriately used to explore differences between various hydrologic regimes in the study streams. Evaluation of existing hydrologic conditions may indicate periods when depth and velocity suitability are exceptionally low. Evaluation of alternative hydrologic scenarios can be used to explore the relative effects of different levels of streamflow augmentation on habitat conditions.

4.3.1 NORTH COAST STREAMS

The form of the relationships between stream flow and rearing habitat suitability for steelhead and coho are also relatively consistent between the three study streams (Figures 27-29). For steelhead juveniles, the suitability index rises steadily across the range of simulated flows, although the rate of increase tends to be higher at lower flow levels and more gradual at higher flow levels. Although the WUA/RSI values are still increasing at the highest simulated flows in each of the streams (about 14 cfs), the index reaches 80% of the maximum simulated value when flow is 5.2 cfs in Liddell Creek, 6.4 cfs in Laguna Creek, and 5.7 cfs in Majors Creek. Streamflows during the dry season often fall well below these levels in each of the streams, even if City diversions were not operating. Individual WUA vs. discharge curves for each rearing transect in the study streams is in Appendix H.

The rearing suitability index for coho salmon is relatively high across the range of simulated flow in each of the three streams. Even at the lowest simulated flow, WUA/RSI for coho salmon rearing was 74% to 80% of peak levels. This is the result of the underlying suitability curves for depth and velocity for coho juveniles reflecting their preference for low velocity, deeper habitat such as found in pools (Figure 9b). The peak suitability index values for coho juveniles occur at relatively low flows in the study streams: 1.5 cfs in Liddell Creek, 2.9 cfs in Laguna Creek and 3 cfs in Majors Creek.

The relationships developed here suggest that rearing habitat for coho salmon is little influenced by changes in streamflow in the study streams and that steelhead are most likely to be influenced by streamflow changes as flows drop below 2 to 4 cfs. The information developed in these analyses is used in the City's HCP to evaluate existing conditions and evaluate the potential effect of streamflow augmentation as part of the HCP Conservation Strategy.

4.3.2 SAN LORENZO RIVER DOWNSTREAM OF TAIT STREET

The PHABSIM model was based on stage-discharge data collected in fall 2005 when gaged flows were in the range of 14 to 30 cfs. Based on standard criteria for calibration flows, the PHABSIM extrapolation would be considered valid down to 5.6 cfs (Table 9). Although the model was used to extrapolate WUA estimates at flows down to 0.5 cfs, estimates may be less accurate at flows below 5.6 cfs. The index of rearing habitat (WUA per 1000 feet of stream) for steelhead in the San Lorenzo River below Tait Street increases steeply from minimum levels at a flow of 0 cfs (Figure 30). As flow reaches 7 to 10 cfs, the rate of increase in WUA becomes less. WUA does not change significantly with flow increase over about 40 cfs. The suitability index for steelhead rearing in this reach reaches 60% of peak levels when flow is 7.9 cfs and 80% of peak levels when flow is 18.8 cfs. Although the channel conditions are different in the two sub-reaches (upstream and downstream of Highway 1), the relationship between WUA and flow is similar.

Response of WUA to changes in flow is different in pools, runs, and riffles (Figures 31 and 32). Individual WUA vs. discharge curves for each spawning transect in the study streams is in Appendix H. In pools, which comprise 49% of the habitat in the flood control channel, most of the increase in WUA occurs at flows up to 6 to 8 cfs (a flow of 7 cfs provides approximately 80% of the maximum WUA). This is because pools in this reach, particularly in the flood control channel, are generally quite deep and within the high suitability range for steelhead even at lower flows (Table 2, Table 16). Therefore, most of the increase in WUA in pools comes from increases in velocity.

Runs made up approximately 42% of the habitat downstream of Highway 1 and 45% of the habitat upstream of Highway 1. Runs in the flood control reach are also quite deep (Table 16) and in some respects behave more like pools. The run cross-sections selected for the PHABSIM study are shallower than most of the run habitat in the reach (Table 2). In run habitats selected for the study, WUA increases with flows up to about 40 cfs before reaching a plateau. Increase in WUA is related to increases of both depth and velocity at lower flows and mostly related to increase in depth at higher flows.

Riffles were a minor component of the habitat downstream of Tait Street, making up only 8% of the total stream length in the flood control channel. WUA in riffles increased at a steady rate up to about 48 cfs, mainly as a result of increasing depth. The response of the majority of steelhead rearing habitat downstream of Tait Street is best reflected by the response for pools (Figure 31) since pools and deeper run habitats are expected to provide the majority of summer habitat for rearing steelhead.

Because of the underlying suitability criteria and the way WUA is calculated in the model, depth is often the major determinant of WUA in this application of the model (HES 2008). There is some question in this case whether the observed increase in depth and, more importantly, the degree of improvement in WUA, would have the degree of biological significance suggested by the WUA values. Selection of greater depths in rearing steelhead may be advantageous in providing some degree of protection from avian predators. At most locations in the flood control channel, there is a large amount of overhead cover in the form of overhanging terrestrial vegetation and floating aquatic vegetation (Appendix B), mostly at the edges of the channel in shallower depths. In such cases, overhead cover may minimize the importance of depth and alter the suitability function. The underlying suitability data for this application of the model was collected in a larger river (the Trinity) where many observations may be further from shore and where depth is a more important component of cover. This is one instance where more site specific suitability data might affect the model results.

Given these uncertainties in application of the model and interpretation of the results a more general classification was adopted rather than adhere strictly to the numerical output in terms of WUA. Based on evaluation of the model results and on-site observations during the study we have defined the following categories to characterize habitat conditions for rearing steelhead under different levels of flow:

Prime conditions occur at flows of about 19 cfs up to the highest simulation range of 75 cfs for this study. Under these flow conditions velocity suitability ranges from 0.9 to 1.0 over substantial portions of each cross-section. Six of the nine cross-sections (all except shallower run and riffle cross-sections) have depth suitability in near optimum range (suitability of 0.9 to 1.0) over at least portions of the cross-section. There is good continuity between pools and depths suitable for movement of rearing juveniles between pools (a depth of at least 0.3 feet over 25% of the channel width and a contiguous portion of 10% of the channel width). Average wetted width is 75% or more of maximum.

Good conditions for steelhead rearing occur between about 8 and 19 cfs. At these flows, velocity suitability in lower gradient habitats (pools and deep runs) declines somewhat but is still at least 65% of optimum levels on portions of the cross-section. Depth suitability at the six deeper cross-sections is in the range of 0.8 to 1.0, and there is still good continuity between pools and depths suitable for movement of rearing juveniles between pools. Average wetted width is still about 75% of the maximum simulated flow (72 cfs).

Fair conditions occur at flows of about 3 to 8 cfs. At these flows, velocity on pool cross-sections drops to levels corresponding with suitability for rearing steelhead of 0.4 to 0.7, although velocity in the runs and riffles is still at high suitability levels. Depth in pools and deep runs remains at levels corresponding to high suitability for rearing steelhead. Average wetted width declines to about two- thirds the width at the highest simulation flow and although there is still continuity between pools, passage is likely more difficult for rearing steelhead or coho in larger size classes.

Poor conditions occur at flows less than 3 cfs. At these flow levels, velocity in pools and deep runs drops to levels corresponding to suitability for rearing steelhead of 0.4 to 0.5 and less although depth remains at suitable levels. In shallower, swift water locations velocity is still at high suitability levels but depth has declined to suitability levels of 0.1 to 0.2 or less. While average wetted width is still at least 60% of the maximum simulated flow, wetted width in riffle habitat declines from 30% to 18% of maximum as flow is reduced. Continuity between pools and potential for movement of rearing fish begins to disappear.

The width of the wetted channel in riffles may be important during the summer rearing period if a significant proportion of the food items in the diet of steelhead or coho salmon is produced in the riffles and if greater numbers of food organisms are produced when the wetted area of the riffle is increased. These are common working assumptions but there is little quantitative work to support them. If a substantial portion of fish diets are derived from other sources such as terrestrial insects or aquatic organisms produced in non-riffle aquatic habitats, or if a relatively small areal extent of riffle is capable of meeting the dietary intake of a large number of rearing fish, the assumption may not be valid. Also, the need for rearing steelhead or coho salmon to move from pool to pool during the summer is questionable. In many smaller Central California streams, even in unimpaired conditions, this is not possible during low flow conditions that recur on an annual basis. Nevertheless, we have included consideration of these factors in evaluating rearing habitat quality in this reach of the San Lorenzo River.

For coho salmon, the index of rearing habitat (WUA per 1,000 feet of stream) in the San Lorenzo River below Tait Street is uniformly high for simulation flows from 0 cfs to 72 cfs (Figure 30). The lowest values of WUA are at zero flow; however, even at that level, WUA is over 75% of the peak value. Peak values of WUA occur at a flow of about 5 cfs. In pools, peak WUA for rearing coho occurs at 2 cfs, while in runs the peak is at 6 to 7 cfs (Figure 32). WUA decreases at higher flows in these habitats due to increasing velocity, which for coho salmon, has lower suitability. In riffle habitat, where very low values of WUA are obtained, WUA increases gradually across the range of simulation flows, primarily due to increasing depth. Velocity is only suitable for coho salmon in a narrow band along the banks in this swift flowing habitat type. The WUA curves reflect the underlying suitability criteria that include higher suitability for low velocity and relatively deep habitat typical of the preferred deep pool habitat of rearing coho salmon. Indeed, the flood control portion, with its extensive deep pools and slower velocity deep run habitat and cover consisting of overhead vegetation, appears to provide reasonably good rearing conditions for coho salmon. Warm temperature is probably a significant limiting factor for coho in this reach (see Appendix A).

If rearing habitat for coho salmon is described using the same approach as for steelhead and considering only WUA, there would be only two categories: ***Prime*** conditions would occur at WUA values between 80% and 100% of the peak value and ***Good*** conditions would be defined at levels between 60% and 80% of the peak. Flows of 1 to 72 cfs would result in ***Prime*** conditions while flow less than 1 cfs would be considered ***Good***. If we also consider wetted width and continuity of passage between pools, then flows of 3 cfs or less might be defined as ***Fair***. At this level there is a decrease in average wetted width down to as little as 50% of the maximum simulated flow and decrease in wetted width in riffle habitat to 25% of maximum or less. In addition, continuity between pools and potential for movement of rearing fish begins to disappear. Therefore habitat conditions for rearing coho salmon would be defined as ***Prime*** for flows between 3 cfs and 72 cfs and as ***Fair*** for flows of less than 3 cfs.

During the instream flow assessment in the fall of 2005, trout were active throughout the study reach at flows near 15 cfs. Trout were observed feeding at the surface in deep run habitat near Pogonip Creek on October 11 at a flow of about 17 cfs and again on October 24 with heavy activity in cells with depths of 1.7 to 2.0 feet and mean column velocity of 0.2 to 0.3 feet per second (fps). Trout were observed surface feeding at site R-4 (head of pool) on October 12 when flow had just dropped from 18 cfs to 11 cfs. Surface feeding was also observed at site R-4 on October 20 at a flow of about 12 cfs and surface feeding was particularly heavy on October 21, also at a flow of 12 cfs. At the location where fish were feeding, cells with suitable depths (>0.8 feet) had mean column velocity ranging from 0.4 to 0.6 fps. A smolt-sized trout (150-160 mm) was observed feeding at the surface in deep pool habitat at R-3 on October 20 with flow at about 12 cfs. The site had abundant overhead cover and the highest mean column velocity at all cells on this date was 0.55 fps.

4.3.3 NEWELL CREEK

The PHABSIM model was based on stage-discharge data collected in the winter of 2009-2010 when gaged flows were in the range of 1.1 to 36 cfs. Based on standard criteria for calibration flows, the PHABSIM extrapolation would be considered valid in the range from 0.6 cfs to 40 cfs (Table 9).

The form of the relationships between stream flow and rearing habitat suitability for steelhead and coho salmon in Newell Creek (Figure 33) are similar to those in the North Coast streams and the San Lorenzo River downstream of Tait St. (Figures 27-30). For steelhead juveniles, the suitability index rises to a peak at about 28 cfs then gradually declines at higher simulated flows. The rate of increase tends to be higher at lower flow levels and more gradual at higher flow levels. The index reaches 80% of the maximum simulated value when flow in Newell Creek is 10 cfs. Streamflows during the dry season would fall well below this level even if Newell Reservoir were not there. Individual WUA vs. discharge curves for each rearing transect in Newell Creek are in Appendix H.

The rearing suitability index for coho salmon is highest at relatively low flows and declines gradually at flows greater than 2 cfs. Even at the lowest simulated flow, WUA/RSI for coho salmon rearing was 83% of peak levels. This is the result of the underlying suitability curves for depth and velocity for coho juveniles reflecting their preference for low velocity, deeper habitat such as found in pools (Figure 9b). The peak suitability index value for coho juveniles occurs at about 2 cfs in Newell Creek.

The relationships developed here suggest that rearing habitat for coho salmon, at least with respect to depth and velocity, is maximized at lower flows while optimum flow for steelhead is higher. The information developed in these analyses is used in the City's HCP to evaluate existing conditions and evaluate the potential effect of streamflow augmentation as part of the HCP Conservation Strategy.

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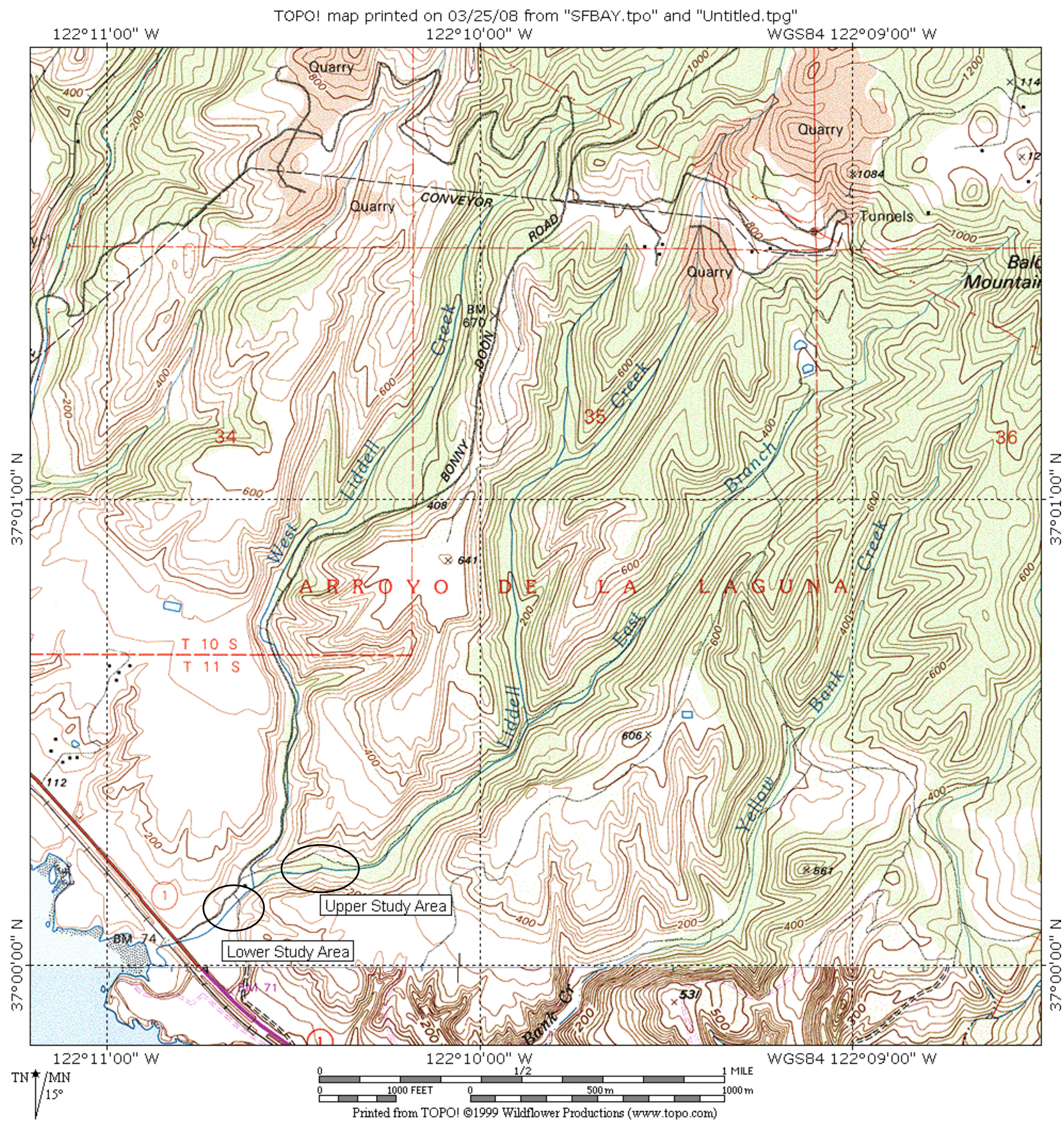


Figure 1. PHABSIM study areas in Liddell Creek.

Figure 2. Flow study sites in Laguna Creek.

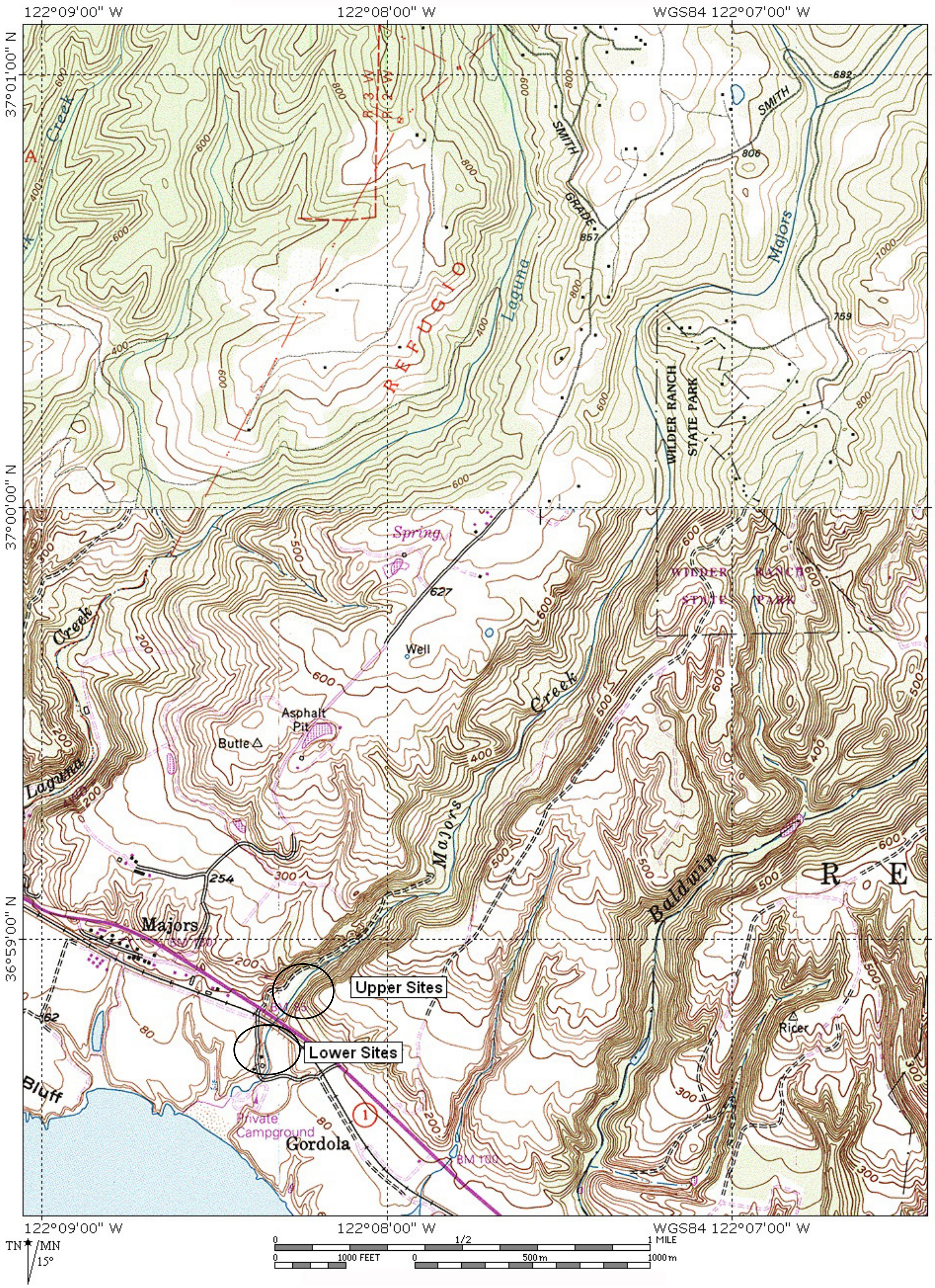


Figure 3. Flow study sites in Majors Creek.

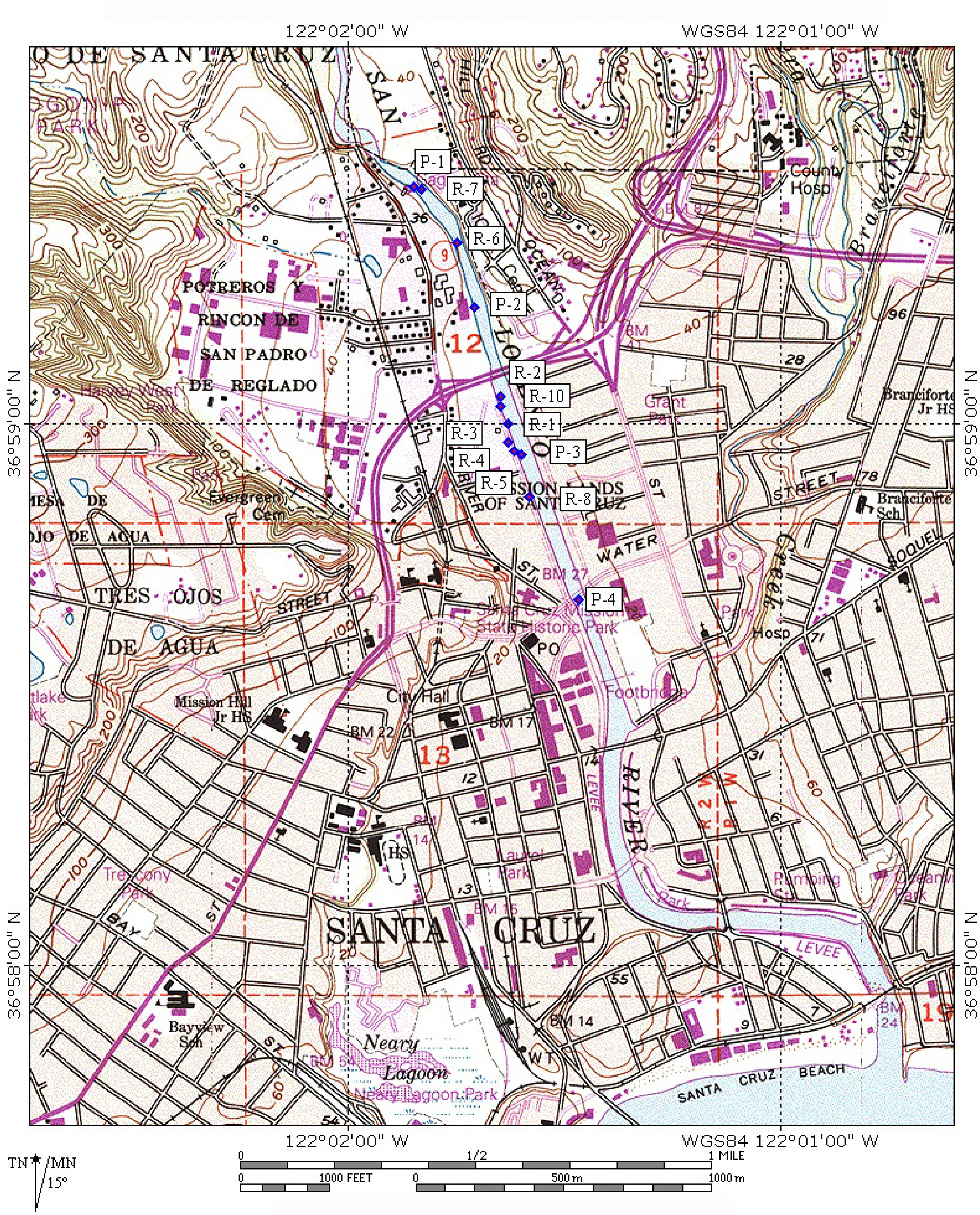


Figure 4. Flow study sites in San Lorenzo River downstream of Tait St.

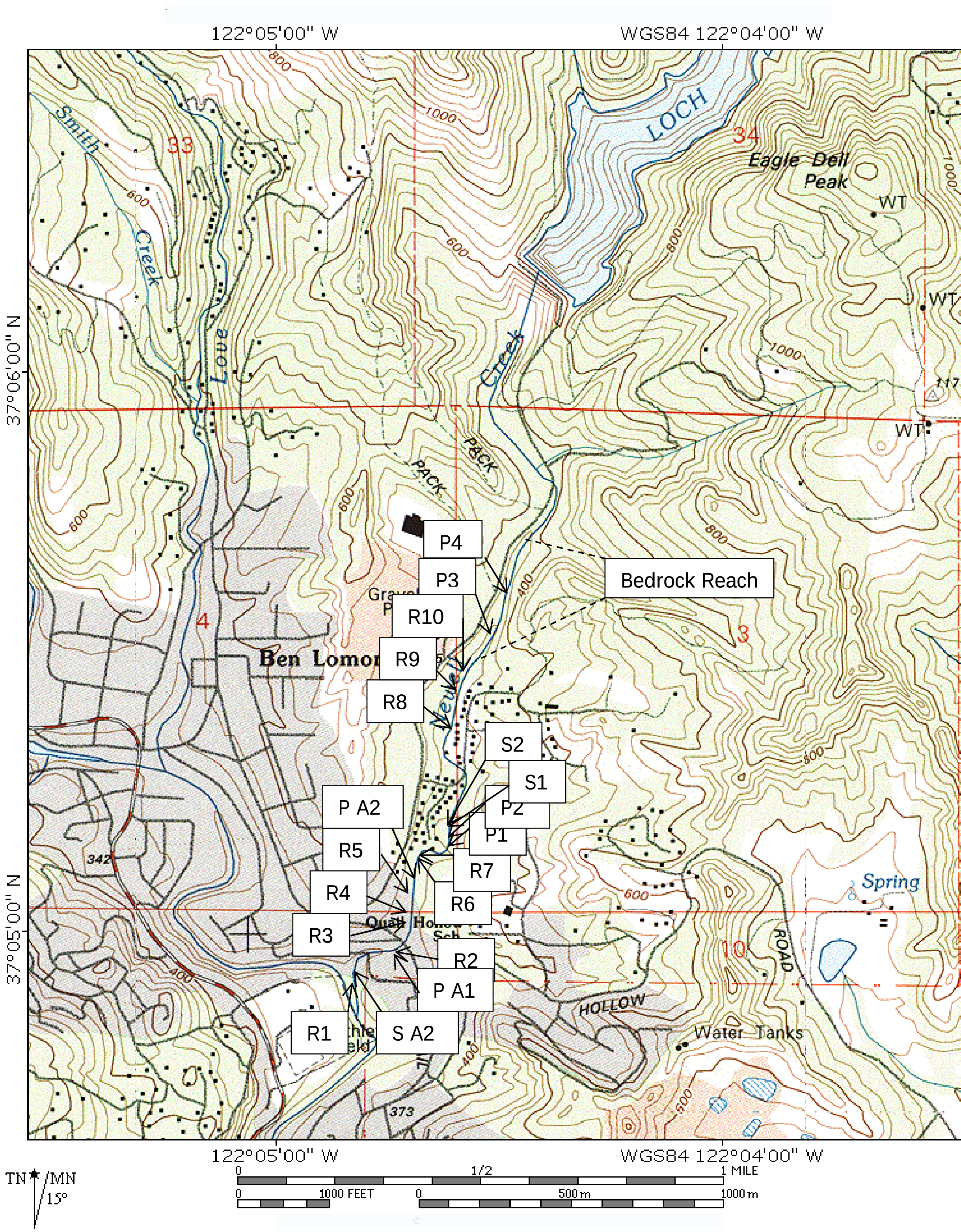
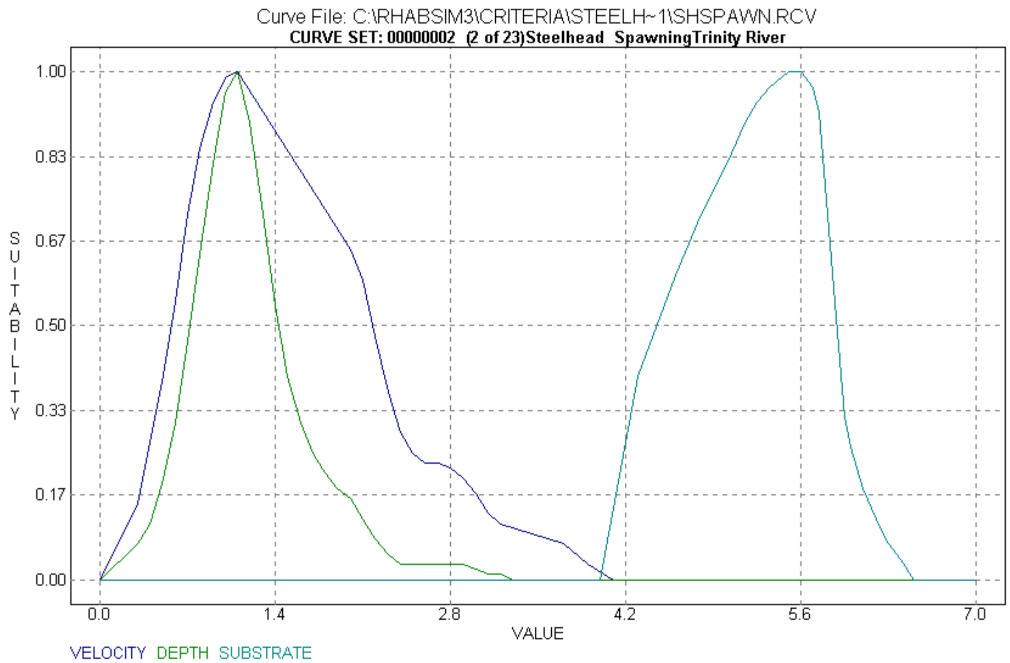


Figure 5. Flow study sites in Newell Creek.

a)



b)

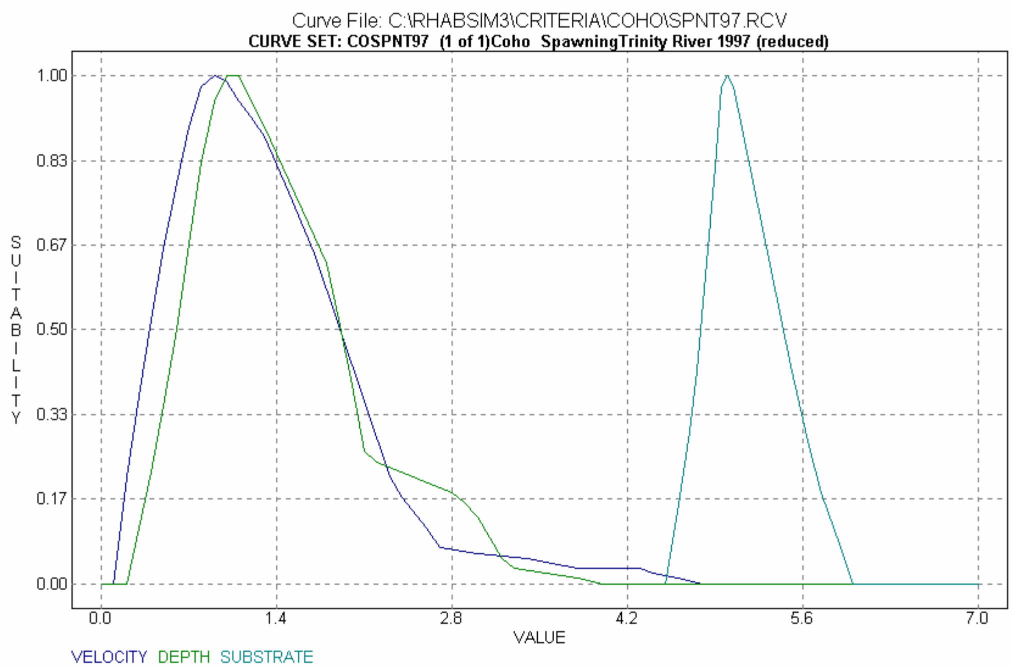


Figure 6. Habitat Suitability Criteria used for PHABSIM analysis of relationship between spawning suitability and flow in HCP study streams for steelhead (a), and coho salmon (b).

a)

b)

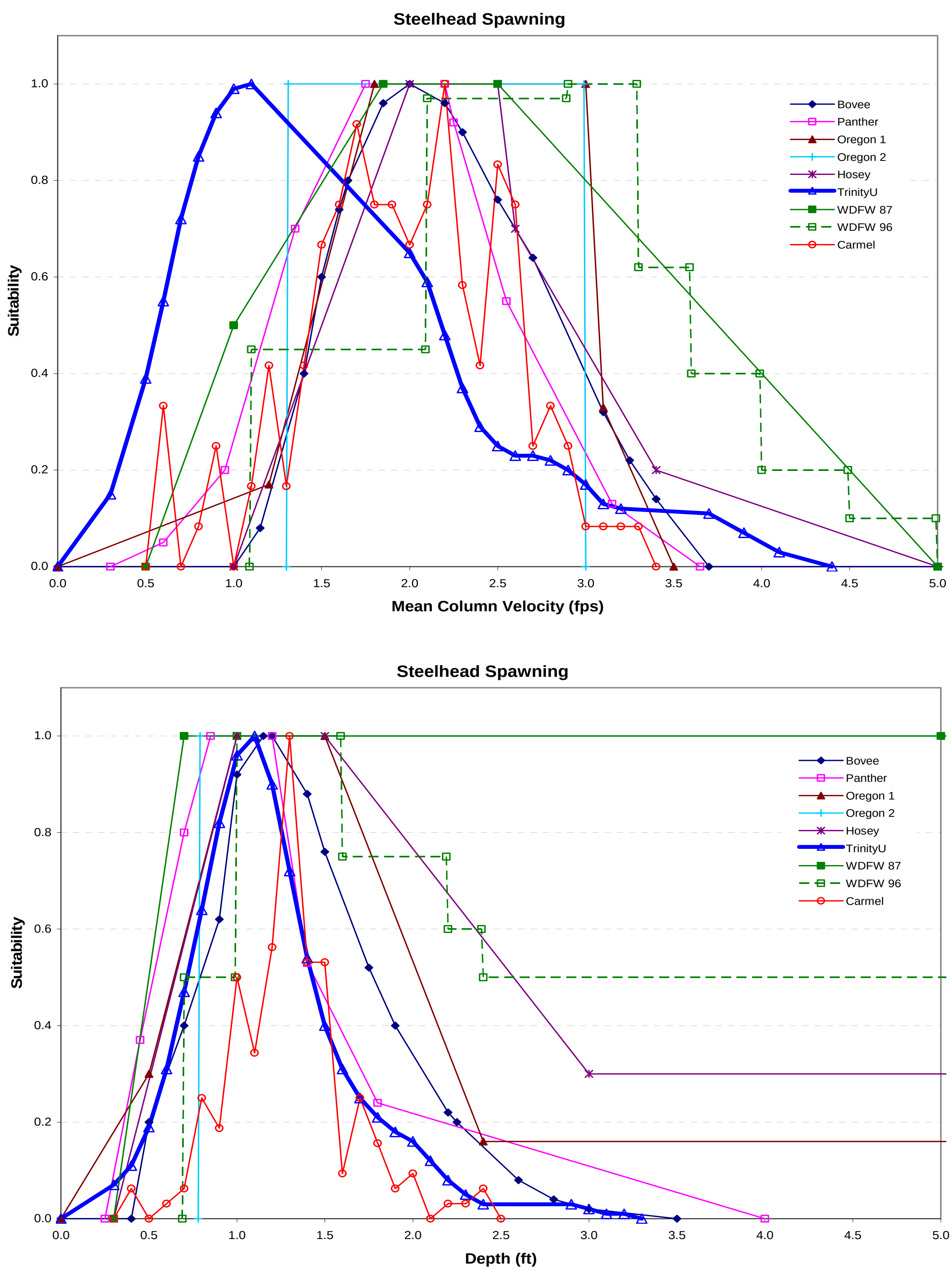


Figure 7. Habitat Suitability Criteria for steelhead spawning in other studies for velocity (a) and depth (b). ***Source: Thomas R. Payne and Associates.***

a)

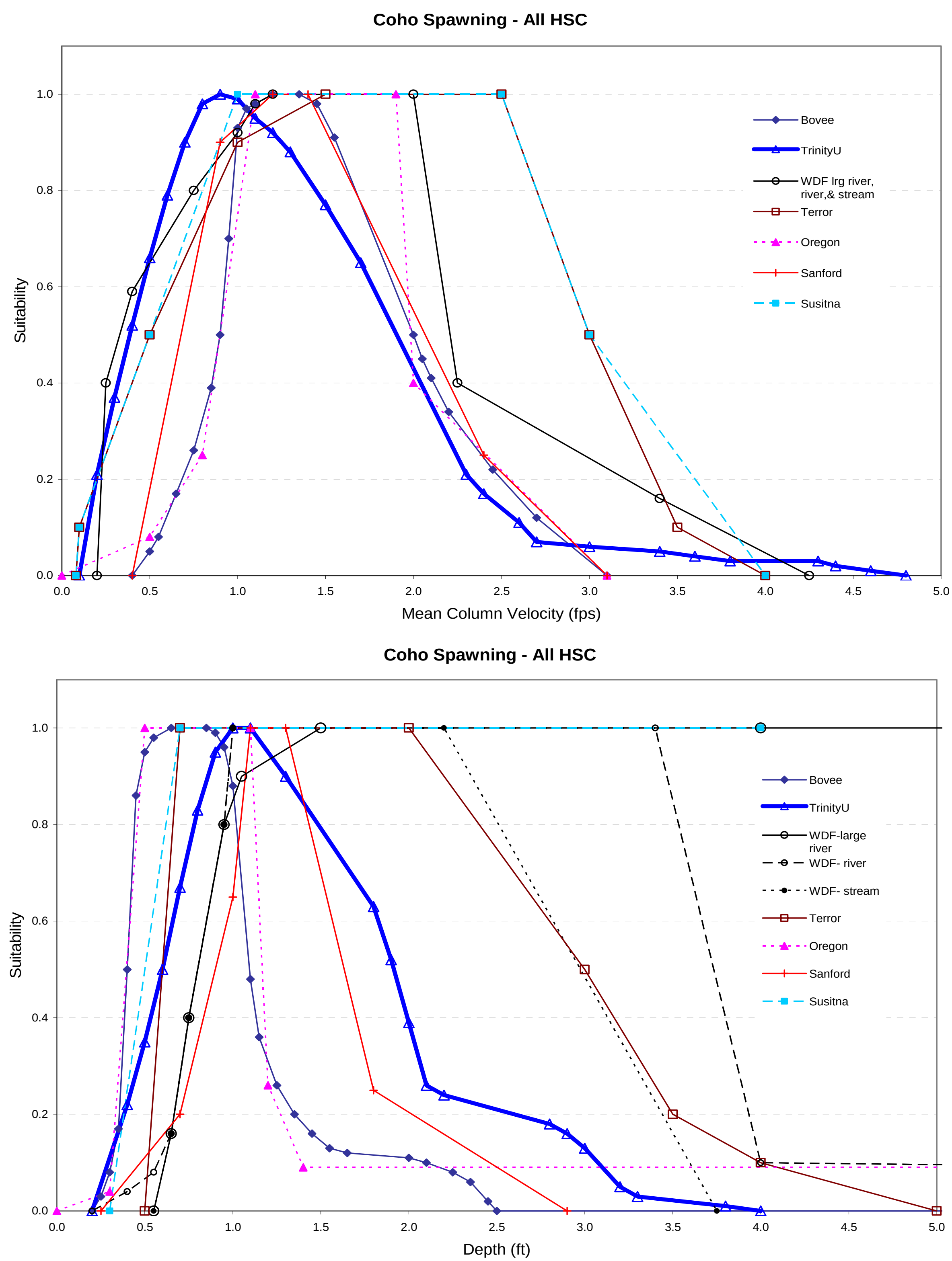
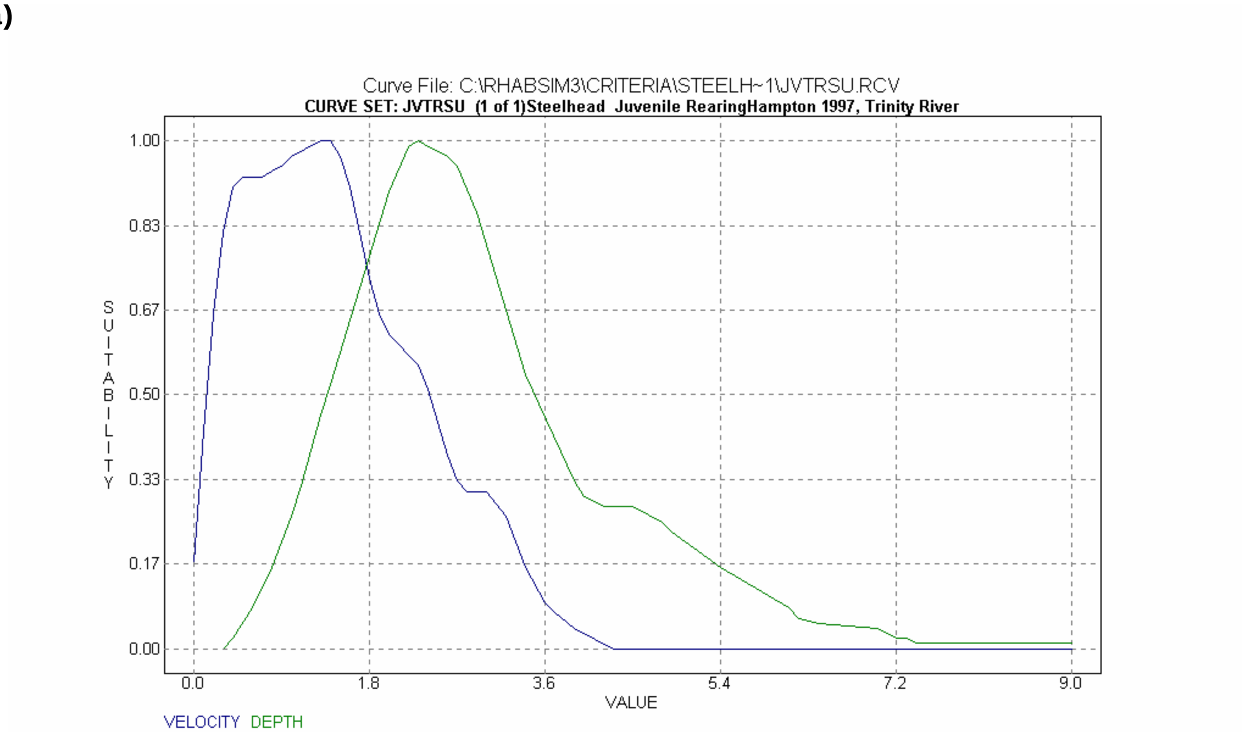


Figure 8. Habitat Suitability Criteria for coho spawning in other studies for velocity (a) and depth (b). ***Source: Thomas R. Payne and Associates.***

a)



b)

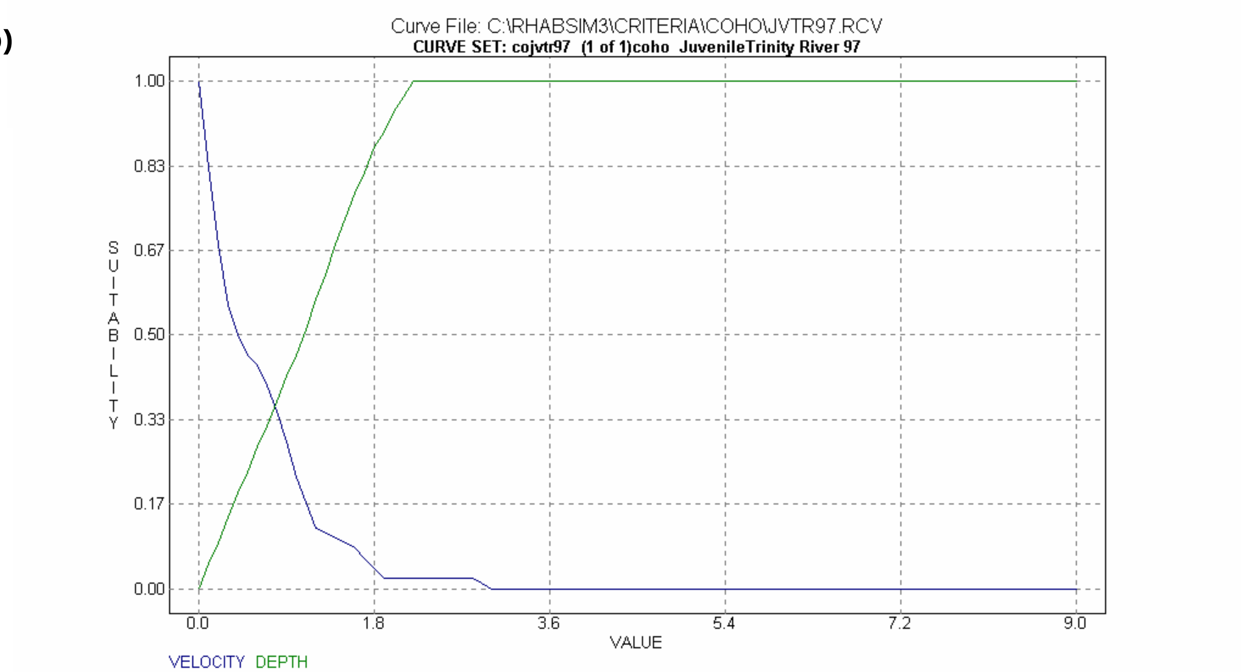
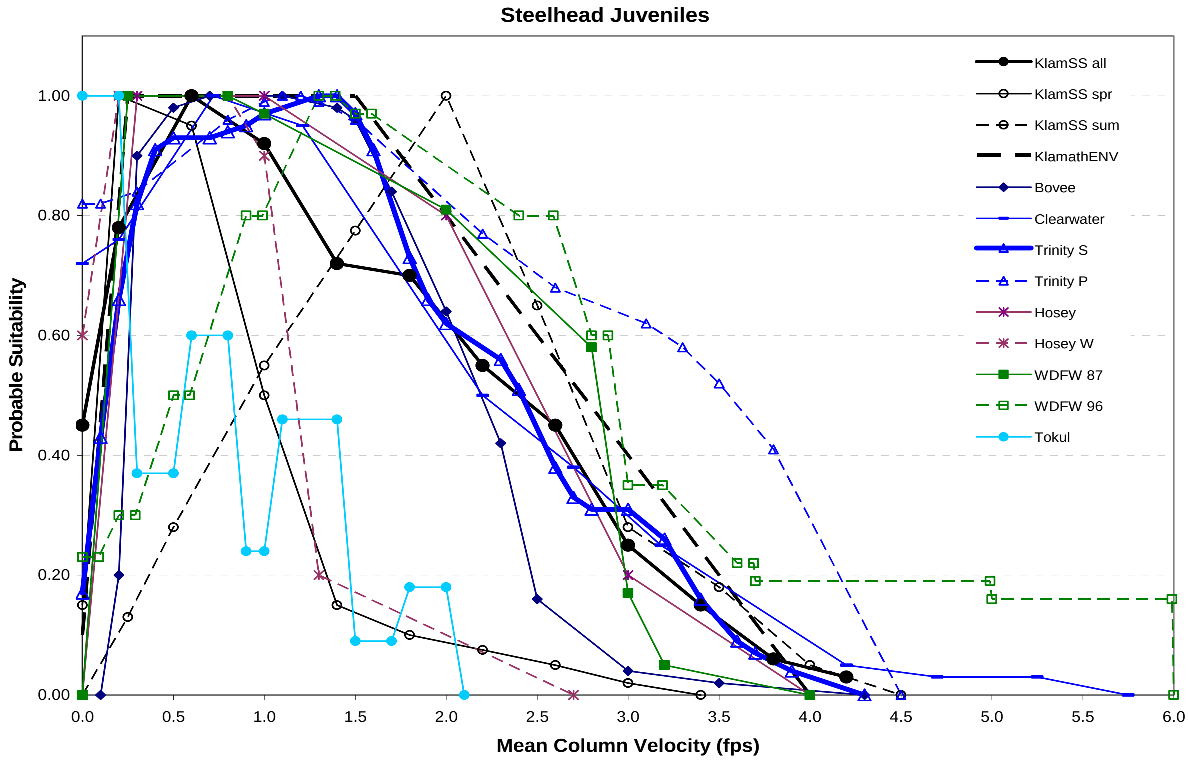


Figure 9. HSC used for PHABSIM analysis of relationship between juvenile rearing suitability and flow in HCP study streams for steelhead (a), and coho salmon (b).

a)



b)

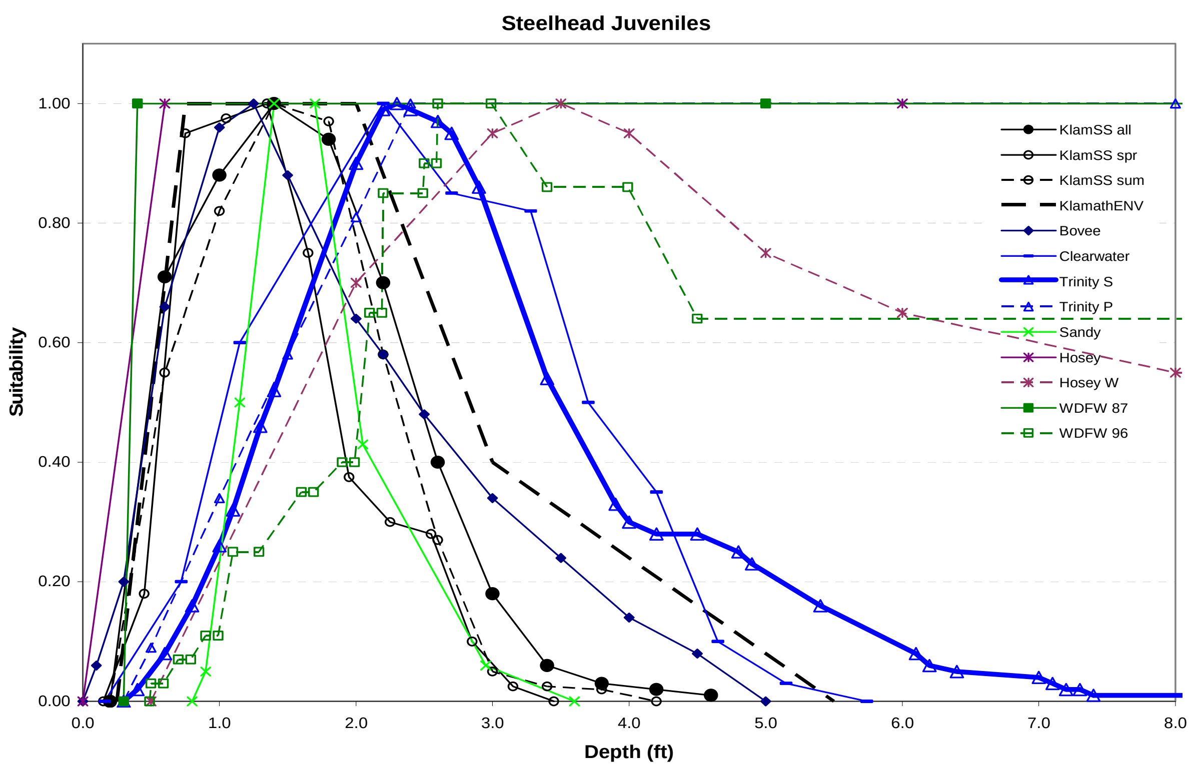


Figure 10. Habitat Suitability Criteria for steelhead juvenile rearing in other studies for velocity (a) and depth (b). ***Source: Thomas R. Payne and Associates.***

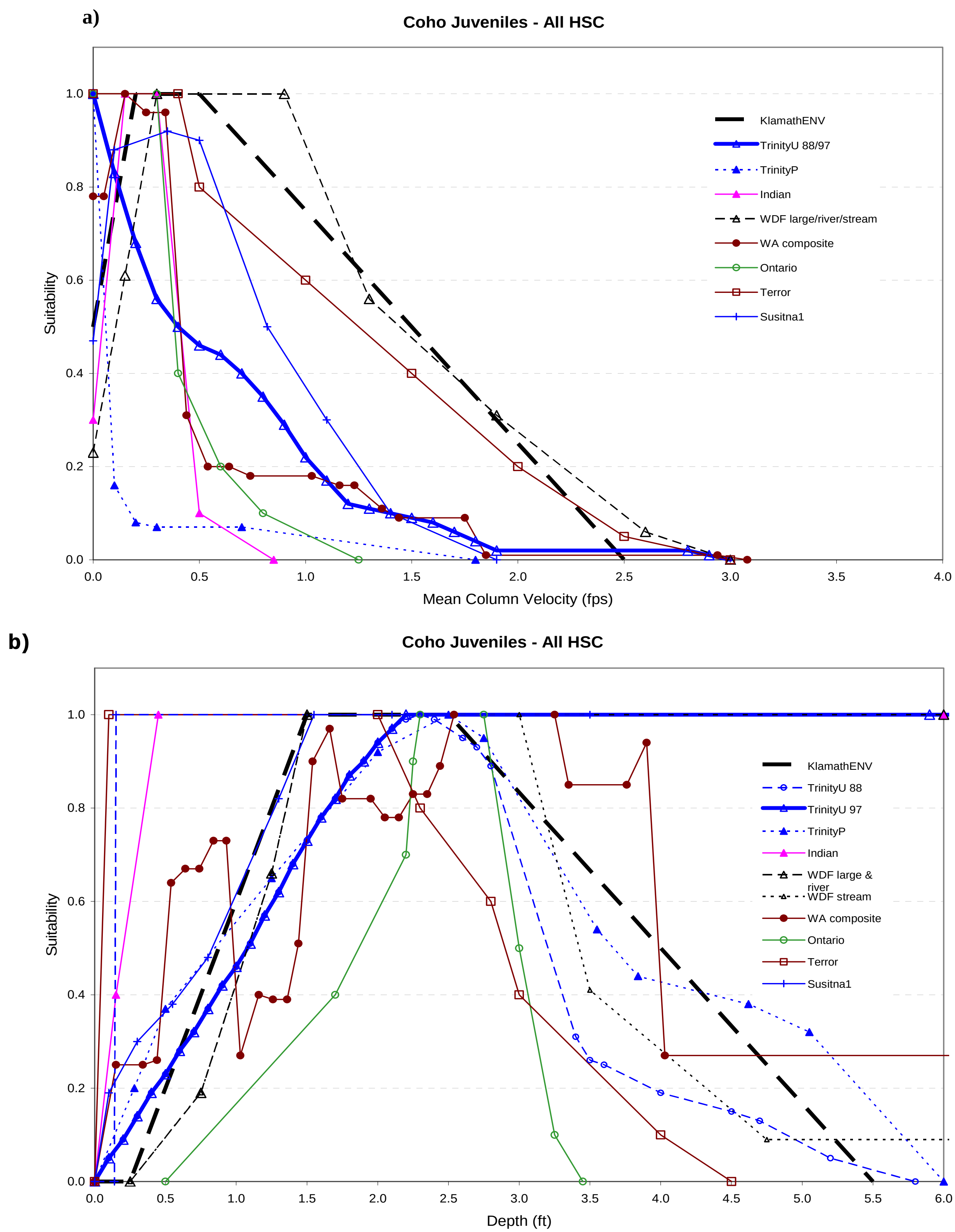
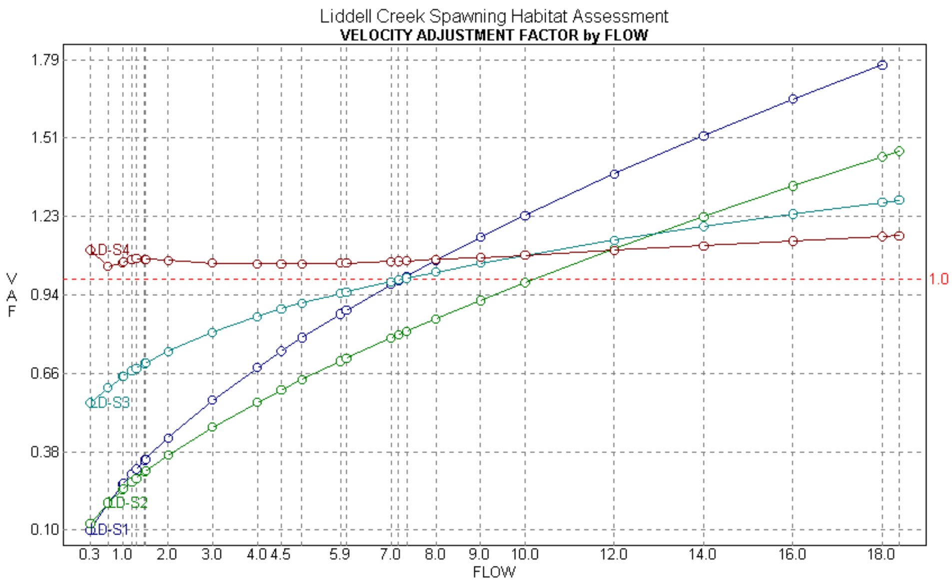


Figure 11. Habitat Suitability Criteria for coho juvenile rearing in other studies for velocity (a) and depth (b). ***Source: Thomas R. Payne and Associates.***

a)



b)

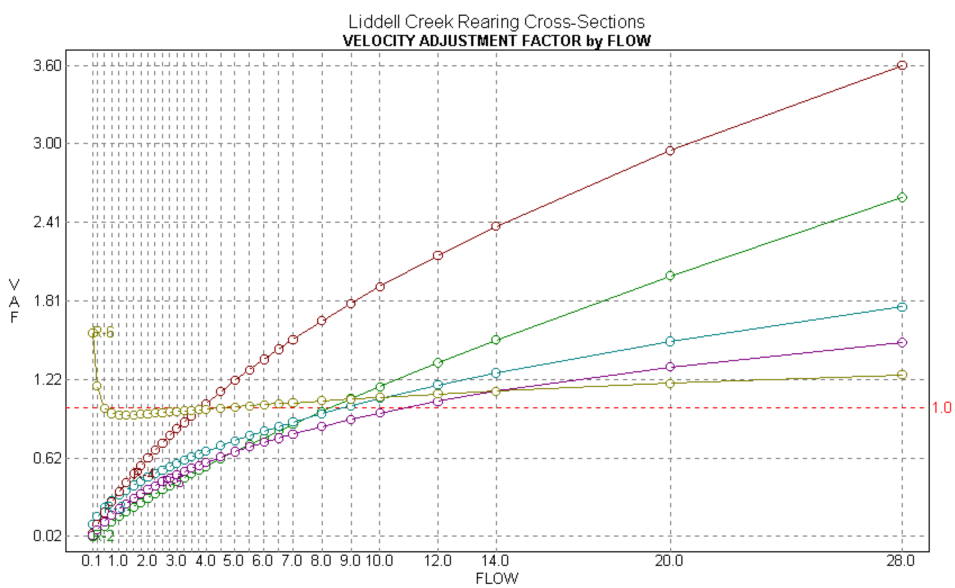
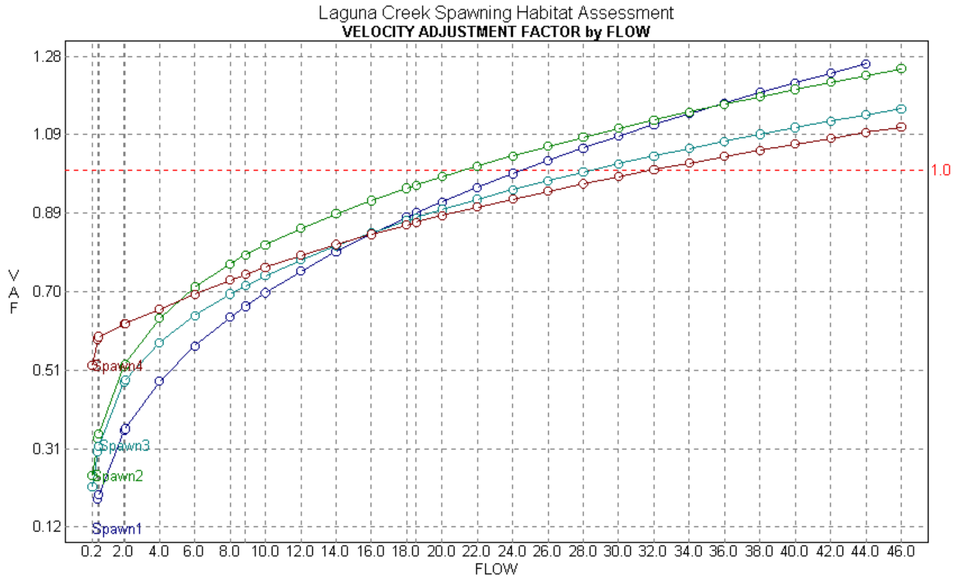


Figure 12. Velocity adjustment factors used for RHABSIM velocity simulations on spawning transects (a), and rearing transects (b) in Liddell Creek.

a)



b)

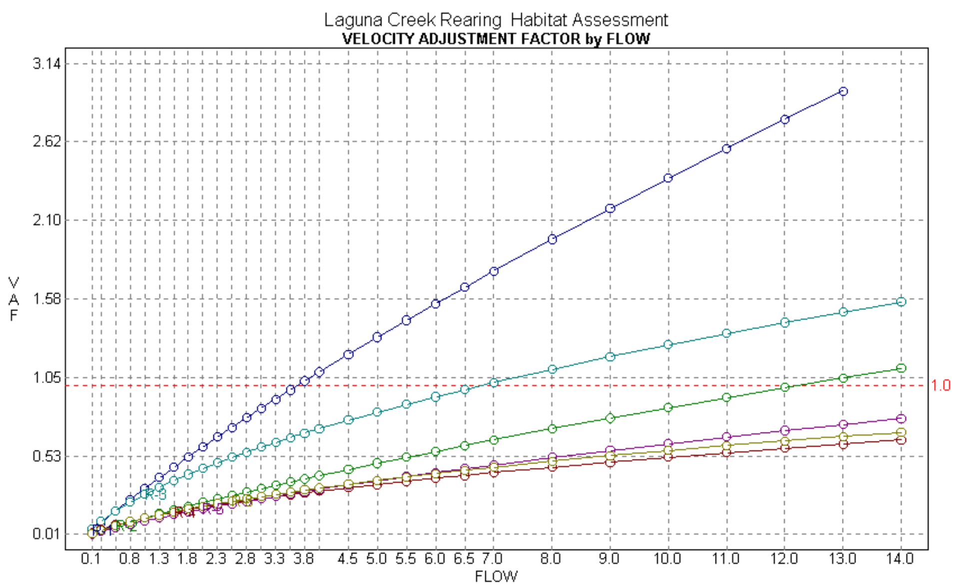
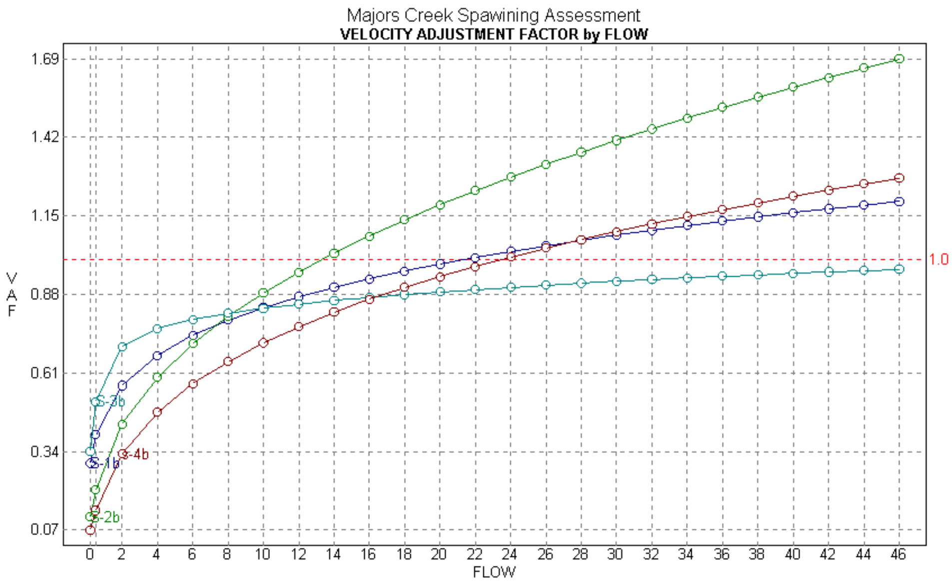


Figure 13. Velocity adjustment factors used for RHABSIM velocity simulations on spawning transects (a), and rearing transects (b) in Laguna Creek.

a)



b)

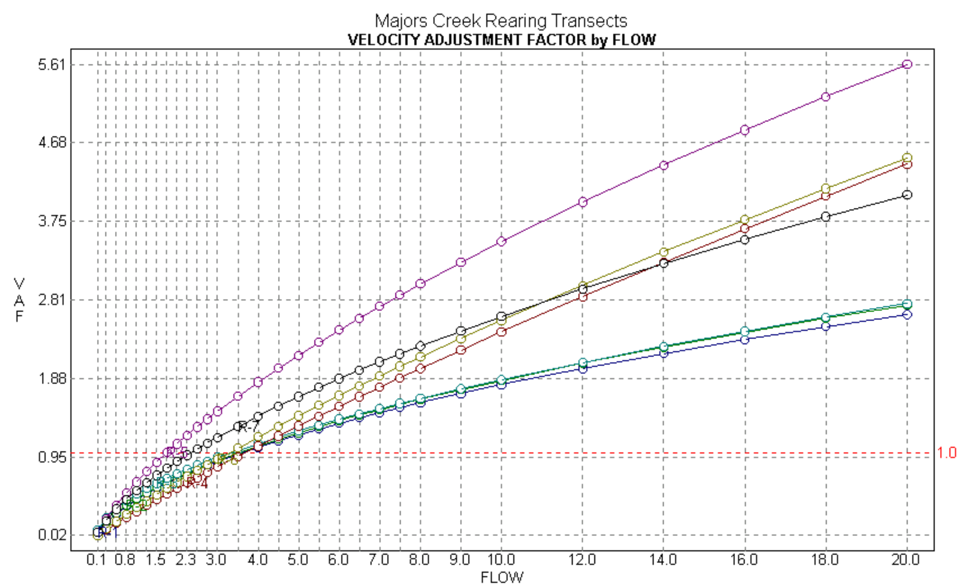


Figure 14. Velocity adjustment factors used for RHABSIM velocity simulations on spawning transects (a), and rearing transects (b) in Majors Creek.

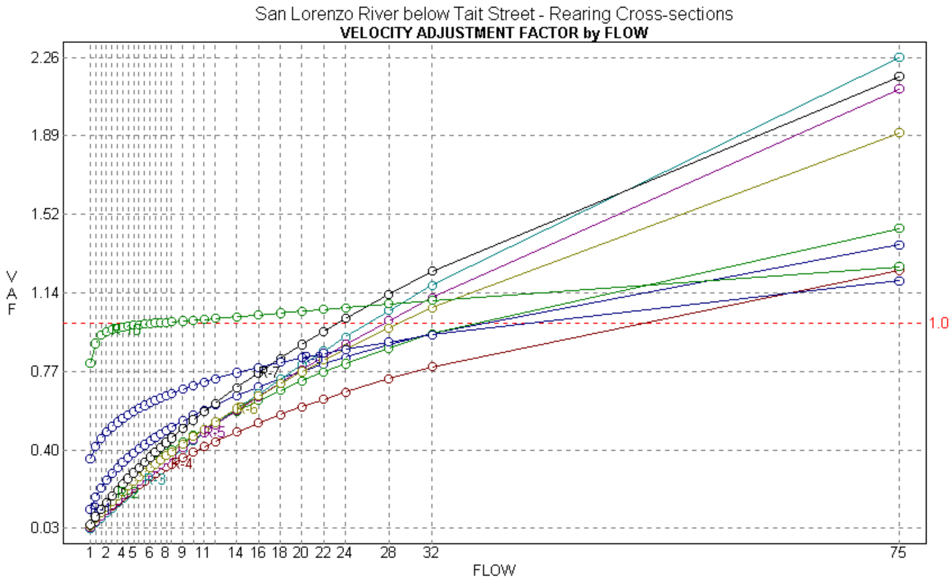
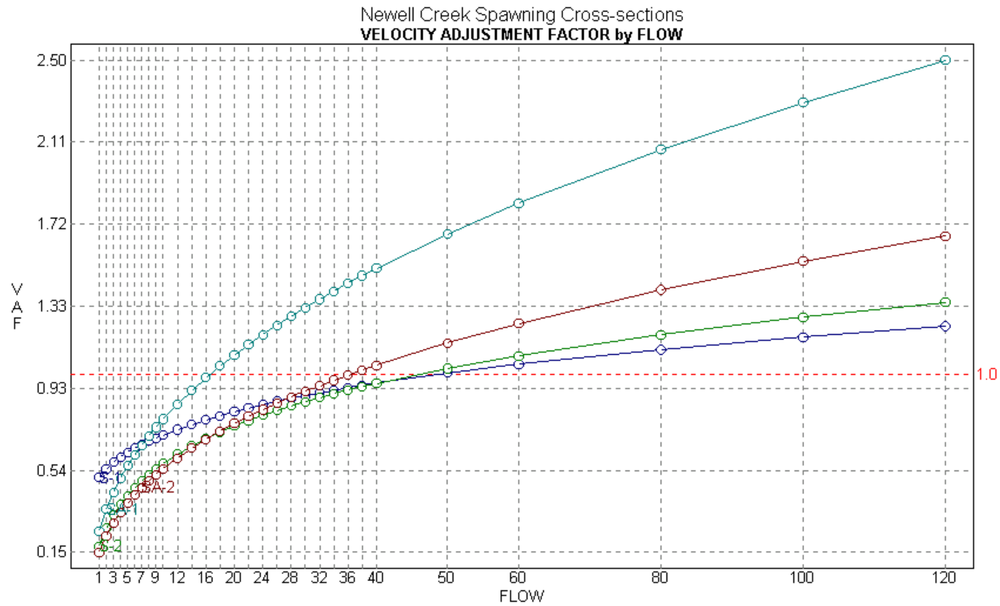


Figure 15. Velocity adjustment factors used for RHABSIM velocity simulations on rearing transects in the San Lorenzo River downstream of Tait Street.

a)



b)

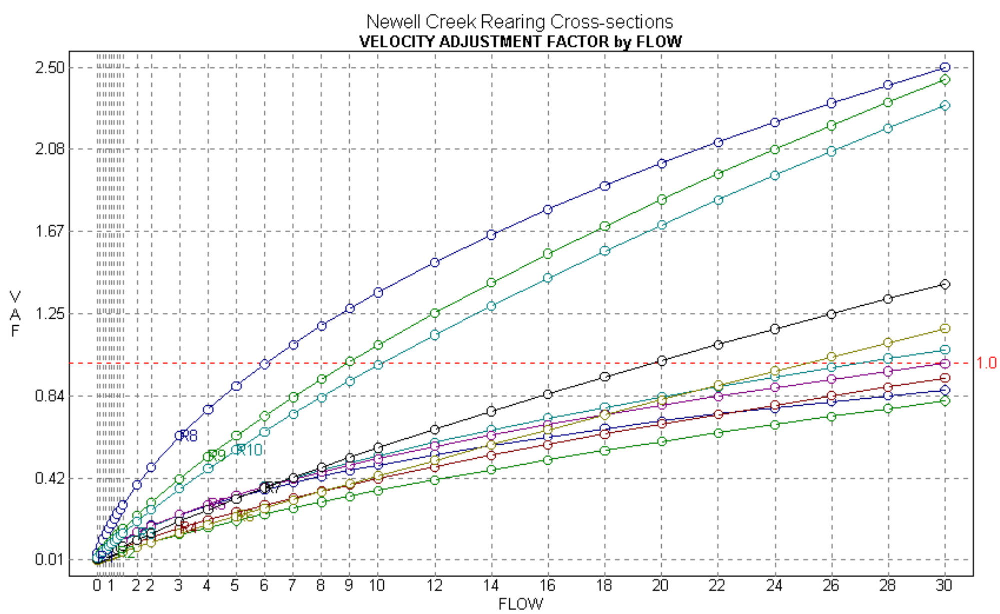


Figure 16. Velocity adjustment factors used for RHABSIM velocity simulations on spawning transects (a), and rearing transects (b) in Newell Creek.

Figure 17. San Lorenzo River downstream of Tait Street, Passage transect P-1.

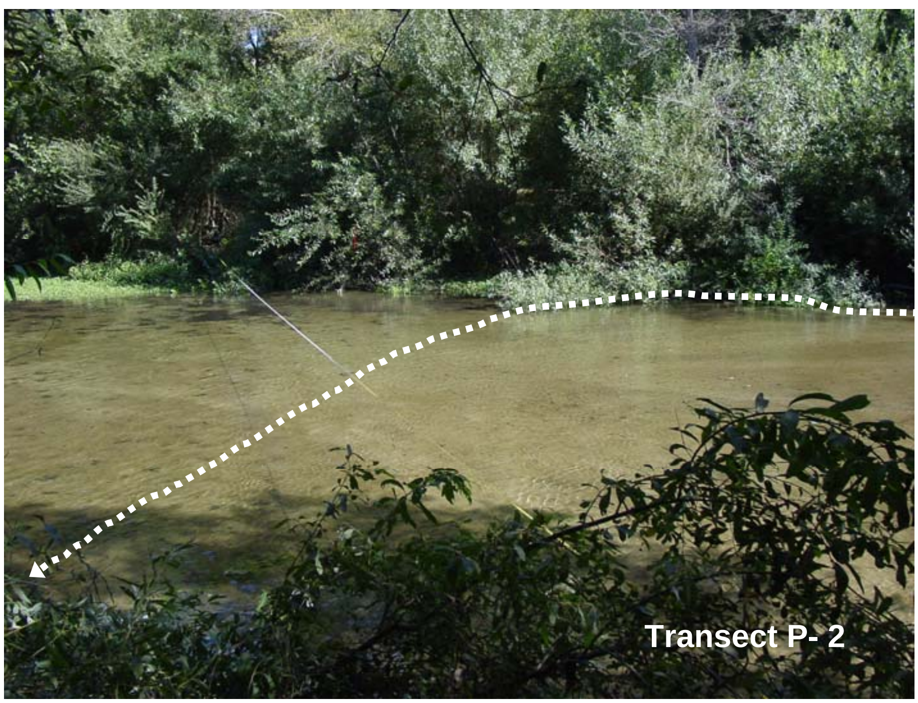


Figure 18. San Lorenzo River downstream of Tait Street, Passage transect P-2.

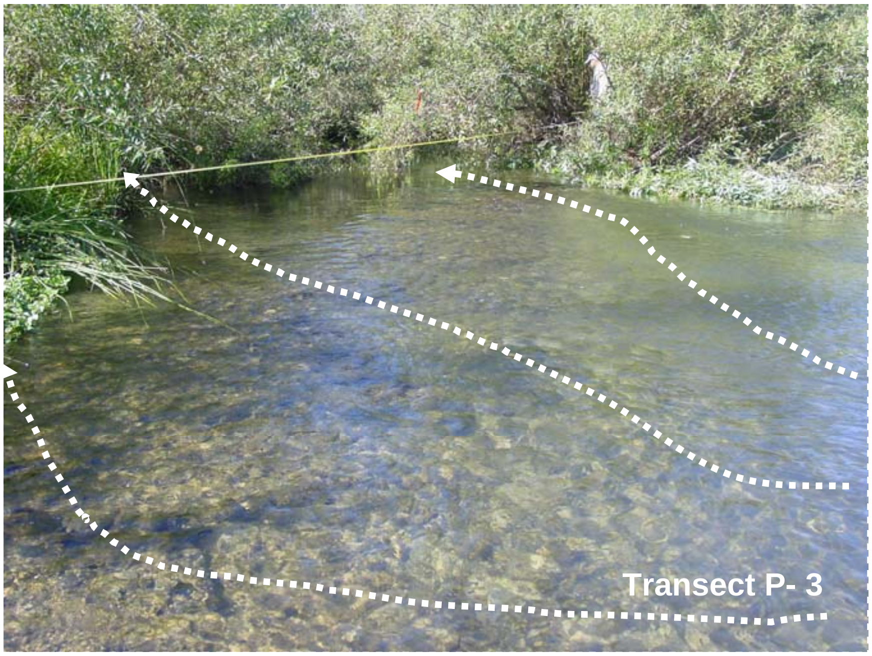


Figure 19. San Lorenzo River downstream of Tait Street, Passage transect P-3.

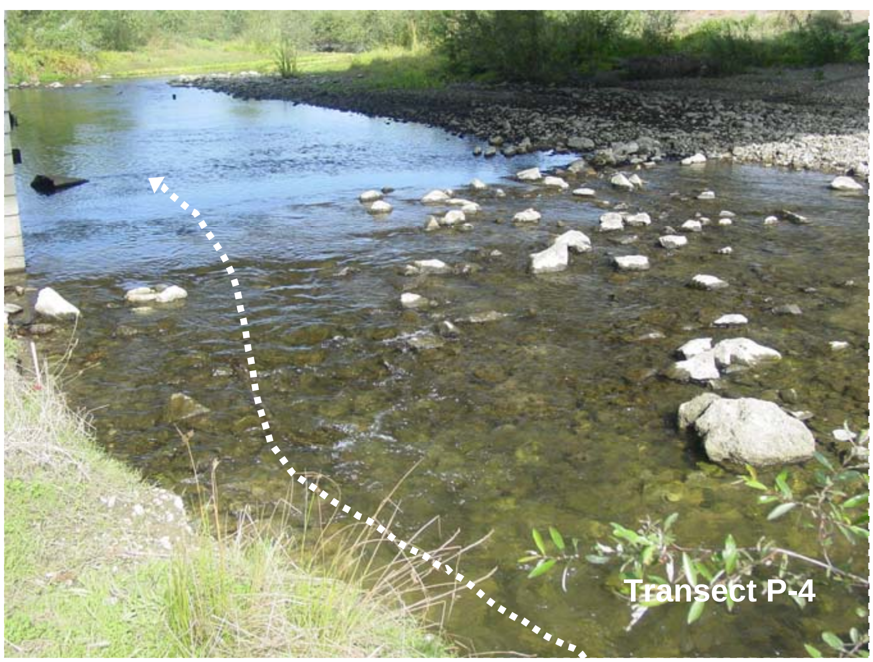


Figure 20. San Lorenzo River downstream of Tait Street, Passage transect P-4.

Figure 21. Newell Creek passage obstacle N P-3 (flow 40-45 cfs)

Figure 22. Newell Creek passage obstacle N P-4 (flow about 50 cfs).

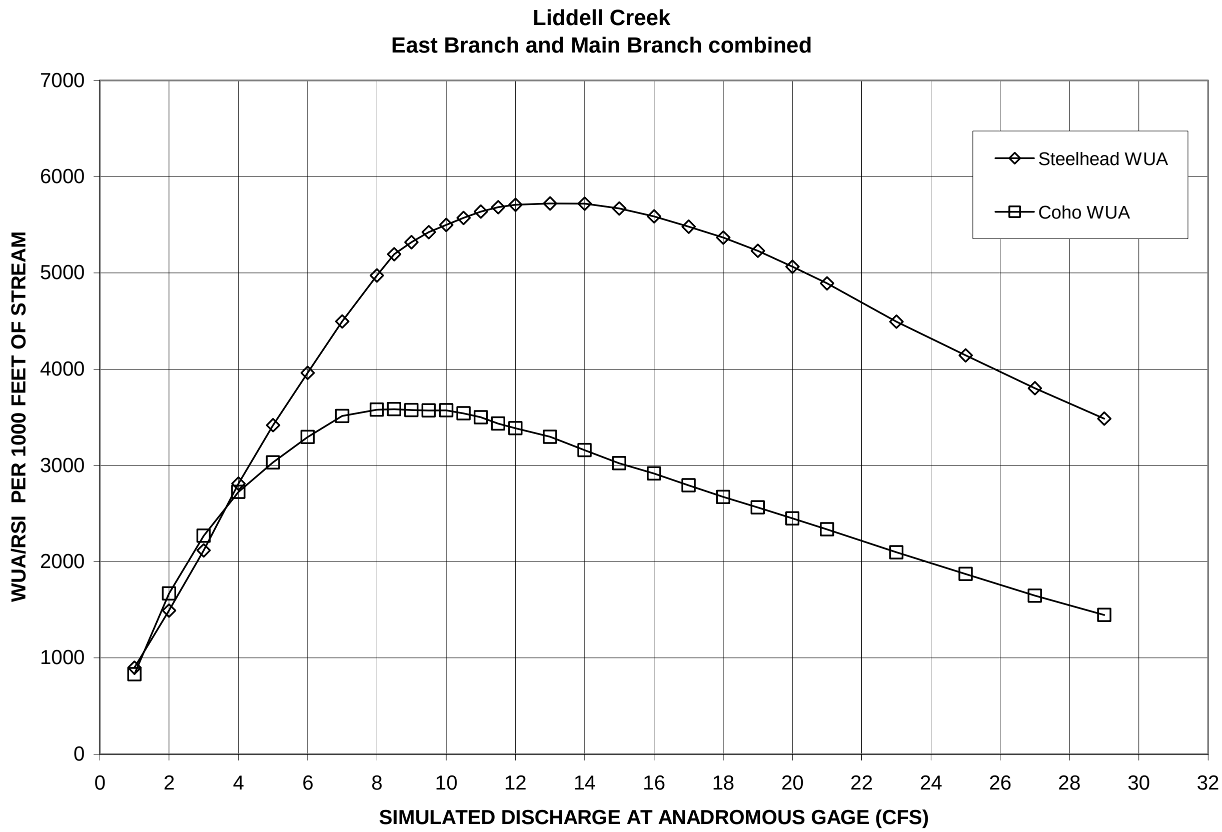


Figure 23. Spawning habitat suitability for steelhead and coho salmon as a function of flow in Liddell Creek.

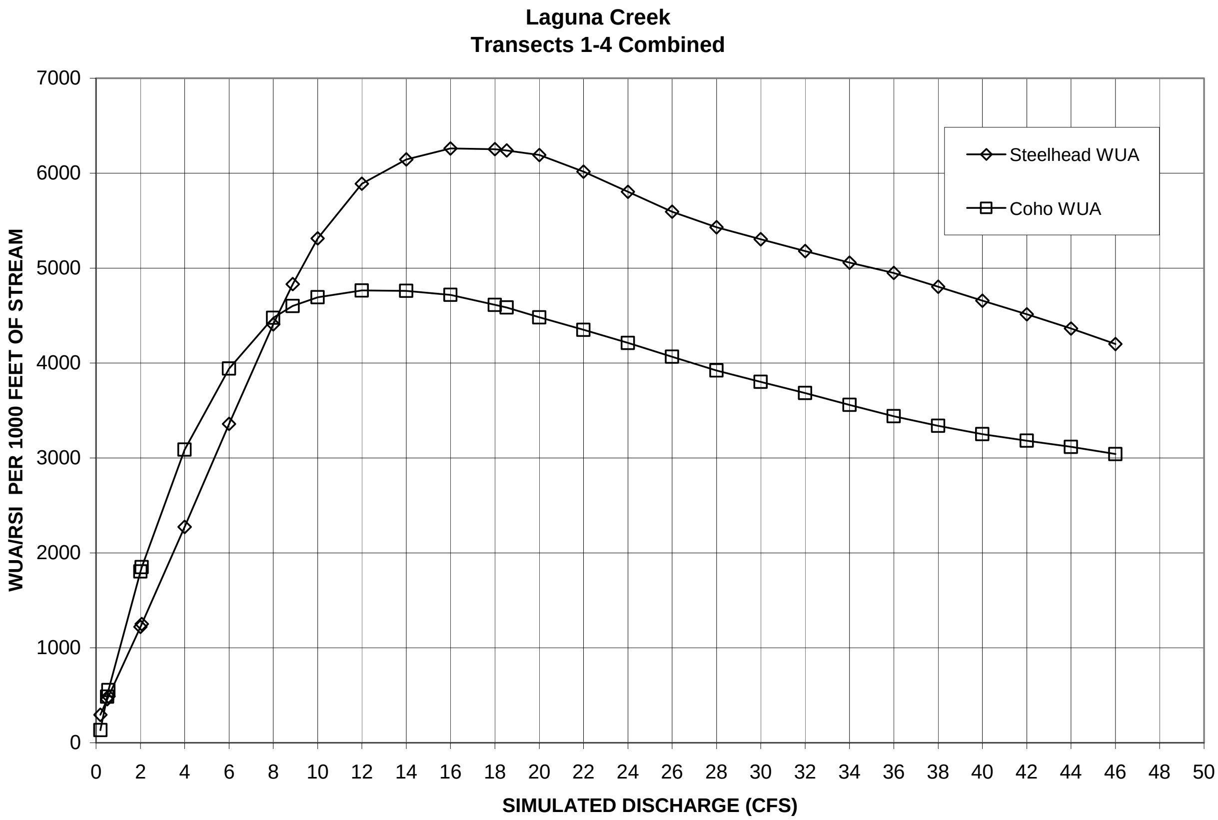


Figure 24. Spawning habitat suitability for steelhead and coho salmon as a function of flow in Laguna Creek.

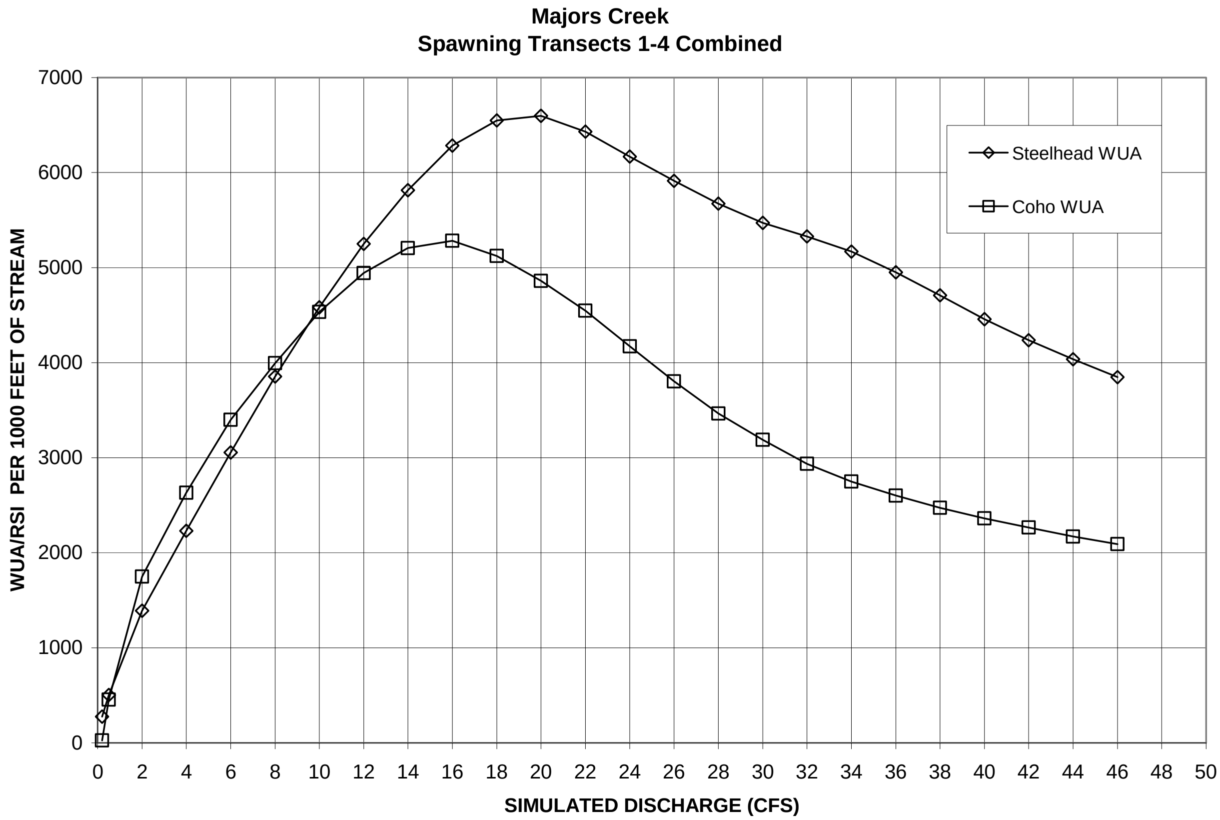


Figure 25. Spawning habitat suitability for steelhead and coho salmon as a function of flow in Majors Creek.

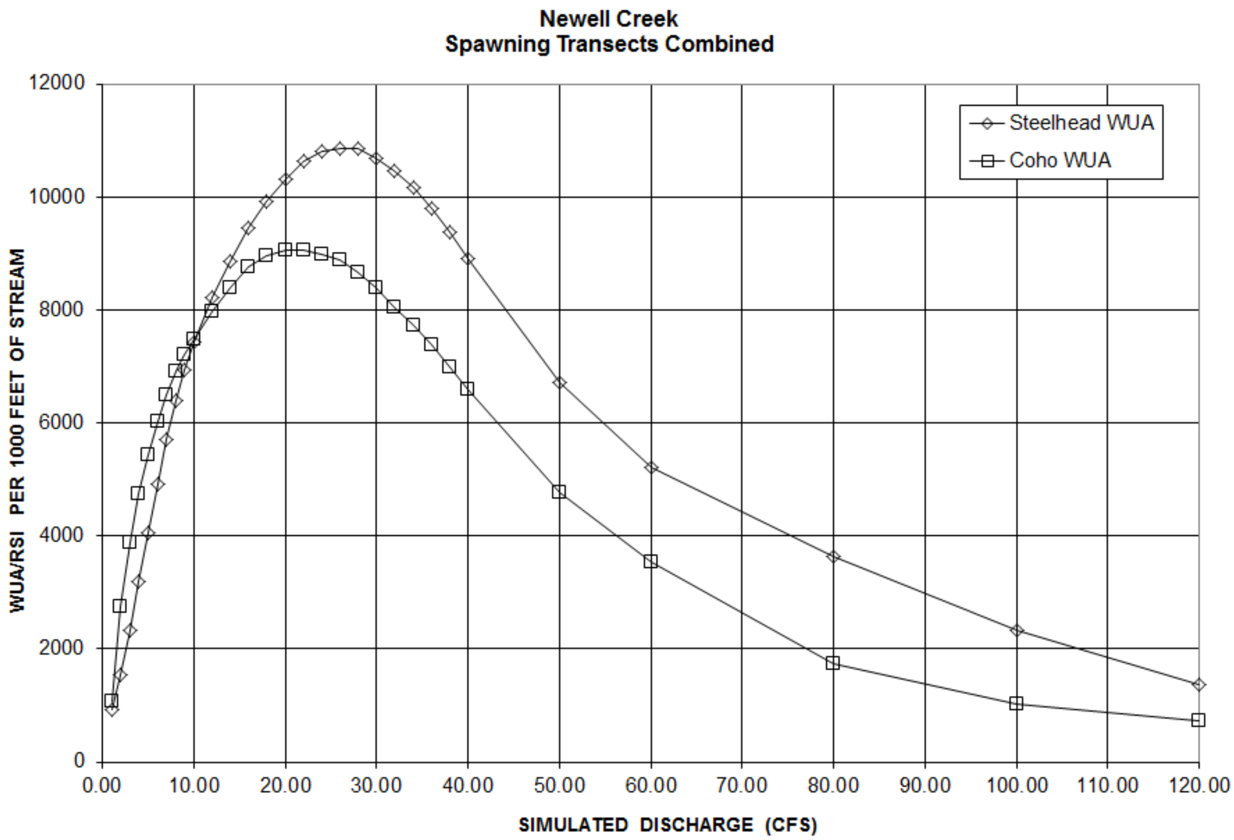


Figure 26. Spawning habitat suitability for steelhead and coho salmon as a function of flow in Newell Creek.

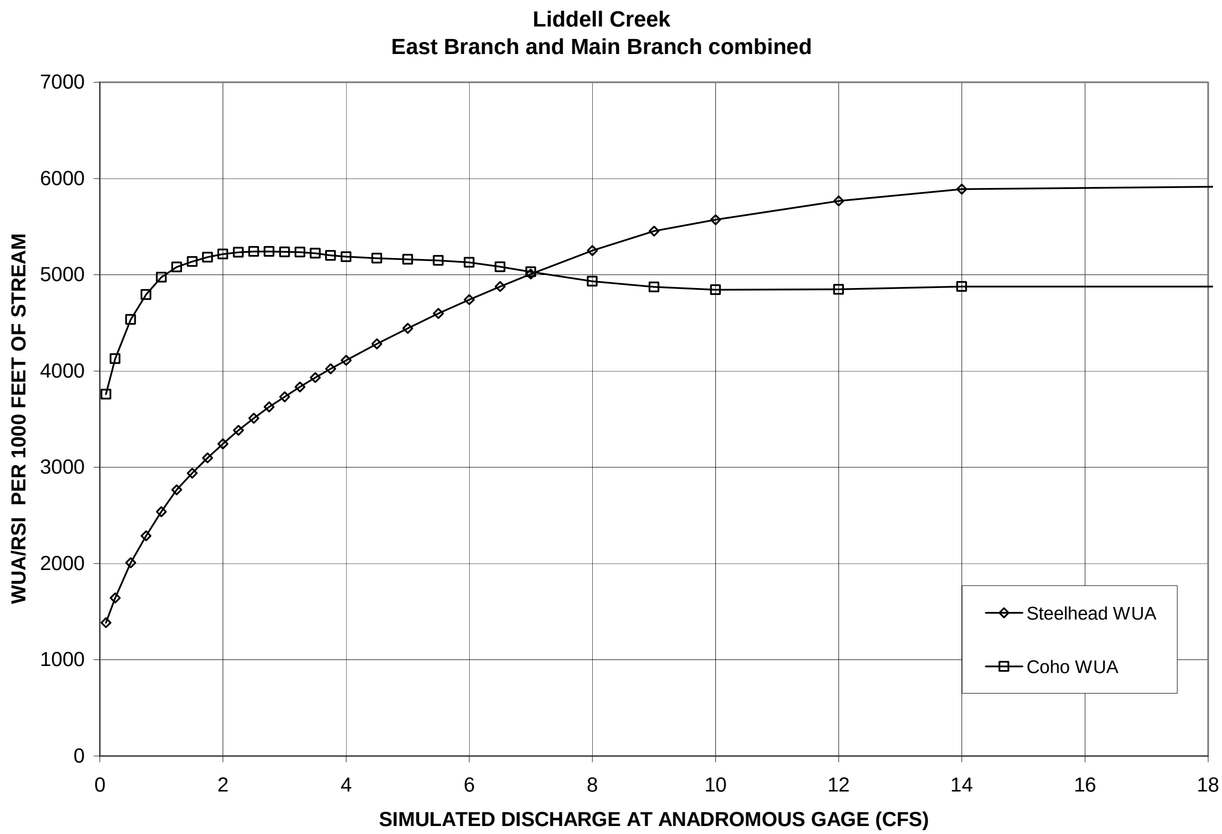


Figure 27. Rearing habitat suitability for steelhead and coho salmon as a function of flow in Liddell Creek.

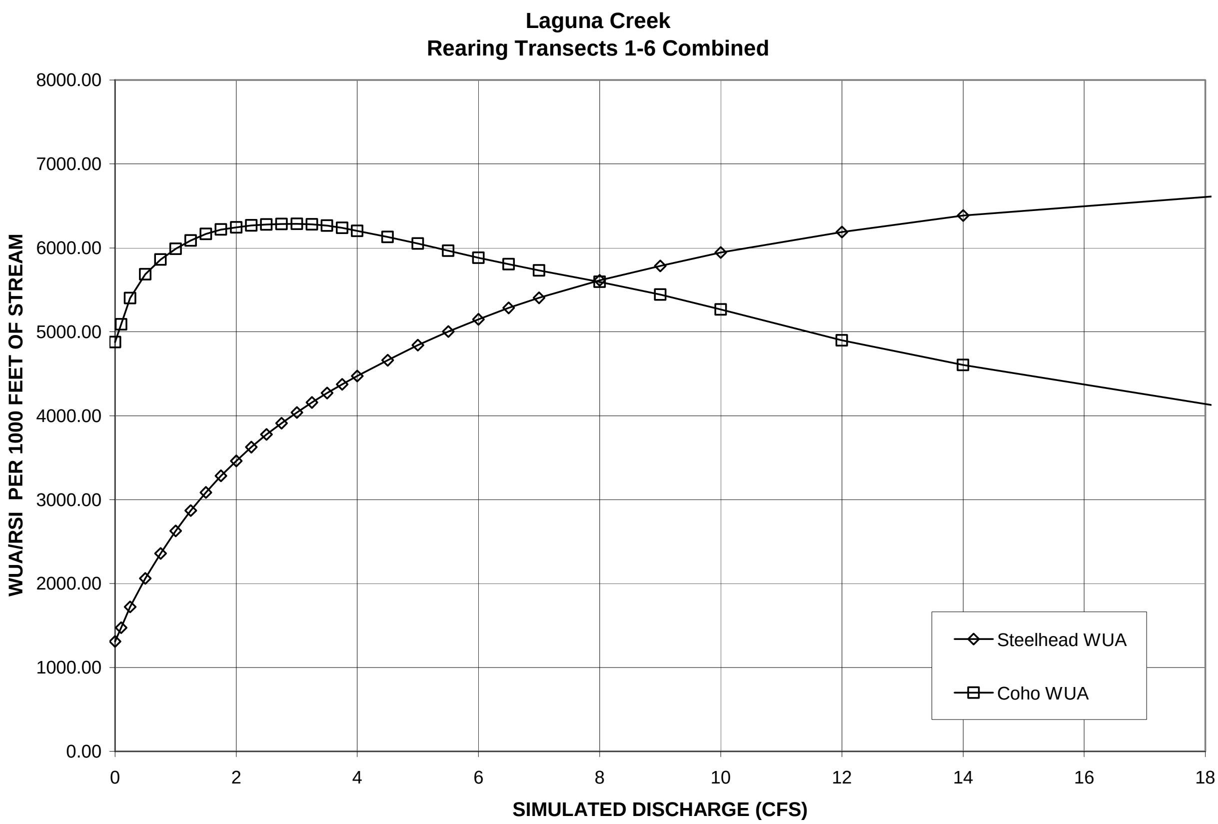


Figure 28. Rearing habitat suitability for steelhead and coho salmon as a function of flow in Laguna Creek.

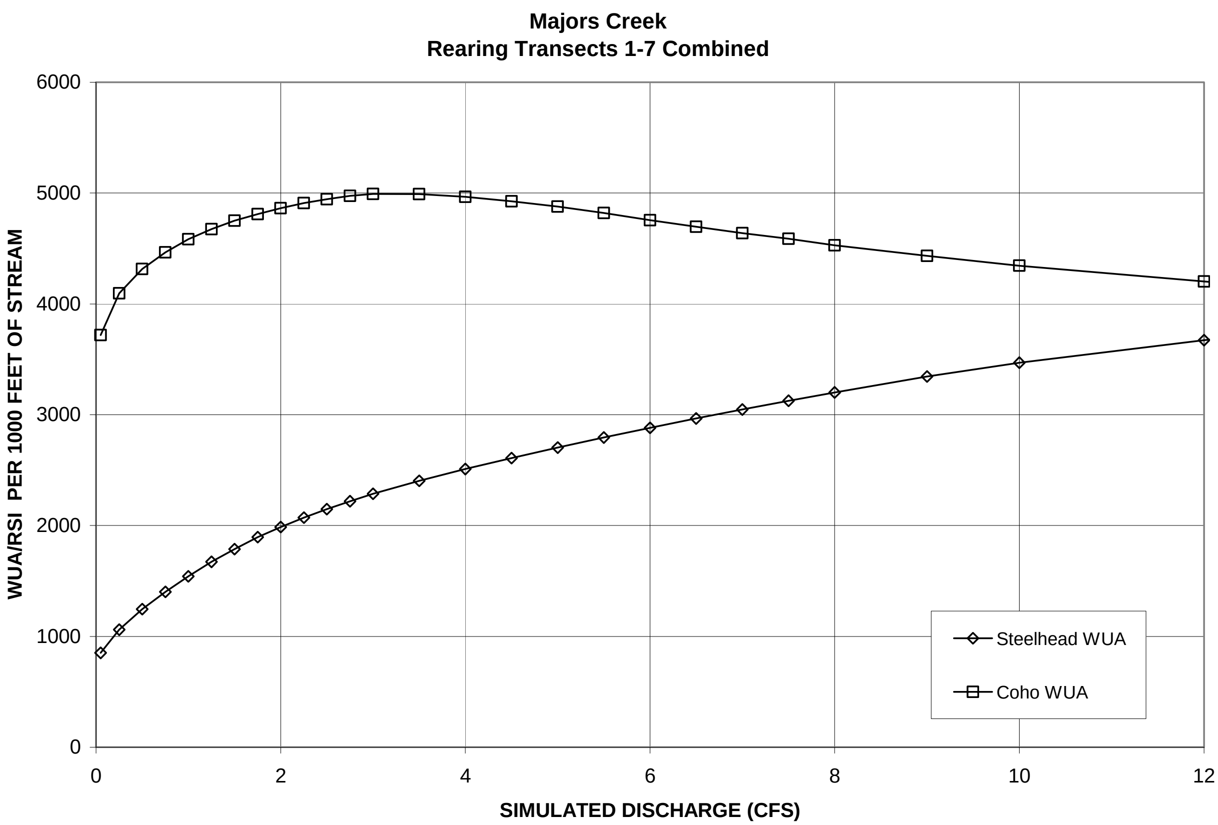


Figure 29. Rearing habitat suitability for steelhead and coho salmon as a function of flow in Majors Creek.

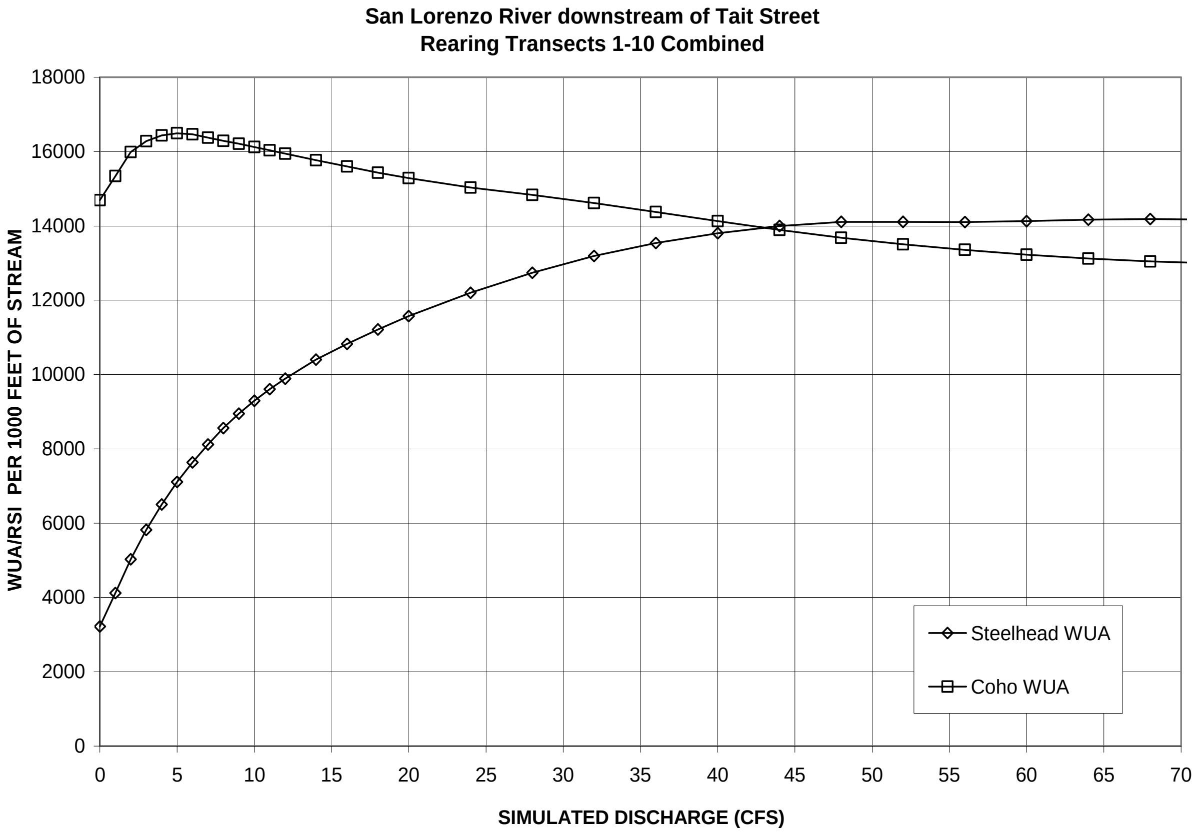


Figure 30. Rearing habitat suitability for steelhead and coho salmon as a function of flow in the San Lorenzo River downstream of Tait Street.

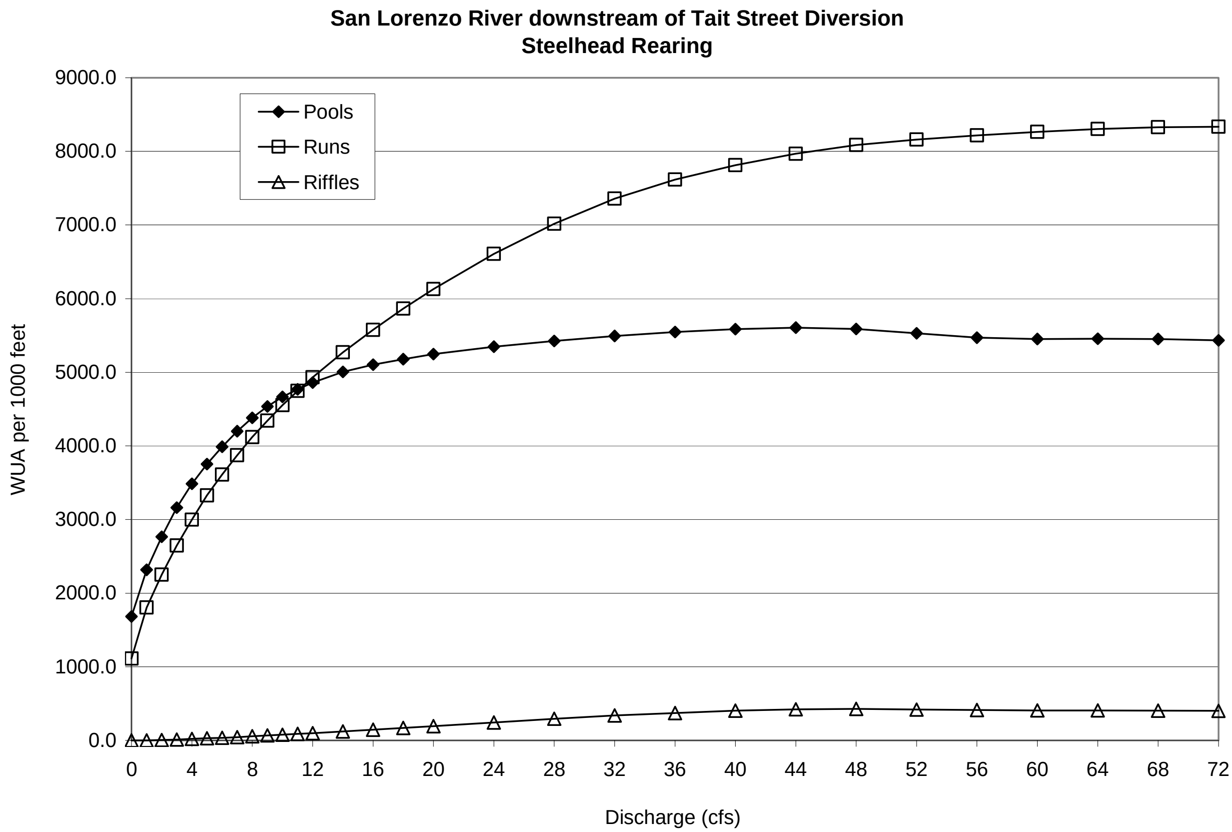


Figure 31. Rearing habitat suitability for steelhead in the San Lorenzo River downstream of Tait Street by habitat type.

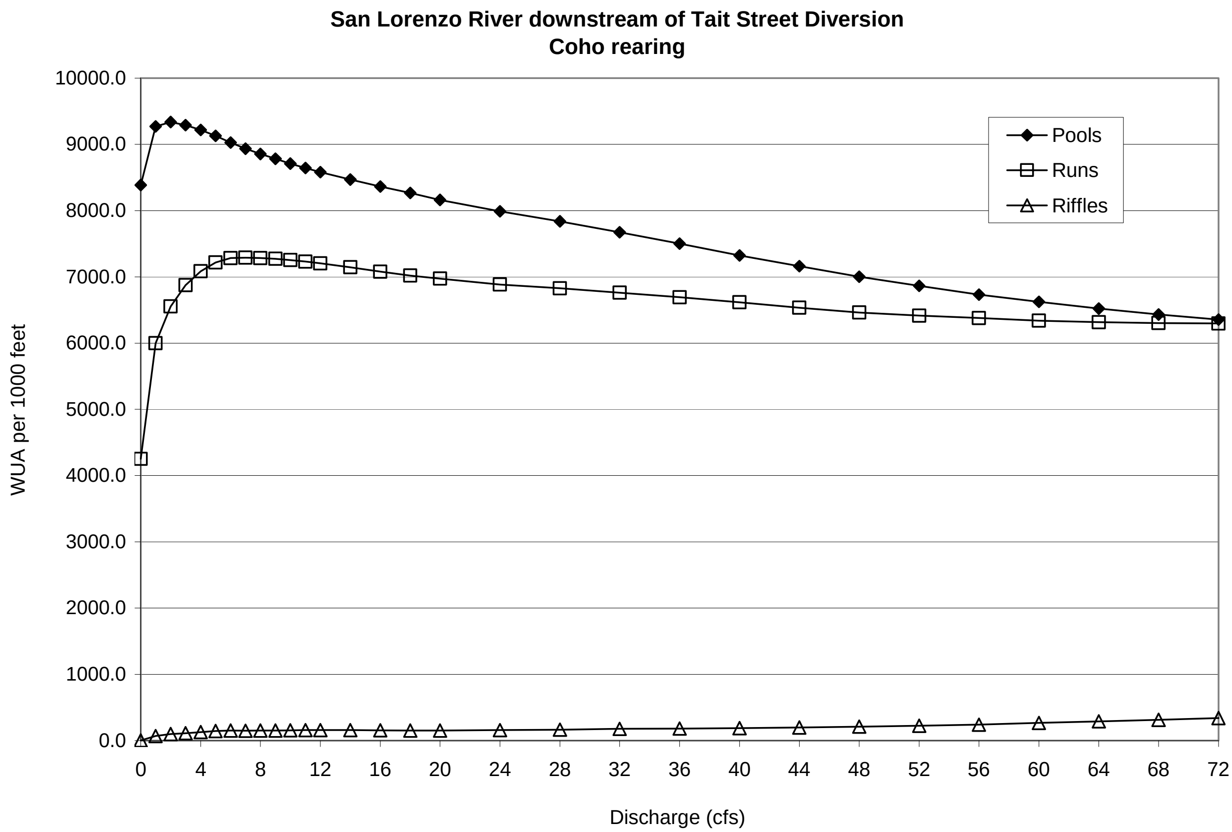


Figure 32. Rearing habitat suitability for coho in the San Lorenzo River downstream of Tait Street by habitat type.

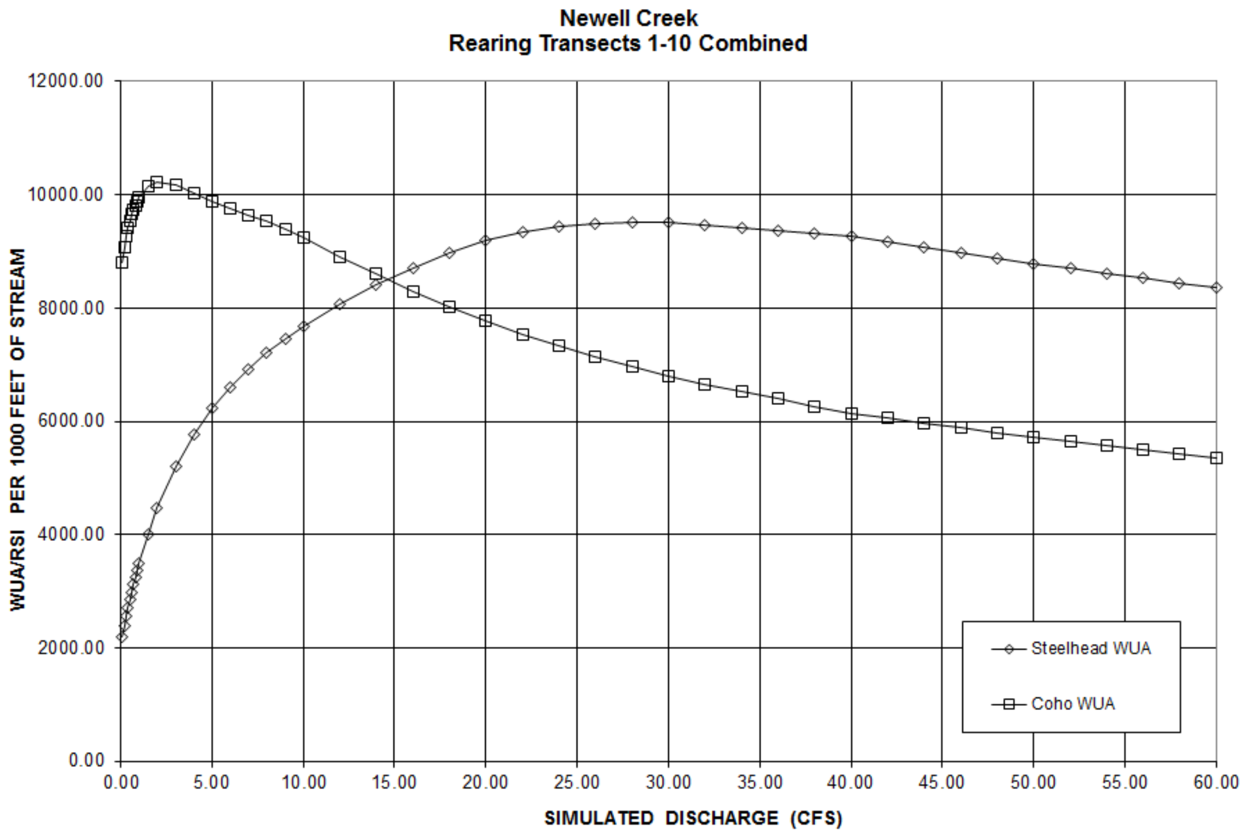


Figure 33. Rearing habitat suitability for steelhead and coho salmon as a function of flow in Newell Creek.

Table 1. North Coast PHABSIM transect characteristics.

Transect Name	Lifestage	Habitat Type	Maximum Depth (on transect)	Substrate (on transect)
Lower Liddell				
S-1	Spawning	Run	0.6	Sand/gravel
S-2	Spawning	Pool tail	0.5	Gravel/sand
R-1	Juvenile Rearing	Pool, lower part, below snag	2.0	Sand/gravel
R-2	Juvenile Rearing	Pool	1.5	Sand/silt
R-3	Juvenile Rearing	Run	0.6	Gravel/sand/cobble
Upper Liddell				
S-3	Spawning	Tail of glide	0.45	Gravel/sand
S-4	Spawning	Deep riffle	0.3	Gravel/sand/cobble
R-4	Juvenile Rearing	Pool	1.3	Sand/gravel
R-5	Juvenile Rearing	Pool, in debris jam	1.4	Sand/gravel/silt
R-6	Juvenile Rearing	Deep riffle	0.4	Gravel/sand
Lower Laguna				
S-1	Spawning	Deep riffle	0.4	Gravel/cobble/sand
S-2	Spawning	Pool tail	0.3	Gravel/sand/cobble
R-1	Juvenile Rearing	Pool, near head	2.3	Sand/silt
R-2	Juvenile Rearing	Head of pool	2.6	Silt/sand/bedrock
R-3	Juvenile Rearing	Run/glide	0.8	Sand/gravel
Upper Laguna				
S-3	Spawning	Pool tail	0.3	Gravel/sand/cobble
S-4	Spawning	Glide, toward tail	0.4	Gravel/sand
R-4	Juvenile Rearing	Run	1.1	Gravel/cobble/sand
R-5	Juvenile Rearing	Pool, just downstream of R-6	1.9	Silt/sand
R-6	Juvenile Rearing	Pool, near head	1.5	Silt/sand
Lower Majors				
S-1	Spawning	Pool tail	0.35	Gravel/sand
S-2	Spawning	Pool tail	0.3	Gravel/sand
R-1	Juvenile Rearing	Run	1.1	Gravel/sand
R-2	Juvenile Rearing	Pool, lateral scour with roots	1.5	Sand/gravel/silt
R-3	Juvenile Rearing	Run	0.6	Sand/gravel
Upper Majors				
S-3	Spawning	Pool tail	0.3	Gravel/sand
S-4	Spawning	Pool tail	0.6	Gravel/cobble
R-4	Juvenile Rearing	Pool, near head	2.9	Silt/gravel/sand
R-5	Juvenile Rearing	Run, near transition to pool	0.9	Gravel/sand/cobble
R-6	Juvenile Rearing	Pool, near head	2.5	Sand/silt
R-7	Juvenile Rearing	Mid-Pool, downstream of R-6	1.0	Sand/gravel/boulder

Table 2. San Lorenzo PHABSIM transect characteristics.

Transect Name	Lifestage	Habitat Type	Maximum Depth (on transect)	Substrate (on transect)
San Lorenzo River downstream of Tait Street				
R-1	Juvenile Rearing	Run, swift	1.2	Gravel/sand/cobble
R-2	Juvenile Rearing	Run, deep/slow	2.1	Sand
R-3	Juvenile Rearing	Pool, middle	4.0	Sand
R-4	Juvenile Rearing	Pool, head	3.7	Sand/gravel
R-5	Juvenile Rearing	Pool, middle, d/s from R-4	3.6	Sand
R-6	Juvenile Rearing	Run, slow	2.7	Sand/silt
R-7	Juvenile Rearing	Pool, upper 1/3	2.4	Sand
R-8	Juvenile Rearing	Run, moderately swift	1.6	Sand/gravel
R-10	Juvenile Rearing	Riffle, deep, low-gradient	0.8	Gravel
Newell				
S-1	Spawning	Pool tail, closer to riffle head	0.6	Gravel/sand
S-2	Spawning	Pool tail, further into pool	0.9	Gravel/sand
S-A1	Spawning	Glide/riffle	1.2	Gravel/cobble
S-A2	Spawning	Pool tail/glide	1.8	Gravel/cobble
R-1	Juvenile Rearing	Run	1.8	Cobble/gravel
R-2	Juvenile Rearing	Pool, middle/head	2.7	Gravel/cobble
R-3	Juvenile Rearing	Pool, middle	3.2	Sand/gravel
R-4	Juvenile Rearing	Pool, head	2.4	Sand/gravel
R-5	Juvenile Rearing	Run	2.0	Cobble/gravel
R-6	Juvenile Rearing	Pool, middle/head	5.5	Sand/gravel
R-7	Juvenile Rearing	Pool, head	5.1	Sand/gravel
R-8	Juvenile Rearing	Glide	1.6	Cobble/gravel
R-9	Juvenile Rearing	Pool	2.4	Cobble/gravel
R-10	Juvenile Rearing	Pool	2.9	Gravel/sand

Table 3. Stage and flow data collected at Liddell Creek PHABSIM study sites.

Site	DateTime	Velocity Data	Stage Data	Flow at Gage	Measured Flow	Estimated Flow (cfs)[2]	Stage above Zero Flow
Lower Study Area							
LD S-1	10/24/2006 10:37		X	1.18		1.18	0.58
LD S-1	12/14/2006 10:59		X	1.41		1.45	0.63
LD S-1	2/12/2007 9:28	X	X	7.54	7.08	7.54	0.96
LD S-2	10/24/2006 13:28		X	0.57		0.57	0.48
LD S-2	12/14/2006 11:43		X	1.44		1.44	0.57
LD S-2	2/12/2007 10:57	X	X	7.4	8.63	7.4	0.79
LD R-1	10/24/2006 11:30		X	0.96		0.96	0.36
LD R-1	12/14/2006 11:18		X	1.44		1.44	0.55
LD R-1	2/12/2007 11:42	X	X	8.76	8.65	8.76	0.59
LD R-2	10/24/2006 14:20		X	0.25	0.25	0.55[3]	0.48
LD R-2	12/14/2006 11:52		X	1.44	1.44	1.44	0.58
LD R-2	2/12/2007 12:54	X	X	9.34	9.34	9.34	0.90
LD R-3	10/24/2006 15:05	X	X	0.36	1.29	0.51[2]	0.49
LD R-3	12/14/2006 12:04		X	1.43		1.43	0.60
LD R-3	2/12/2007 13:43	X	X	8.78	9.78	8.78	0.92
Upper Study Area							
LD S-3	10/24/2006 16:53		X	0.49		0.98	0.44
LD S-3	12/14/2006 12:33		X	1.41		1.29	0.48
LD S-3	2/12/2007 10:34	X	X	7.36	4.54	4.54	0.77
LD S-4	10/25/2006 15:00		X	0.37		0.98	0.32
LD S-4	12/14/2006 14:12		X	1.40		1.29	0.39
LD S-4	2/12/2007 11:08	X	X	8.14	5.86	5.86	0.70
LD R-4	10/24/2006 17:24		X	0.59		1.03	0.38
LD R-4	12/14/2006 12:42		X	1.41		1.22	0.39
LD R-4	2/12/2007 14:38	X	X	7.46	4.07	4.45	0.65
LD R-5	10/25/2006 13:00		X	0.86		0.95	0.40
LD R-5	12/14/2006 13:00		X	1.41		1.29	0.46
LD R-5	2/12/2007 13:59	X	X	8.38	7.29	5.30	0.95
LD R-6	10/25/2006 14:05	X	X	0.65	0.98	0.93	0.31
LD R-6	12/14/2006 13:35	X	X	1.40	1.29	1.35	0.39
LD R-6	2/12/2007 13:08	X	X	9.07	5.43	5.43	0.71

[2] Estimated flow is gaged flow for lower study area. For upper study area estimated flow is measured flow on October and December survey dates (measured at R-6) and either measured or calculated based on measured flow adjusted for declining flows on February survey date.
[3] Adjusted based on field staff gage readings.

Table 4. Stage and flow data collected at Laguna Creek PHABSIM study sites.

Site	DateTime	Velocity Data	Stage Data	Flow at Gage	Measured Flow	Estimated Flow (cfs)[4]	Stage above Zero Flow
Lower Study Area							
LG S-1	10/17/2006 11:27	X	X	0.64	0.41	0.64	**.28**
LG S-1	12/12/2006 12:46		X	7.83		7.83	**0.66**
LG S-1	2/9/2007 15:00	X	X	16.95	20.22	16.95	**0.88**
LG S-1	3/12/2007 11:15	X	X	1.94	1.51	1.94	**0.40**
LG S-2	10/17/2006 13:08		X	0.55		0.55	**0.29**
LG S-2	12/12/2006 13:10		X	7.87		7.87	**0.78**
LG S-2	2/9/2007 15:45	X	X	28.01	24.60	28.01	**1.18**
LG S-2	3/12/2007 11:37		X	1.83		1.83	**0.44**
LG R-1	10/17/2006 10:43		X	0.68		0.68	**0.35**
LG R-1	2/9/2007 9:12	X	X	6.30	3.66	6.30	**0.79**
LG R-1	12/12/2006 12:30		X	7.46		7.46	**0.86**
LG R-2	10/17/2006 14:38		X	0.42		0.42	**0.34**
LG R-2	2/9/2007 11:35	X	X	8.86	11.53	8.86	**0.80**
LG R-2	12/12/2006 13:37		X	7.86		7.86	**0.82**
LG R-3	10/17/2006 13:41		X	0.51		0.51	**0.30**
LG R-3	2/9/2007 10:38	X	X	7.67	7.41	7.38	**0.74**
LG R-3	12/12/2006 13:19		X	7.76		7.76	**0.78**
Upper Study Area							
LG S-3	10/18/2006 10:10		X	0.79		0.61[5]	**0.25**
LG S-3	12/13/2006 11:10		X	2.68		2.21[6]	**0.38**
LG S-3	2/11/2007 10:33	X	X	47.46	38.19	40.1[7]	**1.08**
LG S-3	2/13/2007 13:23		X	11.80		6.19[5]	**0.54**
LG S-4	10/18/2006 13:13	X	X	0.71	0.42	0.39[6]	**0.33**
LG S-4	12/13/2006 9:50	X	X	2.75	2.21	2.21	**0.62**
LG S-4	2/11/2007 13:55	X	X	37.99	27.21	27.21	**1.50**
LG S-4	2/13/2007 14:34	X	X	11.18	6.17	6.48[6]	**0.94**
LG R-4	10/18/2006 12:02		X	0.75		0.44[6]	**0.37**
LG R-4	12/13/2006 11:50		X	2.45		2.21[5]	**0.55**
LG R-4	2/11/2007 15:12	X	X	35.29	29.76	29.76	**1.14**
LG R-5	10/18/2006 14:25		X	0.66		0.42[5]	**0.33**
LG R-5	12/13/2006 10:10		X	2.78		2.21[5]	**0.62**
LG R-5	2/11/2007 16:22	X	X	32.29	21.33	24.82[4]	**1.43**
LG R-6	10/18/2006 14:50		X	0.65		0.42[5]	**0.25**
LG R-6	12/13/2006 10:46		X	2.69		2.21[5]	**0.53**
LG R-6	2/11/2007 17:17	X	X	30.26	23.51	23.26[4]	**1.32**

[4] Estimated flow is gaged flow for lower study area. For upper study area estimated flow is measured or calculated from regression with City gage.
[5] Calculated by regression with City gage.
[6] Measured at upper study area reference site (S-4)
[7] 5% adjustment of measured flow

Table 5. Stage and flow data collected at Majors Creek PHABSIM study sites.

Site	DateTime	Velocity Data	Stage Data	Flow at Gage	Measured Flow	Estimated Flow (cfs)*	Stage above Zero Flow
Lower Study Area							
M S-1	10/20/2006 9:26		X	0.33		0.33	0.16
M S-1	3/8/2007 13:12		X	1.58		1.67[8]	0.34
M S-1	2/11/2007 13:15	X	X	19.50	21.39	20.08[7]	1.05
M S-1	12/12/2006 15:42		X	25.62		25.62	1.10
M S-2	10/20/2006 11:12	X	X	0.31	0.44	0.31	0.22
M S-2	3/8/2007 13:52	X	X	1.54	1.80	1.54	0.37
M S-2	2/11/2007 15:48	X	X	17.81	16.56	17.81	0.82
M S-2	12/12/2006 16:15		X	24.66		24.66	0.87
M R-1	10/20/2006 8:44		X	0.34		0.34	0.32
M R-1	3/8/2007 12:49		X	1.60		1.68[7]	0.56
M R-1	12/28/2006 16:23	X	X	4.12	2.96	2.58[9]	0.61
M R-1	12/12/2006 15:28		X	26.34		27.42[7]	1.44
M R-2	10/20/2006 13:08		X	0.28		0.28	0.32
M R-2	3/8/2007 14:55		X	1.54		1.50[7]	0.52
M R-2	12/28/2006 15:33	X	X	4.01	2.85	2.69[8]	0.62
M R-2	12/12/2006 16:35		X	24.66		24.66	1.26
M R-3	10/20/2006 13:55		X	0.25		0.25	0.38
M R-3	3/8/2007 15:09		X	1.54		1.54	0.58
M R-3	12/28/2006 14:35	X	X	3.92	2.88	2.64[8]	0.64
M R-3	12/13/2006 13:55		X	4.77		4.77	0.75
Upper Study Area							
M S-3	3/8/2007 10:57		X	1.62		1.62	0.21
M S-3	12/13/2006 14:53		X	4.49		4.49	0.33
M S-3	2/10/2007 14:30	X	X	43.89	44.26	43.89	1.15
M S-4	3/8/2007 8:44	X	X	1.63	1.97	1.63	0.24
M S-4	2/22/2007 12:40	X	X	7.33	8.49	7.33	0.46
M S-4	2/11/2007 8:49	X	X	24.32	22.54	24.32	0.72
M R-4	10/18/2006 17:07		X	0.21		0.21	0.20
M R-4	3/8/2007 10:44		X	1.62		1.62	0.37
M R-4	12/28/2006 9:15	X	X	4.16	2.88	2.58[8]	0.42
M R-4	12/13/2006 15:09			4.49		4.49	0.50
M R-5	10/20/2006 15:10		X	0.23		0.23	0.23
M R-5	3/8/2007 10:31		X	1.64		1.64	0.4
M R-5	12/28/2006 10:52	X	X	4.00	1.90	2.69[8]	0.45
M R-5	12/13/2006 15:20		X	4.49		4.49	0.52

[8] Up to 5% adjustment of gage record
[9] Average of measured flows at all sites on date +/- up to 5%

Table 5 (continued) Stage and flow data collected at Majors Creek PHABSIM study sites.

Site	DateTime	Velocity Data	Stage Data	Flow at Gage	Measured Flow	Estimated Flow (cfs)*	Stage above Zero Flow
Upper Study Area (continued)							
M R-6	10/20/2006 16:27		X	0.23		0.76[10]	0.37
M R-6	3/8/2007 8:56		X	1.65		1.65	0.45
M R-6	12/28/2006 12:56	X	X	3.91	3.11	2.74[8]	0.51
M R-6	12/13/2006 16:14		X	4.46		4.24[7]	0.58
M R-6	2/22/2007 12:03	X	X	9.30	5.04	9.76[7]	0.74
M R-7	10/20/2006 17:37		X	0.24		0.76[9]	0.35
M R-7	3/8/2007 9:10		X	1.65		1.65	0.43
M R-7	12/28/2006 12:13	X	X	3.89	2.46	2.78[8]	0.49
M R-7	12/13/2006 16:06		X	4.46		4.24[7]	0.55
M R-7	2/22/2007 13:19	X	X	10.14	8.91	10.65[7]	0.73

[10] Upstream of diversion, flow estimate based on field readings of staff gage and measured flows on 25 Oct 2006

Table 6. Stage and flow data collected at San Lorenzo PHABSIM study sites.

Site	Date Time	Velocity Data	Stage Data	Flow at Gage (cfs)	Measured Flow (cfs)	Estimated Flow (cfs)*	Stage above Zero Flow
SL R-1	11/3/05 14:32		X	11	0	11	0.82
	10/20/05 13:12		X	13	0	13	0.85
	12/5/05 11:13	X	X	35	35.36	35	1.24
SL R-2	11/3/05 14:00		X	11	0	11	0.63
	10/20/05 14:46		X	13	0	13	0.68
	12/5/05 9:50	X	X	37	35.27	37	1.15
SL R-3	11/3/05 14:59		X	11	0	11	0.48
	10/21/05 9:30		X	13	0	13	0.51
	12/5/05 12:19	X	X	33	25.92	33	0.87
SL R-4	11/3/05 15:38		X	11	0	11	1.00
	10/21/05 12:32		X	13	0	13	1.03
	12/5/05 13:32	X	X	32	39.92	32	1.41
SL R-5	11/3/05 15:59		X	11	0	11	0.98
	10/21/05 14:56		X	13	0	13	1.03
	12/5/05 14:40	X	X	32	27.38	32	1.42
SL R-6	10/24/05 9:58		X	13	0	13	0.86
	11/4/05 10:59		X	14	0	14	0.92
	12/6/05 13:00	X	X	30	27.49	30	1.16
SL R-7	10/24/05 11:51		X	13	0	12.8	0.54
	11/4/05 9:43		X	13	0	13.2	0.56
	12/6/05 11:34	X	X	30	24.97	30	0.76
SL R-8	11/3/05 16:59		X	11	0	11	1.33
	10/25/05 10:00		X	13	0	13	1.37
	11/4/05 13:33		X	14	0	14	1.44
	12/6/05 14:23	X	X	30	32.12	30	1.87
	12/5/05 15:55		X	32	0	32	1.92
SL R-10	11/4/05 14:30		X	14	0	14	0.83
	12/6/05 15:25		X	30	0	30	1.09
	12/5/05 10:32	X	X	37	33.69	37	1.22

Table 7. Stage and flow data collected at Newell Creek PHABSIM study sites.

Site	DateTime	Velocity Data	Stage Data	Flow at City Gage (cfs)	Measured Flow (cfs)	Estimated Flow at Site (cfs)[11]	Stage above Zero Flow
N S-1	2/25/08 12:20	X	X	41.81	46.71	49.21	1.22
	2/26/08 13:40	X	X	16.30	21.95	19.79	0.87
	2/27/08 12:55	X	X	12.32	15.80	15.21	0.80
	3/6/08 9:55	X	X	4.60	5.56	6.30	0.58
N S-2	2/25/08 13:04	X	X	39.87	48.77	46.98	1.26
	2/26/08 13:31		X	16.37		19.87	0.88
	2/27/08 12:48		X	12.40		15.29	0.79
	3/6/08 11:10	X	X	4.57	4.95	6.26	0.60
N S-A1	3/1/2010 15:04	X	X	23.52	27.67	28.50	1.10
	3/9/2010 14:43		X	14.32		17.45	0.91
	3/12/2010 14:25		X	12.56		15.34	0.90
	3/15/2010 14:38		X	7.95		9.81	0.80
	5/13/2010 11:21		X	0.93	1.45	1.39	0.46
N S-A2	2/12/2010 9:01	X	X	14.45		17.61	0.96
	3/2/2010 9:46			27.52	33.86	33.30	1.28
	3/9/2010 9:54		X	14.45		17.61	0.91
	3/12/2010 11:11		X	8.95		11.01	0.78
	3/15/2010 10:59		X	7.54		9.31	0.75
	5/12/2010 14:18		X	0.91	1.81	1.35	0.40
N R-1	2/11/2010 12:00	X	X	15.12	18.05	18.41	1.03
	3/2/2010 9:50	X	X	27.52	35.88	33.30	1.37
				14.30		17.43	0.95
	3/12/2010 10:49		X	8.81		10.85	0.84
	3/15/2010 10:35		X	7.54		9.31	0.83
	5/12/2010 13:36		X	0.92	1.81	1.36	0.44
N R-2	3/2/2010 12:20	X	X	29.67	39.67	35.88	1.09
	3/9/2010 11:20		X	14.17		17.28	0.79
	3/12/2010 11:43		X	8.94		11.00	0.67
	3/15/2010 11:42		X	7.86		9.70	0.64
	5/12/2010 15:06		X	0.91	1.81	1.36	0.31
N R-3	2/12/2010 14:33	X	X	14.35		17.49	1.40
	3/2/2010 12:00			28.89	29.58	34.95	1.97
	3/12/2010 13:03		X	10.81		13.24	1.30
	3/15/2010 12:45		X	7.88		9.72	1.17
	5/12/2010 16:07		X	0.92	1.81	1.37	0.68

[11] Estimated flow for sites below Rio Rancho Rd. is measured flow or calculated from regression of flow at Glen Arbor with flow at the gage (below dam); for sites above Rancho Rio is measured flow or flow at gage.

Table 7 (continued) Stage and flow data collected at Newell Creek PHABSIM study sites.

Site	DateTime	Velocity Data	Stage Data	Flow at City Gage (cfs)	Measured Flow (cfs)	Estimated Flow (cfs)[12]	Stage above Zero Flow
N R-4	2/12/2010 15:24		X	14.21		17.33	1.40
	3/2/2010 13:25	X	X	30.07	35.43	36.36	1.82
	3/12/2010 13:12		X	10.81		13.24	1.30
	3/15/2010 12:58		X	7.88		9.72	1.17
	5/12/2010 16:46		X	0.92	1.81	1.36	0.68
N R-5	2/11/2010 15:32		X	14.66		17.87	1.13
	3/2/2010 12:38	X	X	29.48	32.86	35.65	1.49
	3/12/2010 13:20		X	11.28		13.81	1.03
	3/15/2010 13:12		X	8.00		9.87	0.92
	5/12/2010 17:08		X	0.92	1.81	1.37	0.49
N R-6	2/18/2010 9:30		X	6.73		8.35	0.85
	3/1/2010 15:01	X	X	23.52	25.99	28.50	1.33
	3/12/2010 13:56		X	11.90		14.55	1.03
	3/15/2010 13:59		X	7.91		9.76	0.89
	5/13/2010 0:00		X	0.94	1.45	1.39	0.47
N R-7	2/18/2010 8:41		X	6.89		8.53	0.84
	3/1/2010 11:15	X	X	25.17		30.48	1.33
	3/12/2010 14:08		X	12.20		14.91	1.04
	3/15/2010 14:09		X	7.93		9.79	0.88
	5/13/2010 10:52		X	0.94	1.45	1.39	0.45
N R-8	2/17/2010 12:20	X	X	8.78	7.41	10.29	0.70
	3/9/2010 17:08		X	13.79		16.17	0.84
	3/12/2010 8:30		X	8.49		9.96	0.70
	5/12/2010 11:22		X	0.94		1.10	0.31
N R-9	2/17/2010 11:00	X	X	8.22	9.02	9.64	0.71
	3/9/2010 16:51		X	13.44		15.76	0.86
	3/12/2010 8:50		X	8.52		9.99	0.72
	5/12/2010 10:49		X	0.94		1.11	0.30
N R-10	2/17/2010 9:10	X	X	7.26	9.65	8.51	0.83
	3/9/2010 16:31		X	13.57		15.91	0.99
	3/12/2010 9:20		X	8.68		10.18	0.85
	5/12/2010 10:12		X	0.95		1.12	0.39

[12] Estimated flow for sites below Rio Rancho Rd. (1-7) is measured flow or calculated from regression of flow at Glen Arbor with flow at the gage (below dam); for sites above Rancho Rio (7-10) is measured flow or flow at gage.

Table 8. Substrate size class coding using the Bovee system.

Substrate Size Code	Substrate Size Range
1	Organic debris or vegetation
2	Mud or soft clay (<0.002")
3	Silt (<0.002")
4	Sand (0.002"-0.25")
5	Gravel (0.25"-3.0")
6	Cobble/Rubble (3.0"-12.0")
7	Boulder (>12.0")
8	Bedrock

Examples: 5.0 is pure gravel

4.6 is 60% gravel and sand subdominant

5.5 is gravel and 50% cobble

5.3 is gravel and 30% cobble

Table 9. Range of PHABSIM Calibration Flows and Extrapolation Range for WUA/RSI Estimates.

Stream	Lifestage	Uppermost Low Flow (cfs)	Lowermost High Flow (cfs)	Range for WUA/RSI Estimates[13]
Liddell	Spawning	1.18	7.08	0.5 - 18 cfs
	Rearing	0.96	6.92	0.4 - 17 cfs
Laguna	Spawning	0.64	16.95	0.2 - 42 cfs
	Rearing	0.68	7.46	0.3 - 18 cfs
Majors	Spawning	0.33	24.32	0.2 - 60 cfs
	Rearing	0.76	4.49	0.3 - 11 cfs
San Lorenzo	Rearing	14	30	5.6 – 75 cfs
Newell	Spawning	6.30	28.50	2.5-71 cfs
	Rearing	1.39	16.17	0.6-40 cfs

13 40% of low measured flow to 250% of high measured flow.

Table 10. Log-stage/log-discharge regression statistics for North Coast PHABSIM spawning and rearing transects.

Transect Name	N	Y-Intercept	Slope	Mean Error (%)	Variance	Standard Deviation
Lower Liddell						
S1	3	8.7079	3.7566	3.8151	6.6073	2.57046
S2[14]	3	25.0226	5.1282	1.8252	0.7718	0.87853
R-1[15]	3	23.4296	3.2452	65.6279	3890.6995	62.37547
R-2	3	15.2607	4.4613	4.6051	5.4019	2.32421
R-3	3	13.0595	4.4753	4.9139	5.6681	2.38077
Upper Liddell						
S3	3	9.2577	2.7138	1.3973	0.8803	0.93827
S4	3	13.2709	2.3356	4.7688	8.7504	2.95812
R-4	3	13.9057	2.6392	3.4380	7.6224	2.76086
R-5	3	5.8803	1.9745	1.0861	0.5216	0.72224
R-6	3	11.1837	2.1683	4.8800	7.7171	2.77796
Lower Laguna						
S1	4	25.1467	2.8524	3.4931	1.9000	1.37841
S2	4	16.9590	2.7646	4.4040	10.0905	3.17656
R-1	3	11.5188	2.6925	2.0831	2.4062	1.55119
R-2	3	17.2536	3.4445	1.1730	0.9486	0.97398
R-3	3	16.7566	2.8981	3.5054	7.7527	2.78436
Upper Laguna						
S3	4	33.6551	2.8522	5.0392	1.4578	1.20740
S4	4	8.3386	2.7832	4.0368	12.4125	3.52314
R-4	3	18.8195	3.7229	5.5396	6.3621	2.52233
R-5	3	8.9155	2.7878	4.1764	3.9255	1.98129
R-6	3	11.3544	2.4184	6.8397	11.1151	3.33393
Lower Majors						
S1	4	19.1940	2.2301	4.9742	5.6412	2.3751
S2	4	35.5578	3.1408	4.2320	10.0275	3.1666
R-1	4	9.7158	2.9185	5.7357	15.4758	3.93393
R-2	4	12.0992	3.2571	4.7815	0.5757	0.75873
R-3	4	17.3586	4.3796	3.5297	7.3032	2.70245
Upper Majors						
S3	3	34.3786	1.9159	5.8535	9.8205	3.1338
S4	3	52.3526	2.4494	4.3034	4.3247	2.0796
R-4	4	46.1519	3.3514	1.2228	0.9614	0.98053
R-5	4	48.1736	3.6429	2.1244	2.5663	1.60197
R-6	5	30.8270	3.6790	3.4913	3.6058	1.89891
R-7	5	34.8065	3.6055	3.7900	3.3382	1.82707

Note: N is the number of calibration flows

[14] Pool tail with relatively high gradient, unconfined riffle downstream results in high slope and intercept.
[15] Cross-section omitted from analysis due to excessive mean error.

Table 11. Log-stage/log-discharge regression statistics for San Lorenzo PHABSIM spawning and rearing transects.

Transect Name	N	Y-Intercept	Slope	Mean Error (%)	Variance	Standard Deviation
San Lorenzo River downstream of Tait Street						
R-1	3	19.5303	2.7266	2.40450	3.28610	1.81277
R-2	3	27.9779	2.0065	0.49100	0.12040	0.34704
R-3	3	42.5723	1.8068	2.01790	2.20220	1.48397
R-4	3	11.4180	3.0096	2.71660	4.20450	2.05049
R-5	3	11.7892	2.8528	0.89560	0.39030	0.62471
R-6	3	19.1432	2.9217	4.64890	8.15540	2.85577
R-7	3	60.4959	2.5685	2.20920	2.63900	1.62451
R-8	5	5.0697	2.8323	2.19540	3.62370	1.90361
R-10	3	22.9284	2.5738	3.11950	2.62380	1.61982
Newell Creek						
S1	4	28.5375	2.7689	0.9746	0.5511	0.74238
S2	4	26.267	2.701	4.8611	1.2836	1.13295
S-A1	4	21.2262	3.4939	2.5548	3.1407	1.77221
S-A2	4	18.4698	2.7388	5.1184	2.915	1.70734
R-1	5	15.9167	2.8512	5.7669	7.8034	2.79345
R-2	5	30.6134	2.6297	4.0981	3.3941	1.8423
R-3	5	5.3135	3.1395	10.6407	19.2676	4.38948
R-4	5	5.2463	3.375	5.3798	4.5613	2.13573
R-5	5	11.908	2.9717	5.2782	6.1464	2.47919
R-6	5	13.0985	2.9266	3.6437	2.6246	1.62006
R-7	5	13.7812	2.8541	1.63	0.4343	0.65903
R-8	4	26.0742	2.6314	1.195	0.8243	0.90789
R-9	4	22.8966	2.5149	0.3507	0.0347	0.18615
R-10	4	15.639	2.8121	4.2831	10.9769	3.31314

Note: N is the number of calibration flows

Table 12. Stage and flow data collected at North Coast migration passage assessment sites.

Site	DateTime	Velocity Data	Stage Data	Flow at Gage (cfs)	Measured Flow (cfs)	Estimated Flow (cfs)*	Stage above Zero Flow
Liddell Creek							
LD P-1	10/24/2006 12:46		X	0.70		0.70[16]	0.34
LD P-1	12/14/2006 11:27		X	1.44		1.44	0.39
LD P-1	2/12/2007 9:55	X	X	7.44	7.35	7.35	0.59
LD P-2	10/25/2006 15:38		X	0.33		0.98	0.25
LD P-2	12/14/2006 14:23		X	1.39		1.29	0.27
LD P-2	2/12/2007 11:44	X	X	8.54	5.78	5.78	0.71
LD-P3	10/24/2006 9:15		X	1.21		1.21	0.22
LD-P3	12/14/2006 9:44		X	1.44		1.44	0.30
LD-P3	2/12/2007 9:12	X	X	7.48	8.10	7.48	0.56
Laguna Creek							
LG P-1	10/17/2006 9:52		X	0.70		0.70[17]	0.12
LG P-1	3/12/2007 9:53		X	2.09		2.09	0.22
LG P-1	12/12/2006 12:14		X	7.20		7.20	0.47
LG P-2	10/17/2006 15:45		X	0.39		0.39	0.22
LG P-2	3/12/2007 13:08		X	1.75		1.75	0.31
LG P-2	12/12/2006 14:10		X	8.00		8.00	0.56
LG P-3	10/18/2006 9:10		X	0.80		0.61	0.19
LG P-3	3/12/2007 14:30		X	1.73		1.33	0.26
LG P-3	12/13/2006 11:10		X	2.68		2.06	0.29
LG P-3	2/11/2007 9:32	X	X	50.53	40.39	38.85	1.06
LG P-4	10/18/2006 11:20		X	0.77		0.59	0.75
LG P-4	3/12/2007 15:02		X	1.71		1.32	0.77
LG P-4	12/13/2006 11:36		X	2.60		2.00	0.87
LG P-4	2/11/2007 12:05	X	X	42.49	31.66	32.67	1.45
Majors Creek							
M P-1	10/20/06 10:11			0.34		0.34	0.21
M P-1	12/12/06 16:02			25.62		25.62	0.80
M P-1	3/8/07 13:25			1.57		1.57	0.28
M P-2	10/18/06 15:50			0.22		0.22	0.25
M P-2	2/10/07 12:59			45.56	45.92	45.56	1.35
M P-2	3/8/07 11:18			1.69	2.11	1.69	0.40
M P-3	10/20/06 15:47			0.24		0.75[18]	0.36
M P-3	12/13/06 15:43			4.48		4.82	0.56
M P-3	2/10/07 16:00			36.48	37.10	36.44	1.16
M P-3	3/8/07 10:11			1.65		2.10	0.43

[16] Estimated flow is gaged flow or measured flow for lower study area (LD P-1 and P-3). Site LD P-2 is upstream of the West Branch and flow is measured flow above the West Branch confluence (Site P-2 when available, otherwise flow reference site R-6.

[17] Estimated flow is gaged flow for Sites LG P-1 and P-2 and estimated from regression for Sites LG P-3 and P-4.

[18] Site M P-3 is above diversion location, gage site is below diversion. Estimated flows for all dates calculated from regression of gage site with measured flows at Sites P-3 and S-4 (also above diversion).

Table 13. Stage and flow data collected at San Lorenzo migration passage assessment sites.

Site	DateTime	Velocity Data	Stage Data	Flow at Gage	Measured Flow	Estimated Flow (cfs)*	Stage above Zero Flow
San Lorenzo River downstream of Tait Street							
SL P-1	10/12/05 9:25		X	18		18	0.83
	10/20/05 9:10		X	13		13	0.68
	12/6/05 8:40		X	28		28	0.89
	12/6/05 11:22		X	30		30	0.95
SL P-2	10/12/05 11:55		X	19		19	1.03
	10/20/05 10:09		X	13		13	0.78
	11/4/05 11:34		X	14		14	0.86
SL P-3	10/12/05 14:35		X	12		12	0.52
	10/20/05 10:46		X	13		13	0.49
	11/3/05 15:59		X	11		11	0.48
	12/5/05 13:20		X	32		32	0.82
SL P-4	10/12/05 16:20		X	12		12	0.58
	10/20/05 11:24		X	13		13	0.55
	12/5/05 16:20		X	32		32	0.73
Newell Creek							
N P-1	2/25/08 12:39		X	41.27		48.59	1.24
	2/26/08 14:34		X	16.26		19.74	0.81
	2/27/08 13:45		X	12.16		15.01	0.69
	3/6/08 12:30		X	4.57		6.27	0.53
N P-2	2/25/08 12:38		X	41.35		48.68	1.03
	2/26/08 14:32		X	16.33		19.83	0.63
	2/27/08 13:37		X	12.25		15.12	0.61
	3/6/08 11:52		X	4.55		6.24	0.43
N P-A1	2/12/2010 12:10		X	14.48		17.65	0.98
	3/2/2010 11:50		X	29.15		35.26	1.24
	3/9/2010 10:22		X	14.36		17.51	0.92
	3/12/2010 11:30		X	8.94		11.00	0.80
	3/15/2010 11:19		X	7.76		9.58	0.78
	5/12/2010 14:47		X	0.90	1.56	1.35	0.56
N P-A2	2/18/2010 10:34		X	6.62		8.22	0.75
	3/1/2010 17:04		X	23.21		28.12	0.99
	3/9/2010 13:11		X	14.53		17.71	0.83
	3/12/2010 13:34		X	11.46		14.02	0.82
	3/15/2010 13:34		X	7.98		9.84	0.76
	5/13/2010 9:32		X	0.95	1.56	1.40	0.47

Table 14. Log-stage/log-discharge regression statistics for migration passage transects.

Transect Name	N	Y-Intercept	Slope	Adjusted R^2
Liddell				
LD P-1 (below West Br)	3	1.8353	4.1888	99.19%
LD P-2 (above West Br)	3	1.0082	1.6382	98.84%
LD P-3 (Highway 1)	3	1.3496	2.0479	88.14%
Laguna				
LG P-1 (Highway 1)	3	1.4222	1.7008	99.86%
LG P-2 (lower study area)	3	1.7424	3.1691	95.51%
LG P-3 (upper study area)	4	1.5400	2.3892	99.62%
LG P-4 (upper study area)	4	0.6190	5.6096	96.41%
Majors				
M P-1 (below Highway 1)	3	1.7410	3.0831	95.52%
M P-2 (Highway 1)	4	1.3165	3.0332	94.59%
M P-3 (above diversion)	4	1.4001	3.1640	97.14%
San Lorenzo				
SL P-1 (below Tait St. div)	4	1.5328	2.6073	88.17%
SL P-2 (behind tannery)	3	1.2549	1.4060	94.40%
SL P-3 (near Petsmart)	4	1.6676	1.9332	96.00%
SL P-4 (Water St.)	3	1.8993	3.1278	86.82%
Newell[19]				
N P-1 (below Rancho Rio)	4	1.4941	2.3475	97.34%
N P-2 (below Rancho Rio)	4	1.6879	2.3309	96.88%
N P-A1 (below Glen Arbor)	6	1.3048	4.0782	91.12%
N P-A2 (above Glen Arbor)	6	1.4990	4.1899	98.45%

Note: N is the number of stage/discharge points.

[19] Passage at Newell transects P-3 and P-4 was evaluated using a different methodology (see Section 3.3).

Table 15. Minimum passage flow estimates.

Transect Name	Adult Steelhead and Coho	Steelhead and Coho Smolts
Liddell		
LD P-1 (below West Br)	***11.3***	0.8
LD P-2 (above West Br)	4.9	1.7
LD P-3 (Highway 1)	8.1	***2.0***
Laguna		
LG P-1 (Highway 1)	11.7	***3.8***
LG P-2 (lower study area)	***15.5***	2.4
LG P-3 (upper study area)	10.6	1.8
LG P-4 (upper study area)	11.6	1.7
Majors		
M P-1 (below Highway 1)	***16.0***	2.6
M P-2 (Highway 1)	9.0	2.0
M P-3 (above diversion)	14.5	***3.4***
San Lorenzo		
SL P-1 (below Tait St. div)	**25.2**	5.3
SL P-2 (behind tannery)	17.0	**10.0**
SL P-3 (near PetCo)	24.6	8.7
SL P-4 (Water St.)	23.7	3.8
Newell		
N P-1 (below Rancho Rio)	**24.4**	**8.3**
N P-2 (below Rancho Rio)	22.7	6.4
N P-A1 (below Glen Arbor)	11.4	3.9
N P-A2 (above Glen Arbor)	21.3	3.2

Note: Maximum values for each stream and life-stage in ***bold italic***.

Table 16. Habitat survey results for the San Lorenzo River between Water Street and Tait Street Diversion.

	Number of Habitat Units	Total Length (ft)	% by Length	Min/Max Length (ft)	Average Length (ft)	Average Depth (ft)	Maximum Depth (ft)
Downstream of Highway 1							
riffles	6	231	8	27/54	38	0.55	1.1
pools	3	1,404	49	101/760	468	2.9	4.3
runs	6	1,209	42	101/318	202	1.9	3.0
Upstream of Highway 1							
glides	1	1,409	55			0.9	2.4
runs	1	1,167	45			1.5	2.8

Table 17. Analysis of Flows for Passage at Newell Creek Passage Obstacle N P-3.

Passage Depth (ft)	Mean Velocity (fps)	Flow (cfs)	Estimated Swimming Distance (ft)					
			Steelhead Burst Swim Speed			Coho Salmon Burst Swim Speed		
			13.7 fps)	20.1 fps	26.5 fps	10.6 fps	16.1 fps	21.5 fps
Mannings =0.025								
0.4	10.1	129	1	25	49	-11	10	30
0.5	12.0	197	-8	16	40	-20	1	21
0.6	13.5	275	-16	8	32	-28	-7	13
Mannings = 0.040								
0.4	5.3	68	25	49	73	13	34	54
0.5	6.3	104	20	44	68	8	29	49
0.6	7.1	145	16	40	64	4	25	45

Table 18. Habitat suitability for rearing steelhead in the San Lorenzo River downstream of Tait St.

Habitat Characterization	WUA Level	Corresponding Flow Level	Average Wetted Width (ft)	Riffle Width (ft)
Prime	80%-100% of maximum WUA	19-72 cfs	32-39	21-37
Good	60% to 80% of maximum WUA	8-19 cfs	29-32	16-21
Fair	40% to 60% of maximum WUA	3-8 cfs	27-29	11-16
Poor	Less than 40% of maximum WUA	0.5-3 cfs	25-27	6.5-11

Appendix A

Temperature Monitoring Results

Temperature Monitoring

During the summer and early fall of 2005 the City installed temperature monitoring devices to assess temperature conditions in the lower San Lorenzo River (downstream of Felton) and Newell Creek and potential relationship to City activities at Felton Diversion, Newell Diversion and Tait Street Diversion. Temperature monitors were installed at the following locations:

- Newell Creek
    - Limit of anadromy
    - San Lorenzo mainstem above confluence with Newell Creek
    - San Lorenzo mainstem below confluence with Newell Creek
    - Newell Creek above reservoir (2004)
    - Newell Creek below dam (2004)
- San Lorenzo gorge
- Tait Street upstream from diversion
- Tait Street below diversion
- San Lorenzo River at Water Street

This report presents a summary of temperature monitoring data including graphs of daily average temperatures, daily maximum temperatures, and 7-day average of maximum daily temperature (MWAT) for each of the recorder locations.

Background

Water temperature is one of the more important environmental factors affecting fish. Fish and fish communities are often classified in terms of thermal preferences and tolerances as coldwater, coolwater, or warmwater species or assemblages. Fish cannot regulate their body temperature independent of environmental conditions. For any species there is a range at which growth and other functions are optimum. As temperature increases or decreases from the optimum range there is a zone of tolerance where the fish can survive but may experience compromised performance (i.e., reduced growth, reduced reproductive capacity, increased susceptibility to disease). Further temperature changes outside the zone of tolerance result in increasingly stressful conditions and deleterious but sublethal effects. Finally, extended exposure beyond a certain upper and lower limit will result in death.

Temperature is a particularly important factor for steelhead/rainbow trout and coho salmon in Central California where seasonal water temperatures can be higher than in much of the natural range of these species. In many streams in this region, growth slows or ceases in conjunction with warm, low flow conditions in late summer. The influence of water temperature on steelhead and other salmonids has been well studied and the influence on individual populations is complicated by a number of factors such as behavioral responses, daily and annual thermal cycles, food availability, habitat conditions, and possibly, local adaptations.

The upper thermal limit for rearing juvenile rainbow trout/steelhead and coho salmon depends on several factors such as acclimation temperature, food ration levels, activity levels, and others. A temperature of 24-26°C has generally been shown under laboratory conditions to result in 50% mortality rates of well fed fish held under otherwise acceptable environmental conditions and acclimated to high temperature (Brett 1952; Hokanson et al. 1977). This is a common measure of thermal tolerance and is known as the upper incipient lethal temperature (UILT). Upper incipient lethal temperature has been estimated at 26°C for both steelhead (Hokanson et al. 1977) and coho salmon (Brett 1952).

In most streams, water temperature varies over the course of a day and from day to day, generally tracking changes in air temperature. Although the peak temperature on a given day may exceed the lethal level, salmonids can survive short periods at temperatures above the lethal threshold. For example, in a study of juvenile chinook salmon, test fish experienced no mortality at temperatures up to 75°F (24ºC) for 7 days. At 79°F (26ºC), half the juvenile salmon survived a 5-hour exposure period and at 81°F (27ºC) half survived a 1.5-hour exposure (Brett 1952). The temperature that the fish are acclimated to is also an important variable. Juvenile salmon acclimated to 75°F (24ºC) experienced 50% mortality after 8.5 days at 77°F (25ºC) while those acclimated to 59°F (15ºC) experienced 50% mortality after only 42 hours of exposure at 77°F (25ºC) (Brett 1952). Elevated temperature below the lethal threshold can have indirect influence on survival due to depression of growth rate, increased susceptibility to disease, and lowered ability to evade predators. It is more difficult to establish the linkage between these indirect effects and definite temperature thresholds.

Under experimental conditions, Hokanson et al. (1977) found that the maximum growth rate for rainbow trout fed excess rations occurred at 17.2-18.6°C when temperature was held constant, but occurred at 15.5-17.3°C when temperature fluctuated +/-3.8°C around the mean each day. At higher temperatures, growth still occurred but at a slower rate. Mortality rates in these experiments increased as mean temperature increased from 18.6°C to 21.2°C at constant temperatures and, in the fluctuating temperature regime, when mean temperature increased from 19.1°C to 21°C. If one considers the population as a whole there is some point when increased biomass due to growth will be balanced by reduced biomass due to mortality and the population experiences no change in weight (a yield of zero). Hokanson et al. (1977) estimated that at fluctuating temperatures with a mean of 21°C or more, the population yield would become negative.

Food availability is a critical factor influencing thermal tolerance, growth rates, and overall health. Smith (1999) describes two different habitat types used by Central Coast steelhead and resident trout. The primary habitat consists of shaded pools of small, cool, low-flow upstream reaches typical of the original steelhead habitat in the region. In addition, they can use warmwater habitats below some dams or pipeline outfalls, where summer releases provide high summer flows and fast-water feeding habitat. Trout metabolic rate and thus food demand increases with temperature. Trout rely heavily on insect drift for food and drift increases with flow velocity. Under conditions of low flow and high temperatures trout have increasing difficulty obtaining sufficient food to meet metabolic costs. Smith and Li (1983) found that in Uvas Creek (Santa Clara County), a relatively warm stream with summer maximum water temperature of 23ºC to 25°C, steelhead/rainbow trout move into higher velocity microhabitats in riffles and runs where sufficient food can be obtained. These habitats are created by summer releases from an upstream reservoir. Under augmented flow conditions trout can occupy warmer habitats than may otherwise be possible.

Analysis Methods

Data collected by the City were summarized to characterize stream reaches in terms of their suitability for rearing steelhead and coho salmon, primarily by comparing standard summary statistics to standards for steelhead/rainbow trout and coho (Armour 1991). The temperature records were converted to daily maximum and daily average water temperature and the following summary statistics were calculated:

- Number of days with daily maximum exceeding upper incipient lethal level (26°C for steelhead, 25°C for coho).
- Number of days with daily average exceeding hypothetical zero yield for steelhead (21°C, based on Hokanson 1977).
- Number of days with seven-day moving average of daily maximum temperature exceeding MWAT. (19.3°C for steelhead and 18.3°C for coho based on Armour 1991).

Armour (1991) has proposed MWAT as criteria for developing temperature regimes to protect fish. MWAT is the Maximum Weekly Average Temperature that should not be exceeded and is calculated for a given species of fish when experimental temperature tolerance data is available. MWAT is calculated as the optimal temperature for a given species or life-stage plus one third of the difference between the optimal temperature and the upper incipient lethal temperature, or:

MWAT = OT + (UILT-OT)/3

where:

OT = a reported optimal temperature for the particular life stage or function, and

UILT = the upper incipient lethal temperature that does not increase with increasing acclimation temperatures.

Optimal temperature was derived from methods presented in Armour (1991) and was generally consistent with values presented in other literature sources (Bjornn and Reiser 1991, Raleigh et al. 1986; McMahon 1983; Laufle et al. 1986; Brett 1952). In the case of rearing juvenile *O. mykiss*, we used 16°C as the optimal temperature and 26°C as the upper incipient lethal temperature to obtain an MWAT of 19.3°C. For rearing coho salmon we used 14.5°C as the optimal temperature and 26°C as the upper incipient lethal temperature to obtain an MWAT of 18.3°C.

Monitoring Results

Water temperature downstream of Newell Dam (at City streamgage location downstream of spillway pool) averaged one to two degrees cooler than inflow from Newell Creek upstream of the reservoir (about 0.25 mile above the lake high water line) in monitoring data collected during the summer of 2004 (Table A-1, Figure A-1). Cold water is released from Loch Lomond Reservoir to Newell Creek during the summer months at a rate of at least 1 cfs. The effect of this release is apparent where Newell Creek joins the San Lorenzo River. Water temperature downstream of the Newell Creek confluence averaged approximately 1 degree cooler than water temperature immediately upstream of the confluence (Figure A-2). There were no exceedences of the upper incipient lethal temperature for either steelhead or coho at either the Newell Creek locations or in the San Lorenzo River above and below Newell Creek. There were also no days with temperature high enough to reach hypothetical zero-yield for steelhead at any of these locations. There were no occurrences of seven-day moving average of daily maximum temperature that exceeded the MWAT suitability criteria for steelhead in the San Lorenzo River either upstream or downstream of the Newell Creek confluence during the monitoring period but likely occurrences before the monitoring began upstream of the confluence (Figure A-2). There were 4 days that had MWAT that exceeded suitability criteria for coho upstream of the confluence and no days downstream of the confluence although both locations probably exceeded the coho MWAT criteria before the monitoring period began (Figure A-2).

Water temperature monitoring at San Lorenzo River monitoring locations was initiated in August, near the expected seasonal peak in temperature, although July may have had higher temperatures. Water temperature was lowest in the San Lorenzo gorge (Garden of Eden) and increased at downstream locations (Figure A-3). Water temperature conditions in August were near the upper range of suitability for steelhead and slightly in excess of the suitable range for coho salmon. Water temperature was highest at the Water Street monitoring location. None of the monitoring locations had maximum daily water temperatures that approached lethal levels for either steelhead or coho salmon (Figure A-4). None of the locations had daily average temperatures high enough to reach hypothetical zero-yield for steelhead (Figure A-3, Table A-1). All of the locations except the Garden of Eden had seven-day moving average of daily maximum temperature that exceeded the MWAT suitability criteria for steelhead and all locations exceeded the MWAT criteria for coho. With the exception of Water Street, exceedences were only slightly above the criteria for steelhead and only during August and early September (Figure A-5).

Water temperature was generally higher at Water Street than at the Tait Street diversion with temperature differences ranging from -0.4°C to 1.9°C during the monitoring period. The temperature difference is likely explained by thermal gain in the relatively exposed (un-shaded) flood control channel upstream of Water Street. Water temperature at Water Street is influenced by increasing lagoon stage during periods with higher tidal cycles (Figure A-6) as occurred on September 16 during the monitoring period. There does not appear to be a significant relationship between flow levels and temperature increase downstream of the Tait Street diversion under the range of flows and environmental conditions occurring during the monitoring period (Figure A-6). At flows in excess of 21 cfs there may be a tendency for differences in temperature between Water Street and Tait Street to approach zero but data are very limited at higher flow levels (Figure A-6).

Conclusions

Water temperature appears 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 peak period and in the lower San Lorenzo River from above Tait Street to the lagoon. Temperature is relatively warm for coho salmon except in Newell Creek downstream of Newell Dam. Suitability criteria for steelhead are generally met at all locations except the lower river. Temperature conditions are relatively warm upstream of the Tait Street diversion and generally increase at Water Street.

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TABLES

Table A-1 Summary of San Lorenzo River Temperature Monitoring Records and Suitability Criteria

Location	Monitoring Period	Highest Daily Maximum (°C)	Highest Daily Average (°C)	Highest MWAT (°C)
SLR Upstream of Newell Creek	29 Aug to 7 Oct, 2005	20.0	19.1	19.9
SLR Downstream of Newell Creek	29 Aug to 7 Oct, 2005	19.0	18.2	18.8
Newell Ck Upstream of Newell Reservoir	16 June to 11 Aug, 2004	17.4	16.4	16.1
Newell Ck below Newell Dam	16 June to 11 Aug, 2004	15.2	14.0	13.6
San Lorenzo Gorge (Garden of Eden)	22 Aug to 7 Oct, 2005	19.6	18.2	19.1
Tait Street Upstream From Diversion	10 Aug to 21 Oct, 2005	20.5	19.7	19.7
Tait Street Below Diversion	10 Aug to 21 Oct, 2005	20.5	19.7	19.7
Downstream of Tait Street	10 Aug to 24 Aug, 2005	20.5	19.7	19.6
San Lorenzo River at Water Street	26 Aug to 21 Oct, 2005	20.9	19.2	20.9

FIGURES

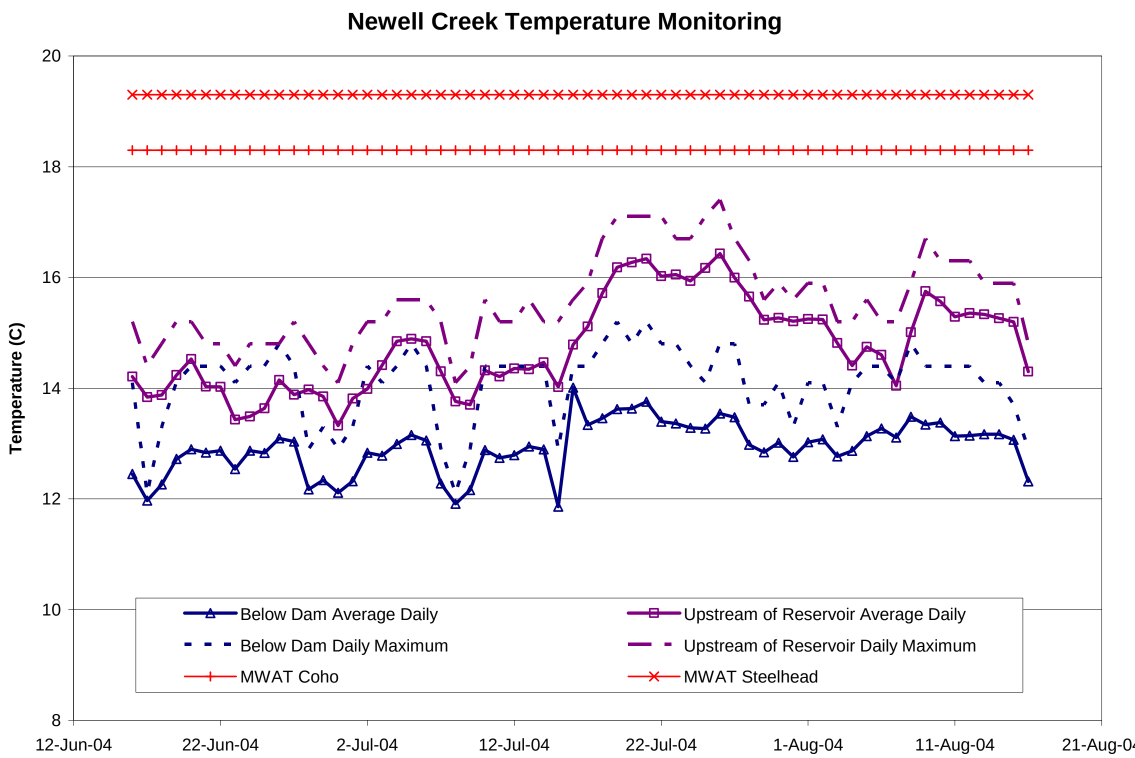

Figure A-1 Newell Creek temperature monitoring results.

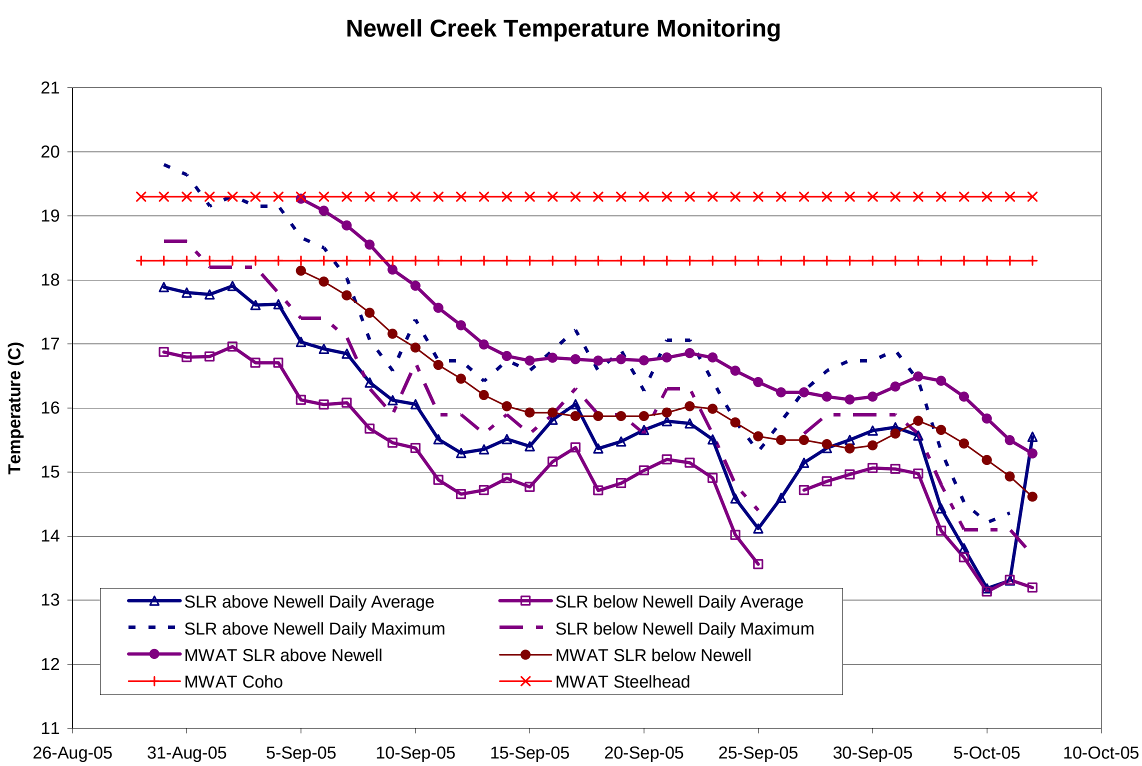

Figure A-2 Newell Creek temperature monitoring results.

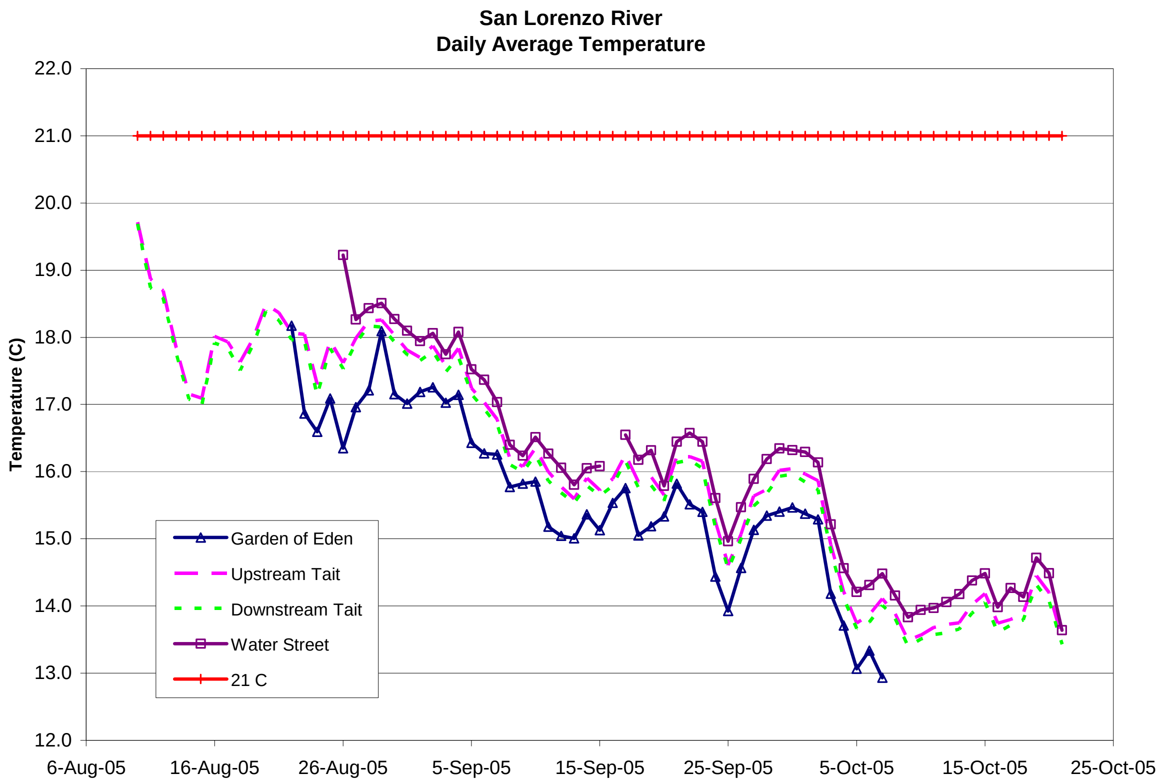

Figure A-3 San Lorenzo River Daily Average Temperature

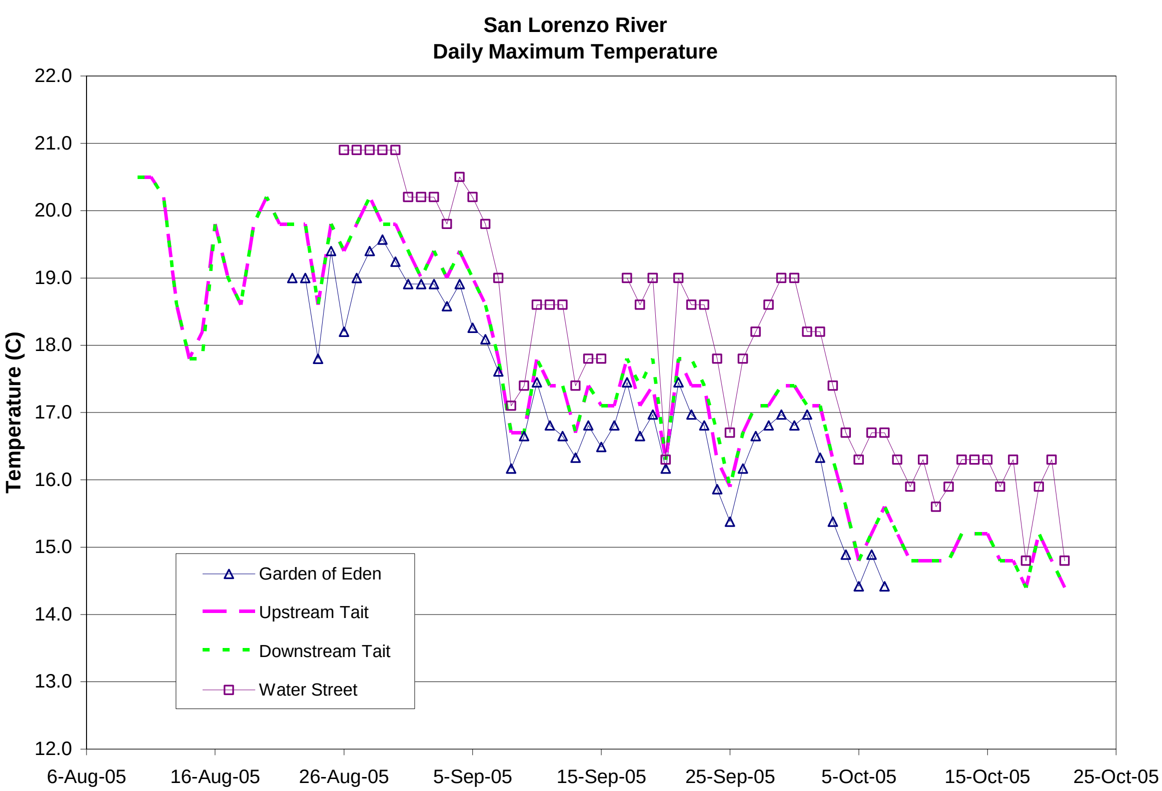

Figure A-4 San Lorenzo River Daily Maximum Temperature.

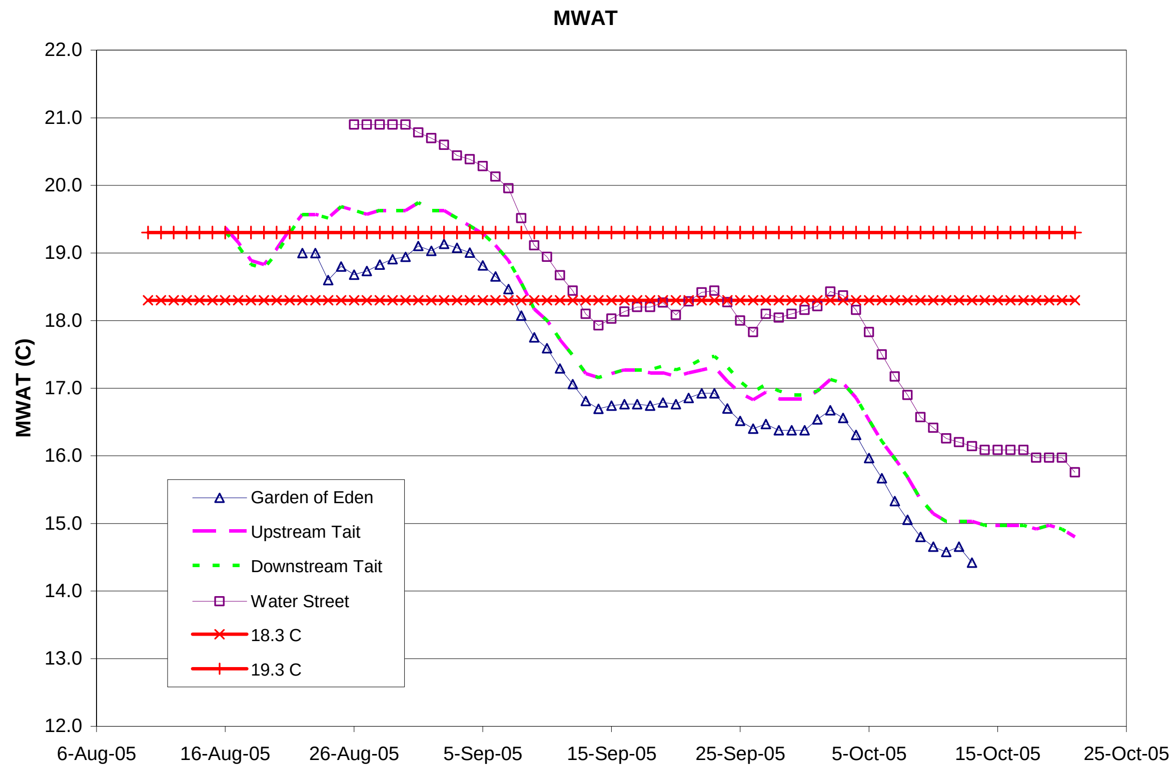

Figure A-5 San Lorenzo River Weekly Average of Maximum Daily Temperature.

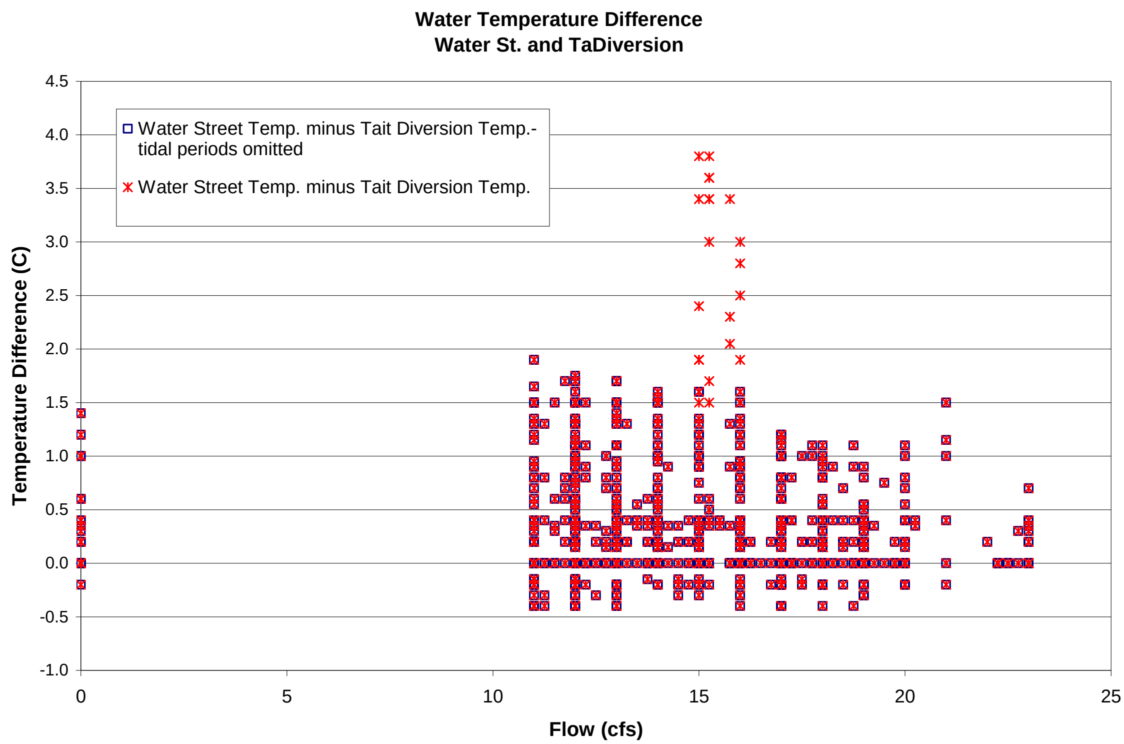

Figure A-6 Difference in Water Temperature between Tait Street and Water Street in relation to river flow

Appendix B

Habitat Survey
Lower San Lorenzo River Below Tait Street

Purpose and Methods

The main purpose of the habitat survey was to identify critical passage sites and sites for evaluation of rearing conditions in the reach of the Lower San Lorenzo River influenced by the Tait Street diversion. The information developed in this study is intended to provide background for development of the City of Santa Cruz HCP concerning habitat quality for migrating steelhead and coho salmon and for rearing of steelhead in relation to operation of the Tait Street diversion.

The habitat assessment included detailed characterization of stream habitat features in accordance with the California Salmonid Stream Habitat Restoration Manual (CDFG Method) (Flosi et al. 1998). Surveys were conducted between June 4 and June 9, 2009. The survey was completed by a two-person team with one person estimating habitat parameters and one recording the data.

Flow during the habitat survey, measured at Tait Street (USGS gage 11161000 San Lorenzo River at Santa Cruz), was approximately 17 to 18 cubic feet per second (cfs). This level of flow represents above average conditions for the time of year (Table B-1). Flow in Pogonip Creek, entering the San Lorenzo River downstream of Tait Street, was approximately 0.5 cfs (Chris Berry, personal communication, October 2005). At this relatively high level of flow it was difficult to distinguish some of the boundaries between habitat types. Several units were first categorized as deep run type habitat since there was significant velocity throughout the unit but they were later re-categorized as pools based on depth characteristics and subsequent observations at lower flow levels.

Results

Downstream of Highway 1, habitat consisted primarily of relatively deep pools and runs with a small amount of relatively short riffles (Table B-2). Upstream of Highway 1, habitat consisted of long shallow glide and long, relatively shallow run habitat with sand substrate. There were shorter sections within the run habitat that had pool-like characteristics but these were not distinct or extensive enough to break out as separate units. The glide had a deeper channel along one bank but this was generally very narrow and constituted a minor part of the habitat. The substrate upstream of Highway 1 was dominated by sand (90%) and silt (5%).

Pools and runs downstream of Highway 1 were long and deep and comprised over 90% of the available habitat. The reach downstream of Highway 1 was generally associated with good cover in the form of emergent and floating aquatic vegetation and overhanging terrestrial vegetation including dense growths of young willows (Figure B-2A). Pool habitat was poorly developed between Highway 1 and Tait Street and mainly consisted of deeper sections within run type habitat. Depth and cover characteristics were not as favorable for rearing salmonids upstream of Highway 1 (Figure B-2B).

A total of six low-gradient riffles were classified between Water Street and Highway 1. In addition, there were two shallow riffle sections within larger habitat units that were too short to break out as individual habitat units (including one that was evaluated as a passage site). The riffles were all relatively short, ranging from 27 feet to 54 feet in length and averaging 38 feet. Upstream of Highway 1 there were no riffles classified although there were short riffle-like sections located at transverse sand bars.

The majority of habitat suitable for rearing salmonids in the study reach is downstream of Highway 1. .

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TABLES

Table B-1 Monthly flow exceedance statistics for San Lorenzo River at Tait Street.

FLOW (cfs)

% Exceed.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	14,378	13,680	8,277	6,336	819	151	86	48	545	3,385	4,192	16,256
1	3,541	3,091	2,247	1,380	280	108	59	40	32	98	570	1,785
5	1,269	1,389	943	533	171	79	48	33	26	33	159	594
25	240.3	352.1	317.0	167.0	77.4	47.1	29.4	20.2	17.3	18.4	29.2	79.6
50	**53.4**	**128.8**	**129.5**	**78.4**	**47.0**	**29.8**	**18.4**	**14.3**	**13.1**	**13.9**	**19.1**	**24.4**
75	20.8	47.4	57.8	37.0	23.2	16.4	12.1	10.5	10.5	11.7	13.8	18.6
95	13.4	16.4	18.7	17.4	14.4	10.5	8.4	7.6	7.3	8.3	9.5	10.5
99	0.0	10.8	12.1	11.2	10.5	7.9	5.8	5.4	6.1	6.7	8.2	8.5
Minimum	0.0	0.0	0.0	10.5	3.4	7.0	4.6	4.8	5.3	5.8	0.0	0.0
Average	**291.0**	**353.3**	**278.9**	**161.7**	**62.6**	**35.0**	**22.3**	**16.4**	**14.8**	**19.8**	**48.8**	**137.3**

Source: Entrix, 2004

Table B-2. Habitat survey results for the San Lorenzo River between Water Street and Tait Street Diversion

	Number of Habitat Units	Total Length (ft)	% by Length	Min/Max Length (ft)	Average Length (ft)	Average Depth (ft)	Maximum Depth (ft)
Downstream of Highway 1							
riffles	6	231	8	27/54	38	0.55	1.1
pools	3	1,404	49	101/760	468	2.9	4.3
runs	6	1,209	42	101/318	202	1.9	3.0
Upstream of Highway 1							
glides	1	1,409	55			0.9	2.4
runs	1	1,167	45			1.5	2.8

FIGURES

Figure B-1. Typical habitat conditions between Highway 1 and Water St (A), and between Tait Street and Highway 1 (B).

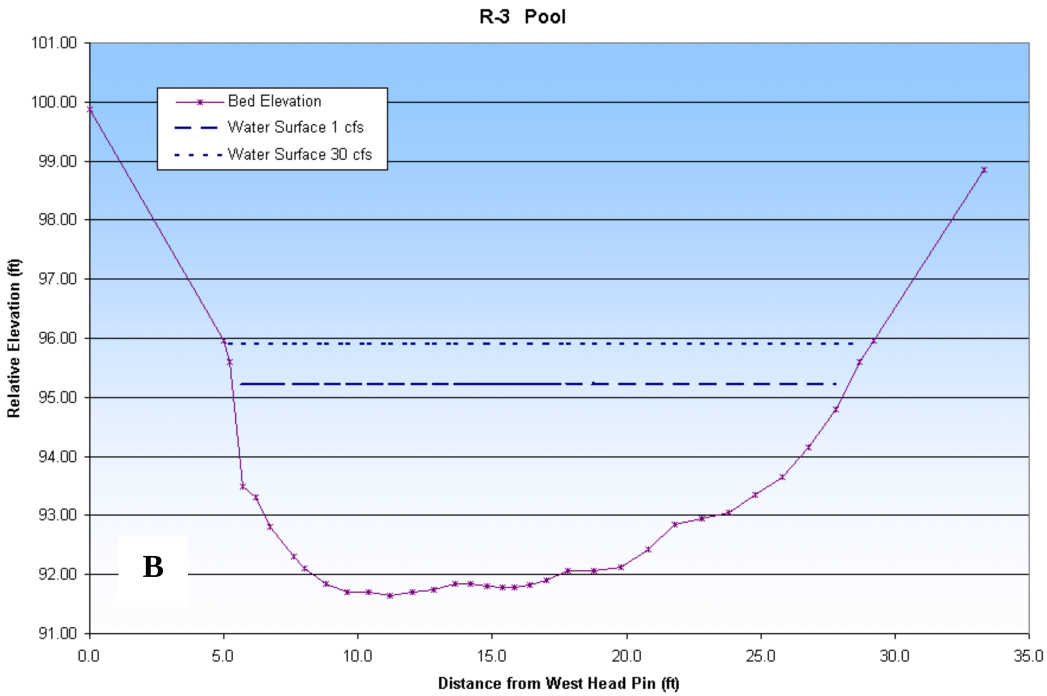

Figure B-2. Pool Site R-3: (A) Transect photo and (B) Cross-section

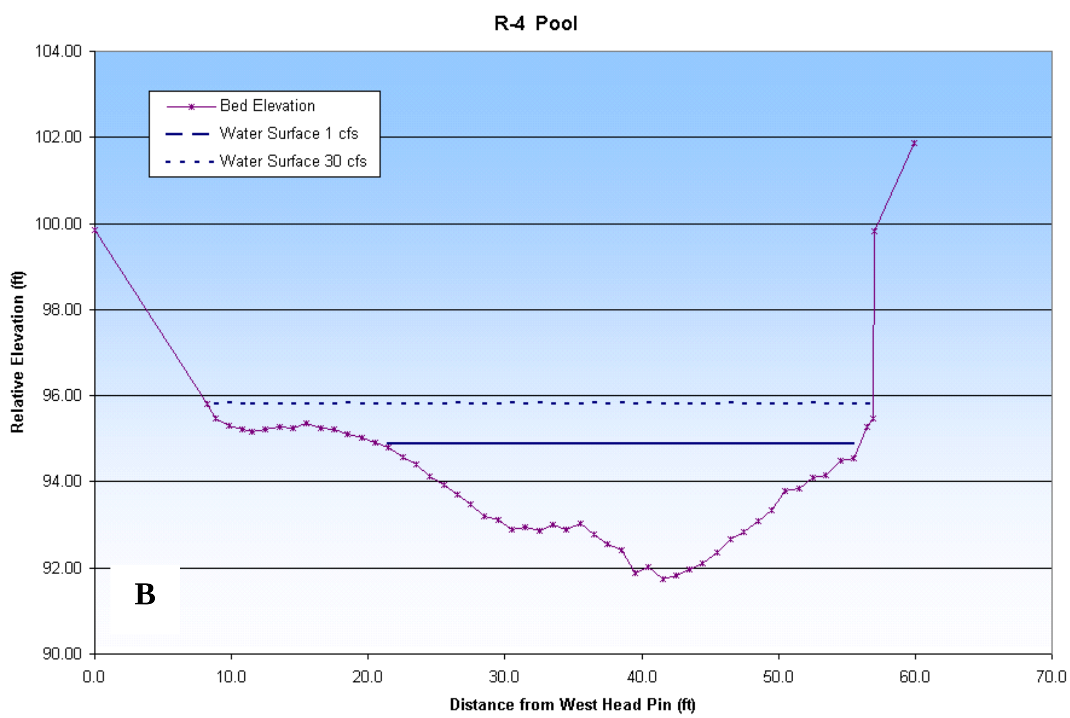

Figure B-3. Pool Rearing Site R-4: (A) Transect photo and (B) Cross-section

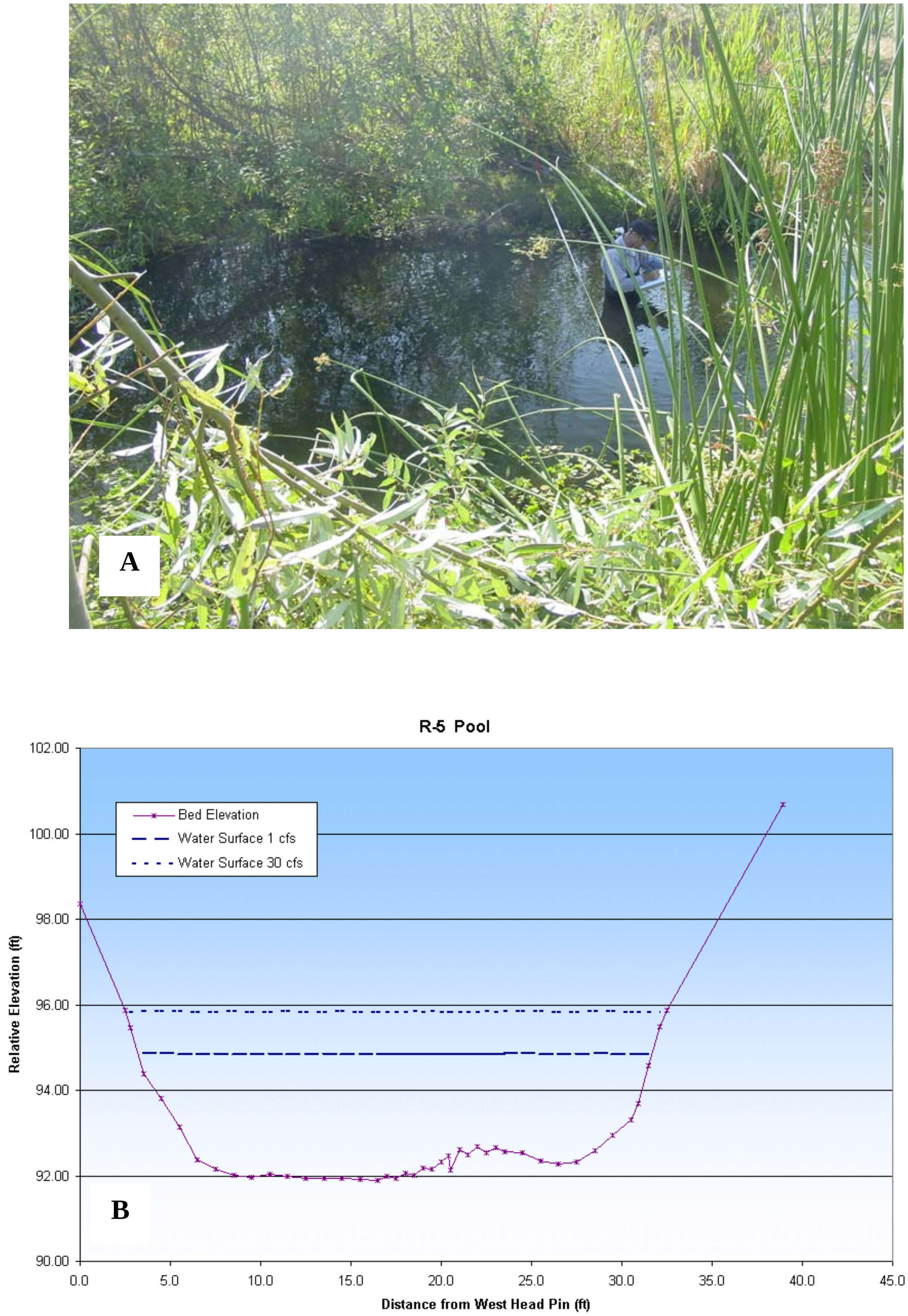

Figure B-4. Pool Rearing Site R-5: (A) Transect photo and (B) Cross-section

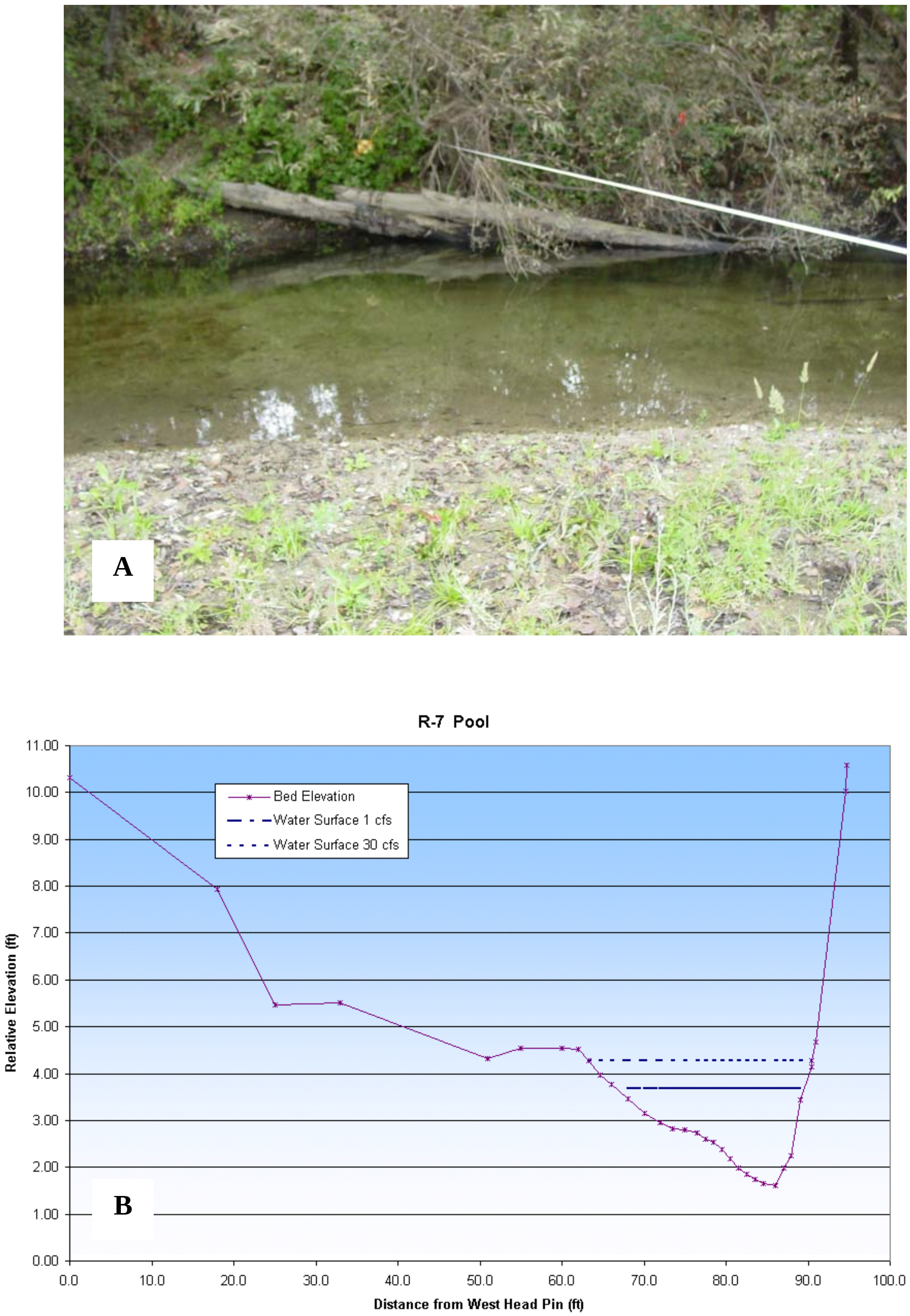

Figure B-5. Pool Rearing Site R-7: (A) Transect photo and (B) Cross-section

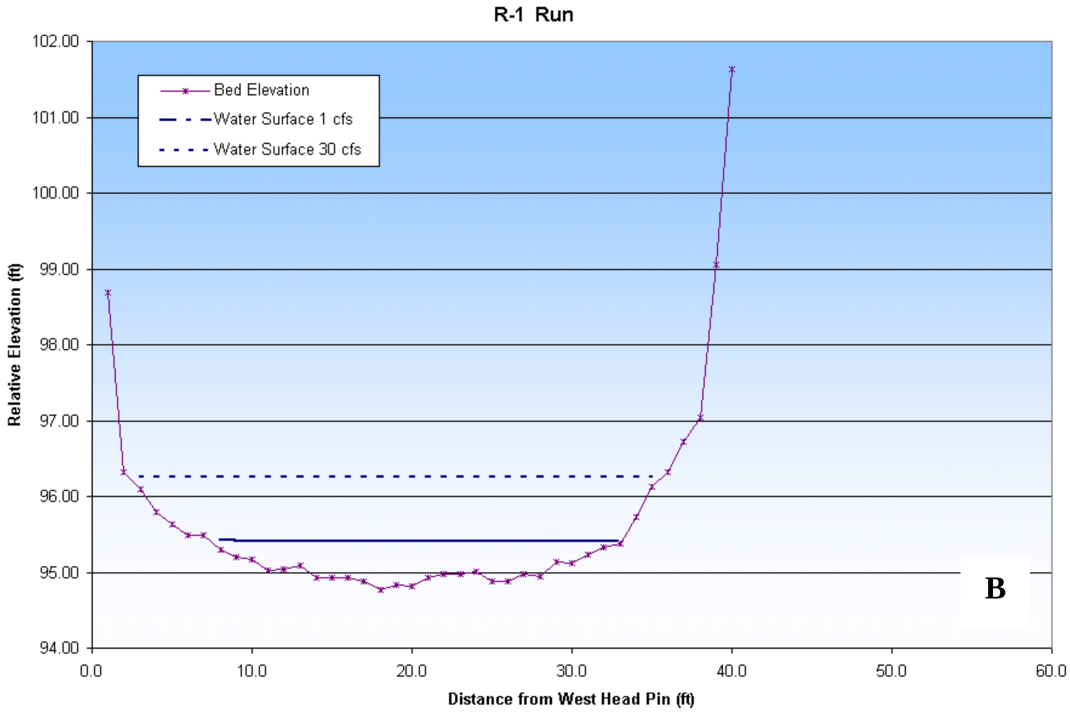

Figure B-6. Run Rearing Site R-1: (A) Transect photo and (B) Cross-section.

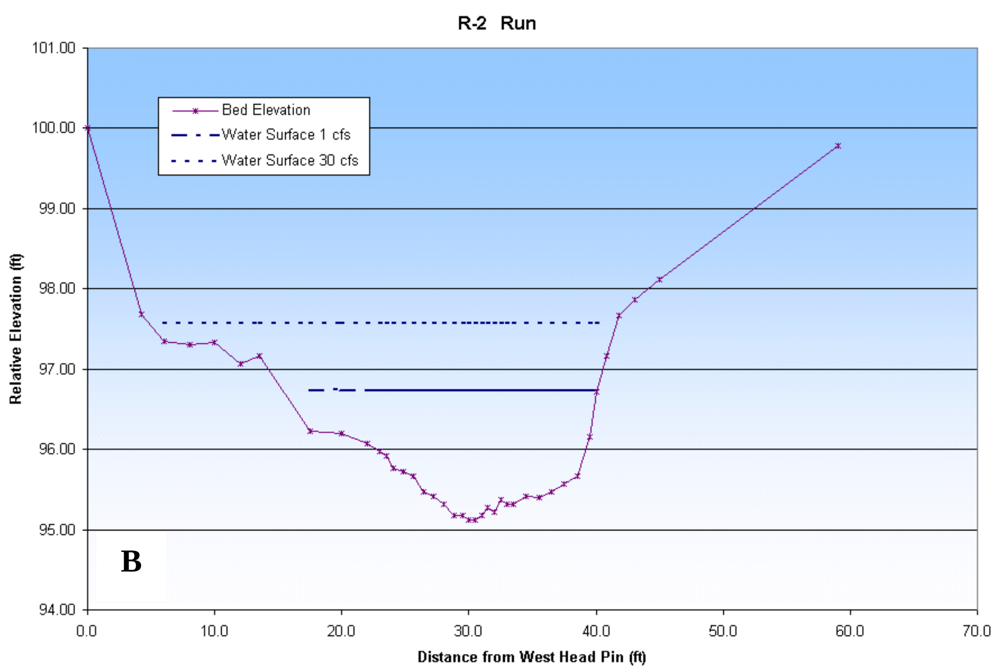

Figure B-7. Run Rearing Site R-2: (A) Transect photo and (B) Cross-section

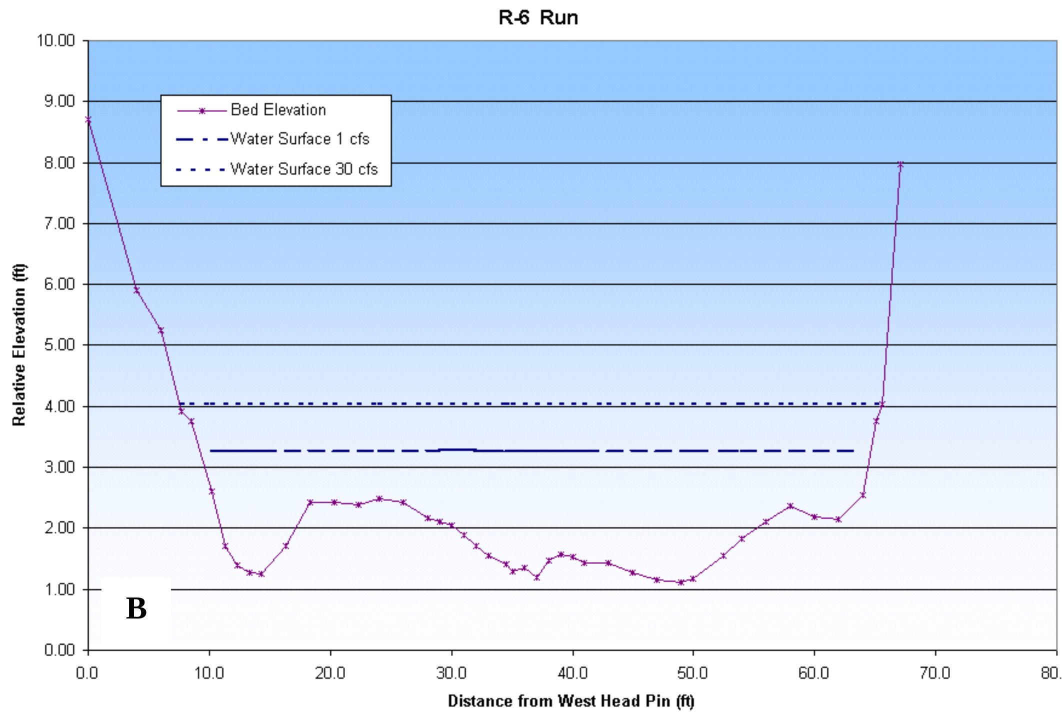

Figure B-8. Run Rearing Site R-6: (A) Transect photo and (B) Cross-section

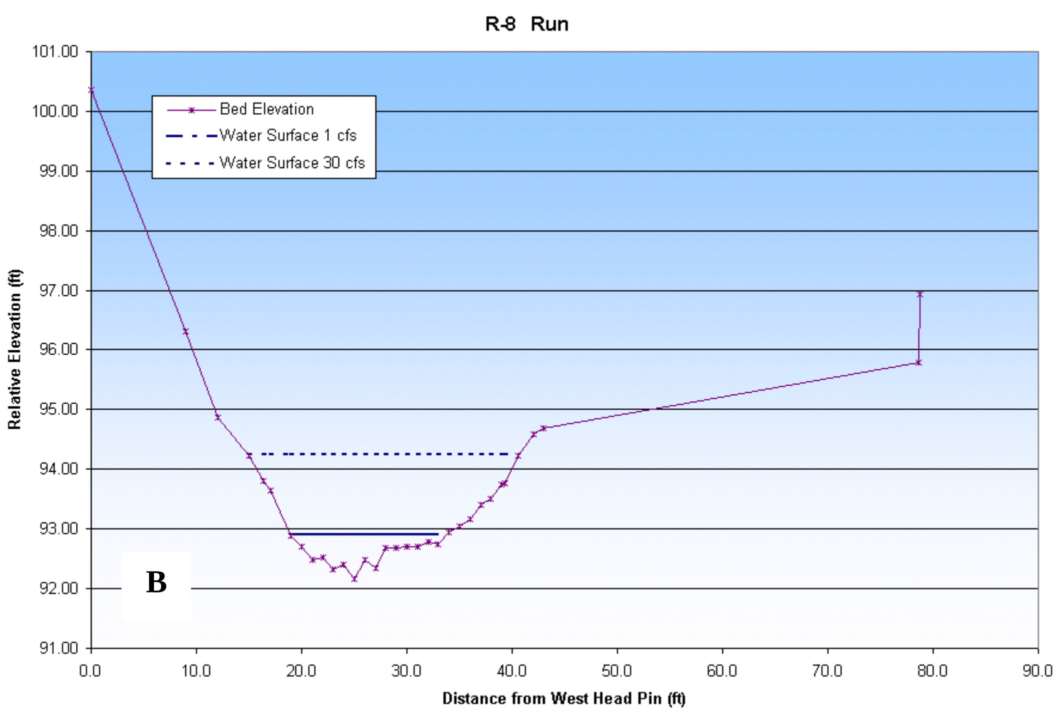

Figure B-9. Run Rearing R-8: (A) Transect photo and (B) Cross-section

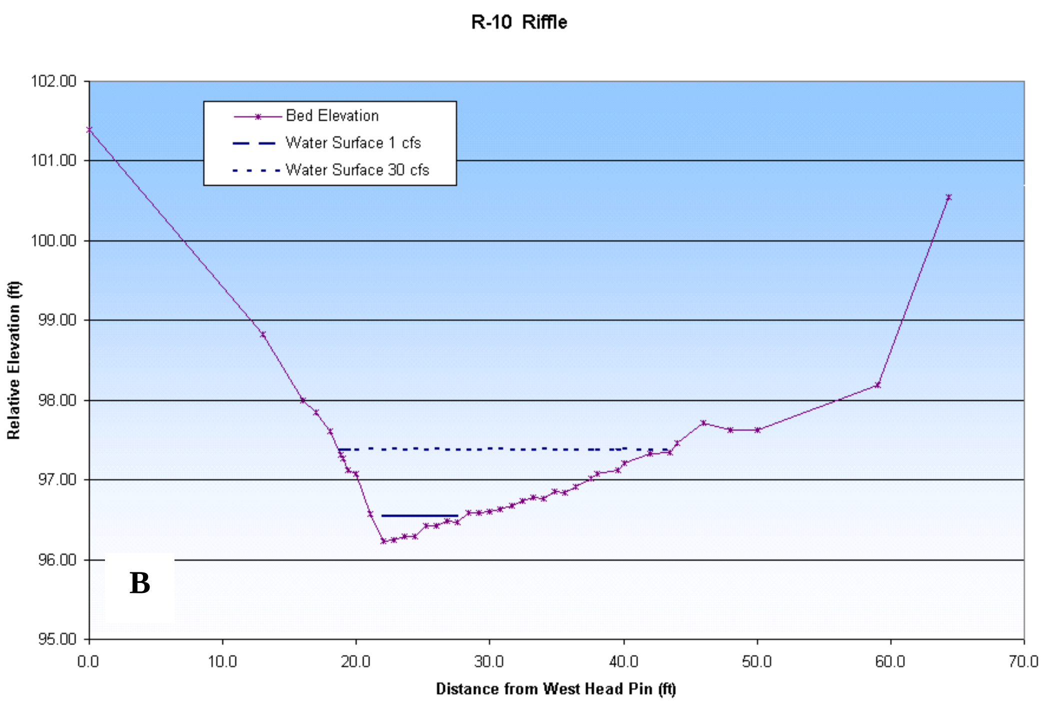

Figure B-10. Riffle Rearing Site R-10: (A) Transect photo and (B) Cross-section.

Appendix C

Newell Creek Habitat and Fish Population Assessment

Technical Memorandum

Prepared for: **Marc Ebbin, Ebbin, Moser, and Skaggs**

Prepared by **Hagar Environmental Science**

Newell Creek Habitat and Fish Population Survey 2007

Summary

There are three distinct reaches of Newell Creek downstream of Newell Reservoir, each with different aquatic habitat characteristics and fish populations. A lower reach, approximately 0.85 miles in length is accessible to anadromous fish and supports steelhead/rainbow trout (*Oncorhynchus mykiss)* and Pacific lamprey. A middle reach of approximately 0.59 miles is dominated by bedrock substrate and supports *O. mykiss* that may be either anadromous or resident in the lower part of the reach. There are bedrock formations in this reach that present numerous potential migration obstacles and one likely passage barrier. The uppermost reach has less suitable habitat for *O. mykiss* which includes less extensive and shallower pools, less Instream cover, and less potential spawning area. There is a very sparse population of *O. mykiss* in the uppermost reach, likely a resident (non-anadromous) population, with apparently low levels of production and reproductive success.

Background and Objectives

Stream habitat assessment and electrofishing surveys were conducted in Newell Creek downstream of Newell Reservoir during August 2007 to assess aquatic habitat conditions and abundance and distribution of steelhead/rainbow trout. This information was collected in support of development of the City's Habitat Conservation Planning (HCP) process.

Although previous San Lorenzo basinwide surveys (Alley 1995, Alley 1999, Alley 2000, Alley 2002, Alley 2004, Alley 2006, Alley 2007) have included part of Newell Creek, more detailed data was desired for the HCP development process. Specifically, during a reconnaissance survey in May 2006 it was observed that there was a significant amount of bedrock forming the substrate of Newell Creek beginning about 0.8 miles upstream of the San Lorenzo River confluence (Figure 1). Bedrock shelves in this section form potential passage obstacles to migrating *O. mykiss* (Figure 2). One bedrock ledge forms a major obstacle that is likely a complete passage barrier under most flow levels (Figure 3). The importance of passage obstacles in Newell Creek depends in part on the quality of habitat upstream of the obstacles and its productive potential for supporting steelhead and coho salmon in Newell Creek. The survey was structured to compare reaches upstream and downstream of the bedrock shelves in terms of habitat features such as depth of pools, cover, extent of cobble/gravel riffles for food production, areal extent of suitable spawning substrate, and amount of fine sediments. Differences in *O. mykiss* population structure upstream and downstream of the bedrock area were also of interest.

The quality of spawning and rearing habitat was quantified using standard methods (CDFG Salmonid Stream Restoration Manual) for the entire reach of Newell Creek from the San Lorenzo River confluence to Newell Dam. Visual observations of relative abundance of fish of different age classes were also recorded during the habitat survey. Population surveys were completed using multiple-pass electrofishing. Sample units for *O. mykiss* population surveys were selected at random from the habitat mapping data.

Habitat Assessment Methods

Surveys covered approximately 1.76 miles in Newell Creek from the San Lorenzo River confluence to the base of the spillway at Newell Dam. The habitat survey included detailed characterization of stream habitat conditions in accordance with the California Salmonid Stream Habitat Restoration Manual (CDFG Method) (Flosi et al. 1998). This is a widely accepted, repeatable, and quantifiable method. Surveys were conducted on August 7 and 8, 2007. Although rainfall was infrequent during the winter of 2006-2007 and the 2007 water year has been classified as a critically dry year, streamflow conditions in Newell Creek downstream of Newell Reservoir were typical since there is a minimum 1 cubic feet per second (cfs) required release from the reservoir in all year types. Habitat characterization was conducted using the following protocols and modifications to the CDFG Method:

- Habitat typing was conducted at a Level IV classification using a one-hundred percent sampling protocol (Flosi et al. 1998). Complete characterization of all features of each identified habitat unit was conducted.
- In each sample reach all habitat units were identified by type and length measured.
- The proportion of each habitat unit that was influenced by some type of shelter was estimated as a percentage of the total surface area of the unit. A shelter complexity rating of low, medium, or high was also estimated for each habitat unit based on structural complexity and diversity of cover types present. Presence of cover is most important in the pool and flatwater habitats used most frequently by trout and is not as important in riffle habitats.
- Maximum depth, pool tail crest depth, and pool tail embeddedness were recorded for every pool encountered. In addition to other characteristics, pools were defined as having a residual maximum depth of 1 foot or more.
- Canopy density was estimated as the proportion of sky obscured directly above each habitat unit (bank to bank).
- Bank composition and vegetation estimates are standard components of the California Salmonid Stream Habitat assessment method. This information was not central to the objectives of the present survey. To streamline data collection, bank composition and vegetation parameters were omitted from the habitat assessment.

Although fish population surveys are not usually part of the habitat assessment, visual observations of fish can be easily incorporated into the habitat assessment and this documentation can provide valuable information to support conclusions concerning habitat quality and suitability. The habitat assessment was completed during the late summer when visibility is best and conditions are likely to be most limiting for rearing parr.

The results of habitat surveys and fish sampling were evaluated to identify key factors that potentially limit fish populations in the watershed. Several key factors were considered in determining potentially limiting factors and potential for improvement including the frequency and quality of summer pool habitat, substrate conditions, bank and canopy conditions, stream temperature, and obstacles to fish movement.

Fish Population Assessment Methods

Sampling sites were selected at random from each of the three reaches identified during the habitat assessment: below the bedrock shelves (lower reach), within the bedrock dominated reach (bedrock reach), and upstream of the bedrock dominated reach (upper reach). A total of 9 sites were sampled for fish populations, four in the Lower Reach, 3 in the Bedrock Reach, and 2 in the Upper Reach.

Sampling was conducted using the multiple-pass depletion method to estimate population abundance (Zippen 1958). Each sample site consisted of a discreet habitat unit that was isolated by placing a 3/16 inch mesh block-net across the channel at the lower and upper ends of the unit. Three complete passes with the electrofisher were made in each unit where *O. mykiss* were found. If no *O. mykiss* were found on the first pass, no further passes were made. If, in the opinion of the lead biologist, subsequent passes did not indicate a good depletion pattern after 3 passes then additional passes were made as needed.

Fish captured in each pass were measured (fork length) and held until all passes had been completed. The condition of each measured fish was noted along with the presence of diseases and overall health. Fish species other than trout were noted for presence/absence. Habitat conditions, such as temperature and discharge, were recorded for each unit sampled. A population estimate and confidence limit were calculated for each habitat unit. Population estimates were not completed by age class due to small sample sizes. All fish were released at the sample site after all electrofishing passes had been completed.

Habitat Assessment Results

The creek was surveyed for approximately 1.76 miles upstream of the San Lorenzo River confluence on August 7 and 8, 2007. From the San Lorenzo confluence upstream to about 0.23 miles upstream of Rancho Rio Bridge (hereafter referred to as the Lower Reach), Newell Creek is a relatively low gradient gravel/cobble bed stream. For the next 0.6 miles upstream the substrate becomes dominated by bedrock that occurs in frequent shelves or steps of a few inches to a few feet in height. This section is referred to as the Bedrock Reach. The uppermost reach, or Upper Reach, beginning about 1.45 miles upstream from the San Lorenzo River and continuing for about 0.3 miles to the low water crossing at the spillway pool, is also relatively low gradient with gravel/cobble substrate.

There is a continuous release of 1 cfs from Newell Reservoir throughout these three reaches. Spot measurements of water temperature during the habitat survey ranged from 14°C to 16°C (57°F to 61°F) in the Lower Reach, 12°C to 13°C (54°F to 55°F) in the bedrock reach, and 13°C (55°F) in the Upper Reach.

Pools made up approximately 40% of the Lower Reach and Bedrock Reach but only about 28% of the Upper Reach (Table 1, Figure 4). The Bedrock Reach had a higher proportion of riffles (primarily bedrock sheets) than the Upper and Lower Reaches. The Upper Reach was dominated by step runs, glides, and runs (Table 1, Figure 4). Pools were longer in the Lower Reach than the other two reaches, averaging 85 feet in length compared to 59 feet in the Bedrock Reach and 57 feet in the Upper Reach (Table 2). Pools were more frequent in the Bedrock Reach than the other two reaches, averaging 35 pools per mile as compared to 25 and 26 pools per mile (Table 2). Pools tended to be deepest in the Lower Reach and shallowest in the Upper Reach (Table 2, Figures 5 and 6). Most pools in the Lower and Bedrock Reaches had maximum depths over 2 feet while only 38% of pools in the Upper Reach did (Table 3).

Shelter complexity, though mostly at low to moderate levels in all reaches, tended to be higher in the Lower Reach. Over 80% of pools in the Lower Reach had shelter influencing at least 20% of the habitat area while only 29% and 13% of pools in the Bedrock Reach and Upper Reach had shelter that extensive (Table 4). The most extensive and frequently encountered cover type was the spaces around and between cobble and boulder substrate. Substrate was encountered as a cover type in 80% to 95% of the habitat units in each reach and provided between 31% and 59% of the overall area with cover (Tables 5 and 6, Figures 7 and 8). Terrestrial vegetation and undercut banks were important cover types in the Lower Reach while bedrock ledge and undercut banks were important in the Bedrock Reach. Nearly 80% of the cover in the Upper Reach was provided by substrate and surface turbulence.

Canopy coverage was relatively dense throughout all three reaches, averaging around 80% (Table 7). The Lower Reach had slightly more habitat units with lower canopy coverage but overall, canopy coverage was similar between the reaches. The author regards canopy coverage of 55% to 85% as ideal for streams supporting *O. mykiss* and 50% to 60% of habitat units fell in this range (Table 7). A relatively high proportion of habitat units (35% to 40%) had canopy coverage of more than 85% in all reaches. This may somewhat reduce productivity due to extensive shading. The dominant canopy species were alder and box elder in the Lower Reach with increasing importance of maple and in the Bedrock Reach and maple and fir in the Upper Reach (Table 8).

Substrate was dominated by gravel and small cobble in the Lower and Upper Reaches and by bedrock in the Bedrock Reach (Table 9, Figure 9). Gravel or cobble were the dominant substrate in 71% of habitat units in the Lower Reach and 90% of habitats in the Upper Reach. Bedrock dominated in 59% of habitat units in the Bedrock Reach and gravel was dominant in 28%. Sand was found as a dominant substrate in 12% of habitat units in the lower reach but not a dominant in any habitat units in either the Bedrock Reach or the Upper Reach. This may be due to either more disturbance from adjacent residential development, lower gradient, or both. In riffle type habitat units, gravel or cobble was the dominant substrate in both the Lower and Upper Reaches while bedrock (in the form of bedrock sheets) dominated in the Bedrock Reach (Table 10).

Embeddedness ratings are an indication of the degree to which the surface layer of larger substrate particles (cobble or large gravel) is embedded in fine sediments. Incubation and emergence success are influenced by accumulation of fine sediments (generally less than 3.3 mm) in the substrate. Embryo survival for steelhead decreases when the percentage of substrate particles less than 6.4mm reaches 25% to 30% and is extremely low when fines are 60% or more. Emergence of steelhead and coho fry is generally high when fine sediments are less than 5% of substrate volume but drops sharply with fine sediment volume of 15% or more (Bjornn and Reiser 1991). While embeddedness ratings are not a direct measure of percentage of fine sediment in the substrate, they are related.

Pool tail and spawning gravel embeddedness ratings were low to moderate in Newell Creek (Tables 11 and 12). Only a few pool tails had embeddedness ratings of more than 30% while 50% to 65% had embeddedness of 15% or less (Table 13). Pool-tail embeddedness ratings were not possible in some habitat units in the Bedrock and Upper Reaches since the pool tail was composed of bedrock. Most spawning areas had embeddedness of less than 30% (Table 12) and 70% of spawning areas in the Lower and Bedrock Reaches had embeddedness of less than 15% (Table 13). These values are indicative of relatively low amounts of fine sediments in the substrate of Newell Creek relative to other Central California Coastal streams. Potential spawning area was more extensive in the Lower Reach than in the Bedrock and Upper Reaches. There were, on average, 24 square feet of potential spawning area per 100 feet of stream surveyed in the Lower Reach compared to only 13 square feet in the Bedrock Reach and 10 square feet in the Upper Reach (Table 13).

O. mykiss of various size classes were seen through the Lower Reach and the lower part of the Bedrock Reach but few, if any, were seen in the upper Bedrock and Upper Reaches.

Fish Population Assessment Results

O. mykiss and sculpin were captured in all three reaches. The sculpin were not examined closely for classification but appeared to be prickly sculpin (*Cottus asper*). In the Lower Reach, California roach, speckled dace, Sacramento sucker, and Pacific lamprey ammocoetes were also captured (Table 14). *O. mykiss* were most abundant in the Lower Reach and the lower part of the Bedrock Reach. Capture efficiency was poor in two of the habitat units (Table 15), resulting in no population estimate for one unit (#26b) and unreasonably large population estimate in another (#26). Average density for *O. mykiss* in sampled units was 21 per 100 feet of stream in the Lower Reach, 15 per 100 feet in the Bedrock Reach, and 2 per 100 feet in the Upper Reach (Table 16). The small sample sizes did not justify population estimates by age class although the catch was dominated by fish in the 60 mm to 110 mm (2.3 inches to 4.3 inches) length range (fork length). Age determination was not completed but most of these fish are presumed to be young-of-year (Figure 10). Of the two *O. mykiss* captured in the Upper Reach, neither were young-of-year.

Nearly all *O. mykiss* exhibited a high incidence of a condition known as black spot disease (BSD). BSD is indicated by external dark spots attributed to the resting stage of trematodes that encyst under the scales of the fish. Melanin deposits are formed around the developing trematode and are visible under the scales. The trematode is dormant at this stage and does not appear to harm the trout in any way. It is found in trout that inhabit warmer waters (the trematode requires temperatures above 18°C to complete its life history).

Overall density estimates for *O. mykiss* in the Lower Reach are slightly lower but comparable to those obtained in 2006 by Alley in the same section of stream (Alley 2007) although the proportion of smolt sized fish (as defined by Alley) was probably higher in 2006.

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Table 1. Newell Creek Fish Habitat Summary

	Lower Reach	Bedrock Reach	Upper Reach
Length of Stream Surveyed (feet)	4502	3140	**1652**
Average of Mean Width (feet)	16.1	20.7	**18.0**
	Number of units		
Flatwater	18	11	**9**
Pool	21	21	**8**
Riffle	13	14	**3**
Total	*52*	*46*	***20***
	Percentage by length		
Flatwater	44%	30%	**61%**
Pool	39%	40%	**28%**
Riffle	**17%**	**30%**	**11%**

Table 2. Newell Creek Habitat Survey Pool Depth Summary

	Lower Reach	Bedrock Reach	Upper Reach
Total Number of Pools	21	21	8
Wetted Length Surveyed (ft)	4502	3140	1652
Average Number Pools/Mile	25	35	26
Average Pool Length (ft)	85	59	57
Average Pool Depth (ft)	**Number of Pools**		
0.0 – 0.5			
0.5 – 1.0	2	4	3
1.0 – 1.5	7	7	4
1.5 – 2.0	7	8	
2.0 – 2.5	5	1	
2.5 – 3.0			1
Maximum Pool Depth (ft)	**Number of Pools**		
1.0 – 1.5			2
1.5 – 2.0	6		3
2.0 – 2.5		9	2
2.5 – 3.0	7	4	
3.0 – 3.5	2	3	
3.5 – 4.0	2	3	
4.0 – 4.5	2	1	
4.5 – 5.0	1		1
5.0 – 5.5		1	
5.5 – 6.0	1		

Table 3. Newell Creek Habitat Survey Pool Depth Summary

	Lower Reach	Bedrock Reach	Upper Reach
% pools with mean depth >=1 ft	90%	76%	63%
% pools with mean depth >=2 ft	24%	5%	13%
% pools with mean depth >= 3ft	0%	0%	0%
% pools with max depth >=2 ft	71%	100%	38%
% pools with max depth >=3 ft	38%	38%	13%
% pools with max depth >= 5ft	5%	5%	0%

Table 4. Newell Creek Habitat Survey Shelter Complexity

	Lower Reach	Bedrock Reach	Upper Reach
Shelter Complexity	Number of Habitat Units		
Low	22	28	7
Medium	18	11	10
High	12	5	3
	Percent of all Pools		
>=20% of Unit with Shelter	81%	29%	13%
>=25% of Unit with Shelter	52%	10%	13%
>=30% of Unit with Shelter	33%	10%	0%

Table 5. Newell Creek Habitat Survey Frequency of Occurrence of Shelter Components

	Lower Reach	Bedrock Reach	Upper Reach
Cover Type	**Proportion of Habitat Units With Cover Type**		
undercut bank	44%	50%	55%
small woody debris	42%	45%	55%
large woody debris	13%	11%	40%
root mass	38%	34%	15%
terrestrial vegetation	77%	50%	25%
rooted aquatic vegetation	2%	2%	20%
floating aquatic vegetation	0%	0%	0%
surface turbulence	38%	36%	35%
substrate	90%	80%	95%
bedrock ledge	8%	73%	15%
Total Surveyed Units	52	44	20

Table 6. Newell Creek Habitat Survey Relative Extent of Shelter Components

	Lower Reach	Bedrock Reach	Upper Reach
Cover Type	**Contribution to Total Areal Extent**		
undercut bank	12.5%	12.4%	7.2%
small woody debris	5.3%	9.9%	7.7%
large woody debris	1.7%	2.4%	7.6%
root mass	12.5%	8.2%	1.3%
terrestrial vegetation	28.8%	7.0%	3.9%
rooted aquatic vegetation	1.6%	0.1%	1.7%
floating aquatic vegetation	0.0%	0.0%	0.0%
surface turbulence	5.2%	5.3%	9.4%
substrate	31.1%	37.0%	59.4%
bedrock ledge	1.3%	17.8%	1.8%
Total Surveyed Units	52	44	20

Table 7. Newell Creek Habitat Survey Canopy Characteristics

	Lower Reach	Bedrock Reach	Upper Reach
Average canopy (%)	79	80	79
Maximum canopy (%)	95	95	95
Minimum total canopy (%)	15	45	45
Canopy Coverage (%)	Number of Habitat Units		
15	1		
40	1		
45	2	1	1
50	1		
55	2	2	1
60	2	3	
65	3	3	1
70	1	3	
75	6	6	3
80	3	3	1
85	9	6	1
90	6	8	
95	15	9	1
	Proportion of all Habitat Units		
55%-85% Canopy Coverage	50%	59%	60%
>85% Canopy Coverage	40%	39%	35%

Table 8. Newell Creek Habitat Survey Canopy Species

	Lower Reach	Bedrock Reach	Upper Reach
Dominant Canopy Species	Number of Habitat Units		
Willow	1		
Alder	35	26	6
Sycamore	1		
Bay	2	2	1
Locust	1		
Box Elder	10		
Dogwood	1		
Cottonwood	1		
Maple		13	8
Fir		2	5
Other		1	
Total Surveyed Units	52	44	20

Table 9. Newell Creek Habitat Survey Substrate Characteristics

	Lower Reach	Bedrock Reach	Upper Reach
Total Surveyed Units	52	46	20
Dominant Substrate Class	Proportion of all Habitat Units		
Silt/clay	17%	4%	0%
Sand	12%	0%	0%
Gravel	44%	28%	50%
Small cobble	25%	7%	30%
Large cobble	2%	2%	10%
Boulder	0%	0%	0%
Bedrock	0%	59%	10%
Gravel-cobble dominant	71%	37%	90%
Sand as dominant	12%	0%	0%
Sand dominant or subdominant	13%	2%	0%
Bedrock dominant or subdominant	4%	85%	10%

Table 10. Newell Creek Habitat Survey Riffle Substrate Characteristics

	Lower Reach	Bedrock Reach	Upper Reach
Total Riffles Surveyed	13	14	3
	Proportion of all Riffles		
Gravel-cobble dominant	100%	21%	100%
Sand as dominant	0%	0%	0%
Sand dominant or subdominant	0%	7%	0%
Bedrock dominant or subdominant	0%	71%	0%

Table 11. Newell Creek Habitat Survey Pool-Tail Embeddedness

	Lower Reach	Bedrock Reach	Upper Reach
Pool Tail Embeddedness (%)	**Number of Habitat Units**		
0			
5	6	4	
10		3	3
15	3	6	2
20		1	
25	3		1
30	3		
35	1	2	
40	1		1
45		1	
50	1		
N/A		3	1
Number of Pools Surveyed	18	20	8

Table 12. Newell Creek Habitat Survey Spawning Gravel Embeddedness

	Lower Reach	Bedrock Reach	Upper Reach
Spawning Gravel Embeddedness (%)	**Number of Habitat Units**		
0			
5	7	4	
10	2	4	2
15	6	6	3
20	4	2	
25		2	3
30	2	1	
35		1	
Number of Spawning Areas Surveyed	21	20	8

Table 13. Newell Creek Habitat Survey Gravel Quality Summary

	Lower Reach	Bedrock Reach	Upper Reach
Number of Spawning Areas Surveyed	21	20	8
Sum of Spawning gravel area (sq.ft.)	1095	406	170
Wetted Length (ft)	4502	3140	1652
Spawning area (sq. ft.) per 100 feet	24	13	10
Percent of pool tails with embeddedness of 15% or less	50%	65%	63%
Percent of spawning areas with embeddedness of 15% or less	71%	70%	63%

Table 14. Fish Species Captured in Newell Creek Fish Sampling by Location

Species	Species	Lower Reach				Bedrock Reach			Upper Reach	
		Unit 25 Pool	Unit 26 Glide	Unit 26b Riffle	Unit 29 Pool	Unit 55 Bedrock sheet	Unit 69 Pool	Unit 80 Steprun	Unit 105 Pool	Unit 110 Steprun
		Number of Fish								
Steelhead/rainbow trout	*Oncorhynchus mykiss*	15	16	4	14	15	4	0	2	0
Speckled dace	*Rhinichthys osculus*			1						
California roach	*Lavinia symmetricus*	19			126					
Sculpin	*Cottus sp.*	16	1	1	7	34	10	6	24	33
Sacrameto sucker	*Catostomus occidentalis*	3								
Pacific lamprey (ammocoete)	*Lampetra tridentata*	5								

Table 15. Number of *O. mykiss* captured in Newell Creek Fish Sampling by Reach, Unit, and Electrofishing Pass

Reach	Habitat Unit	Habitat Type	Pass 1	Pass 2	Pass 3	Pass 4	Pass 5
			Number of O. mykiss				
Lower	25	Pool	10	2	3		
	26	Glide	4	5	5	2	
	26b	Riffle	0	1	3		
	29	Pool	10	3	1		
Bedrock	55	Bedrock sheet	4	6	5	0	
	69	Pool	1	1	1	1	0
	80	Steprun	0				
Upper	105	Pool	2	0			
	110	Steprun	0				

Table 16. *O. mykiss* Population Estimates for Newell Creek Fish Sampling in 2007

Reach	Habitat Unit	Habitat Type	*O. mykiss* Captured	Population Estimate	Upper 95% Confidence Limit	Length Sampled	*Density* (*fish*/100 ft)	Reach Average Density
Lower	25	Pool	15	17	21	81	21	21[1]
	26	Glide	16	36	53	42	85	
	26b	Riffle	4	N/A	N/A	N/A	N/A	
	29	Pool	14	15	17	71	21	
Bedrock	55	Bedrock sheet	15	19	26	67	29	15
	69	Pool	4	5	9	38	14	
	80	Step run	0	0	N/A	66	0	
Upper	105	Pool	2	2	2	39	5	2
	110	Step run	0	0	N/A	61	0	

[1] Units 25 and 29 only

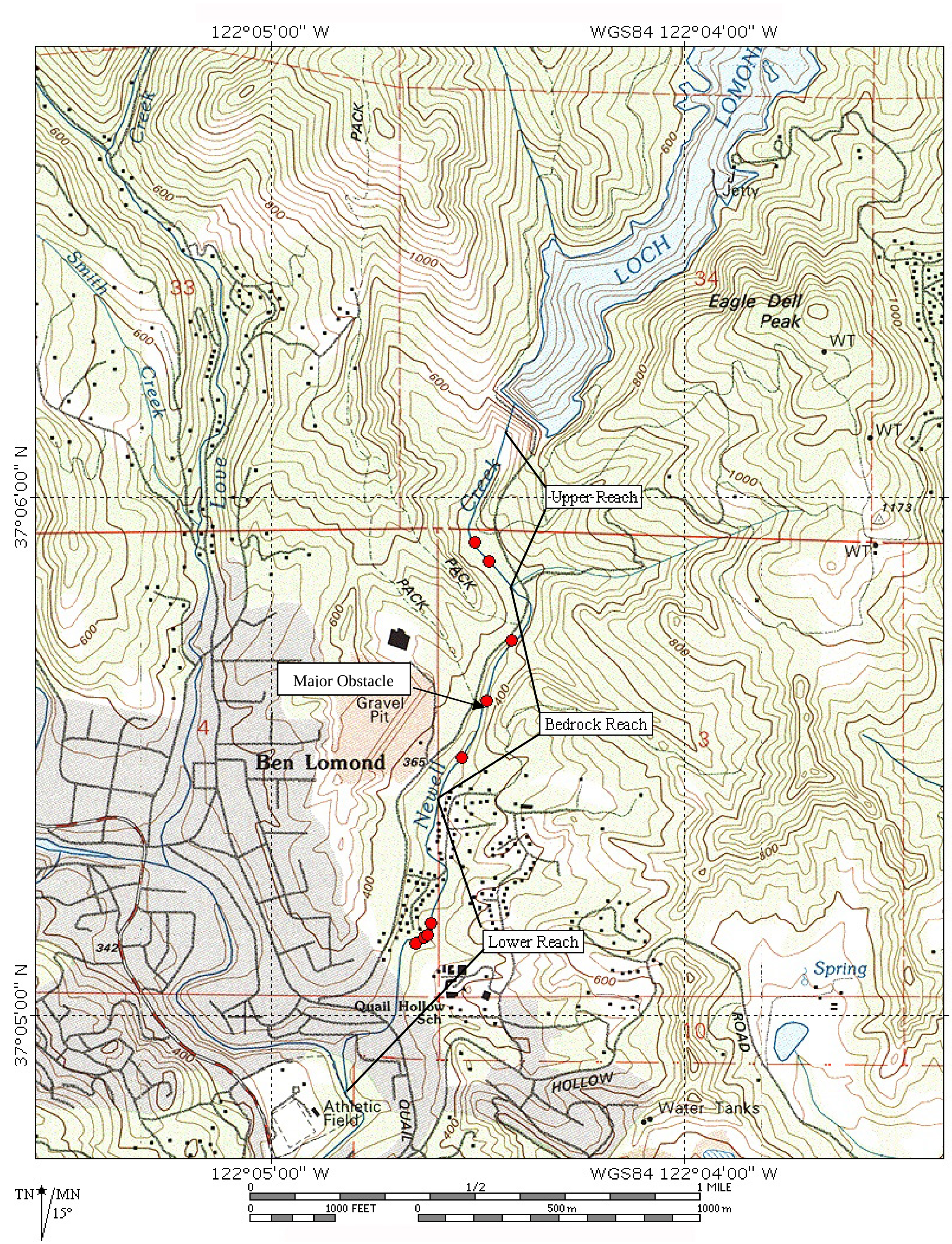


Figure 1. Lower Newell Creek study area (red dots indicate electrofishing sites)

Figure 2. Bedrock shelves in Lower Newell Creek

Figure 3. Bedrock shelf forming major obstacle to fish migration

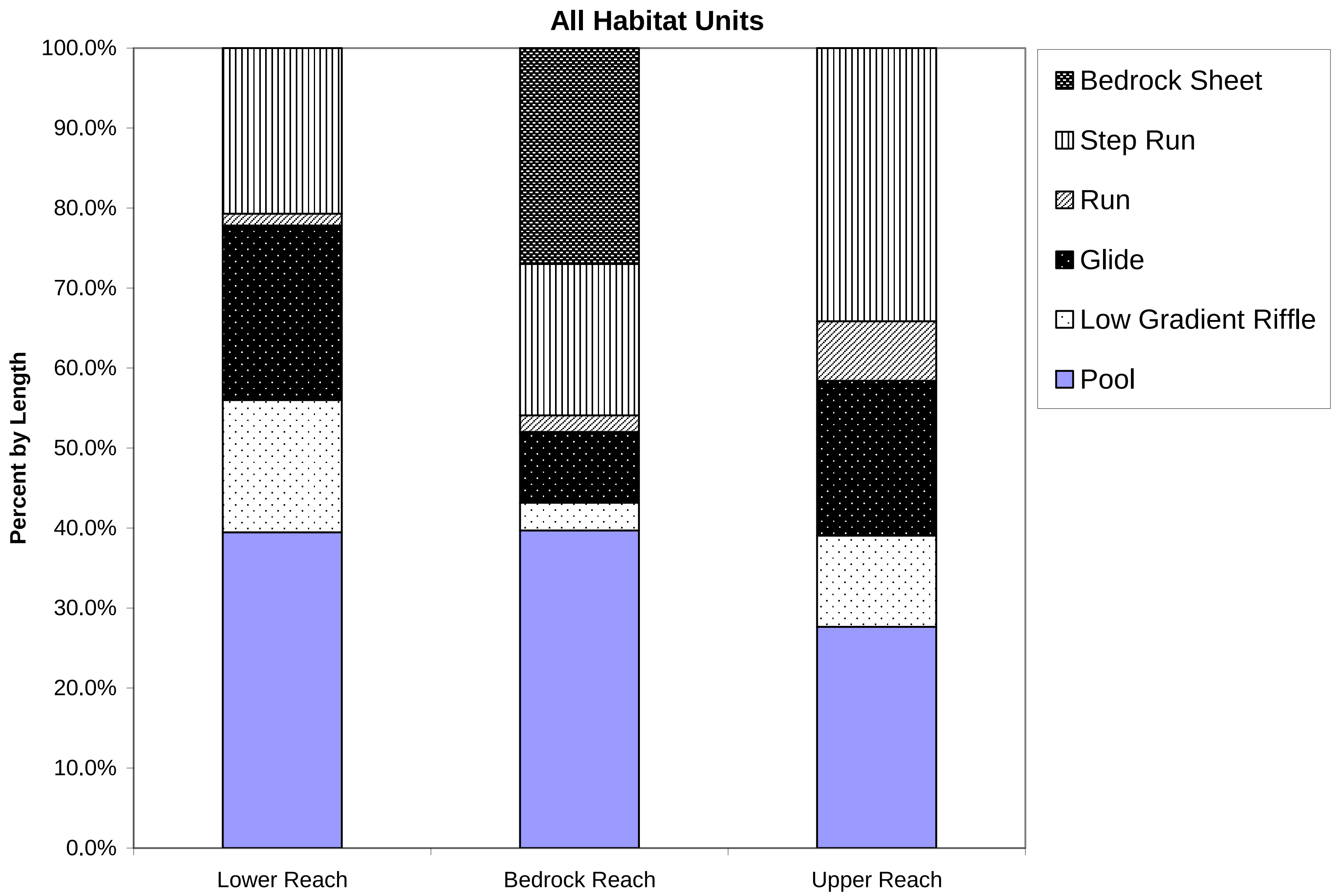


Figure 4. Proportional representation of habitat types by reach

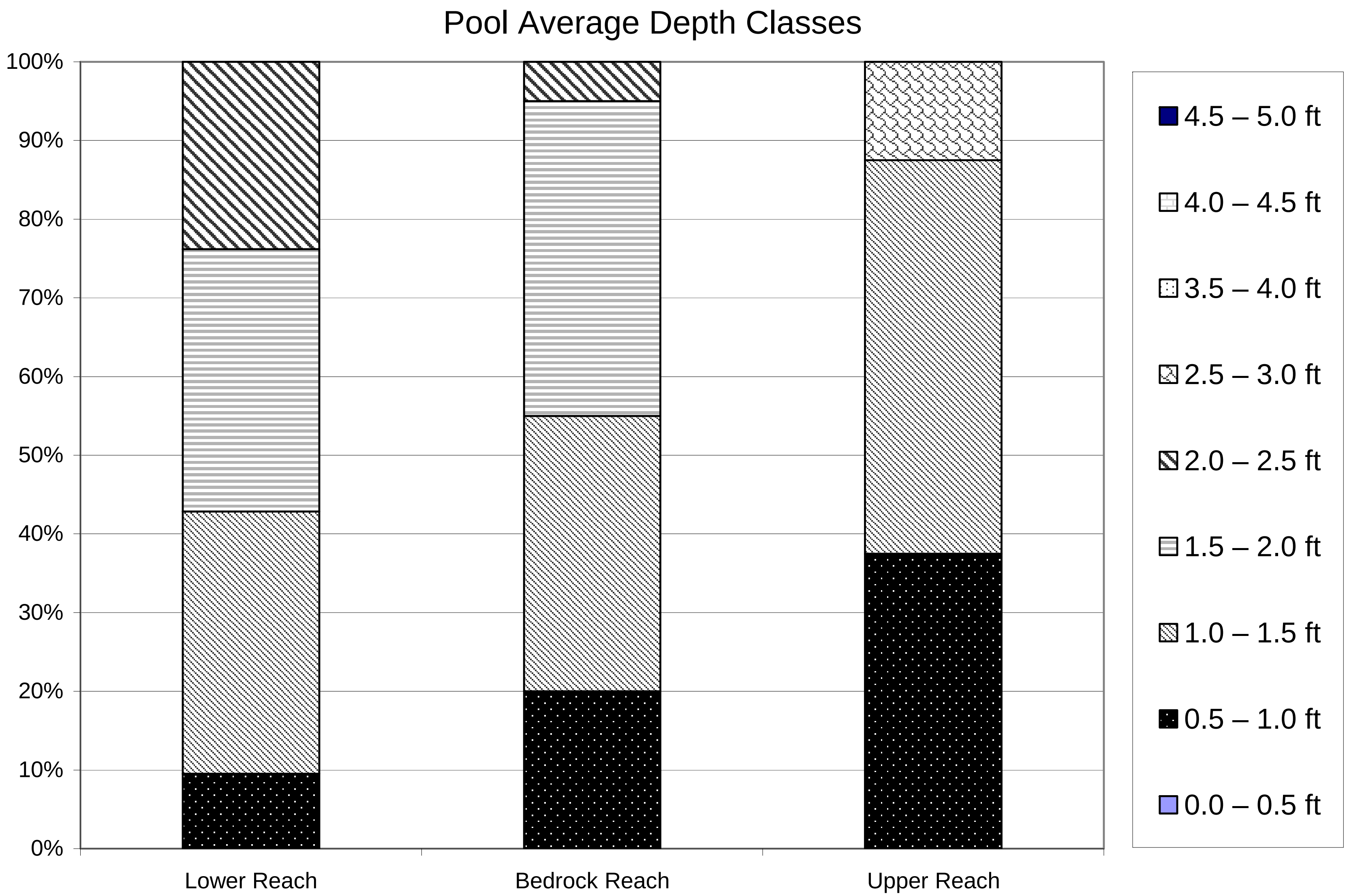


Figure 5. Pool average depth by reach

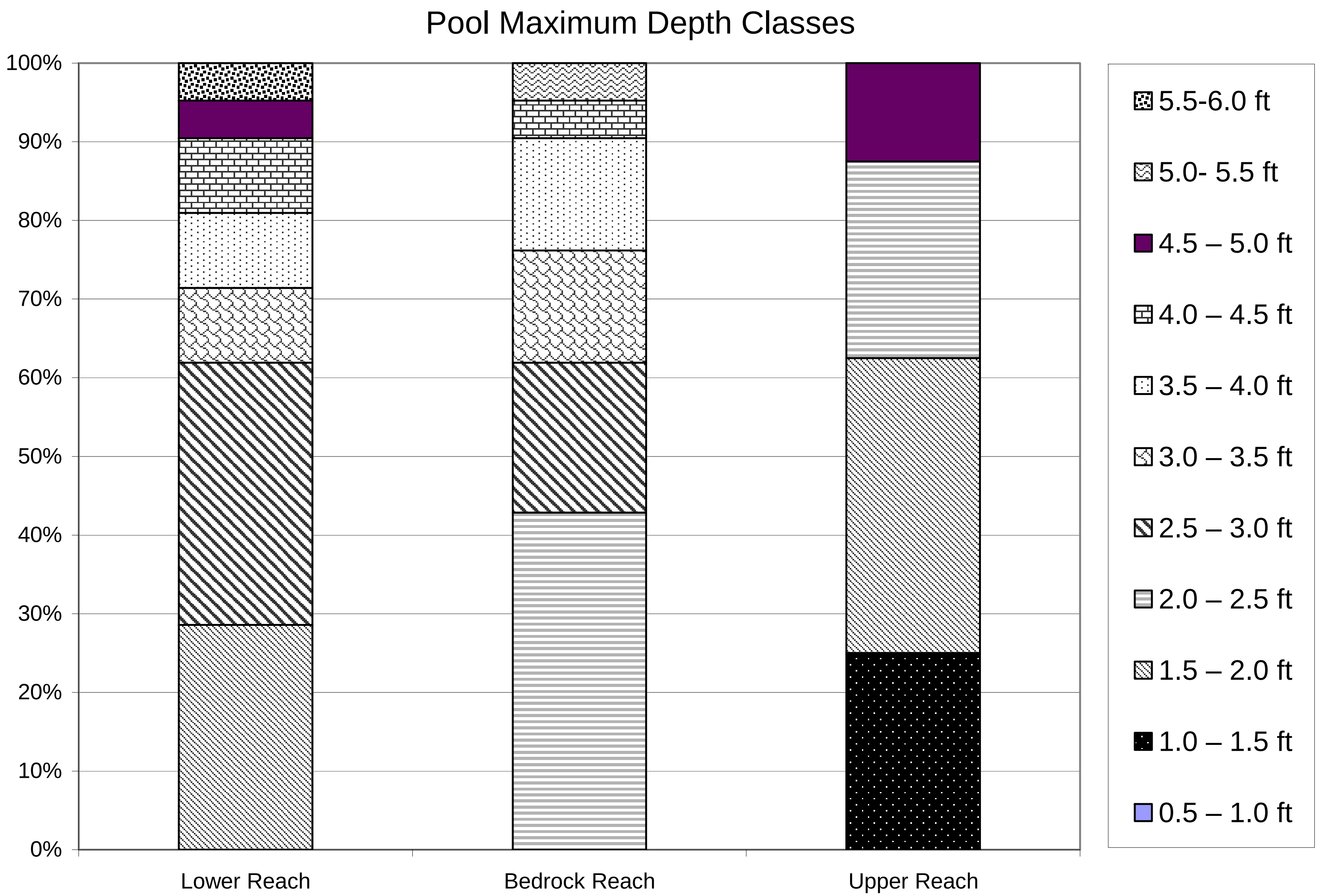


Figure 6. Pool maximum depth by reach

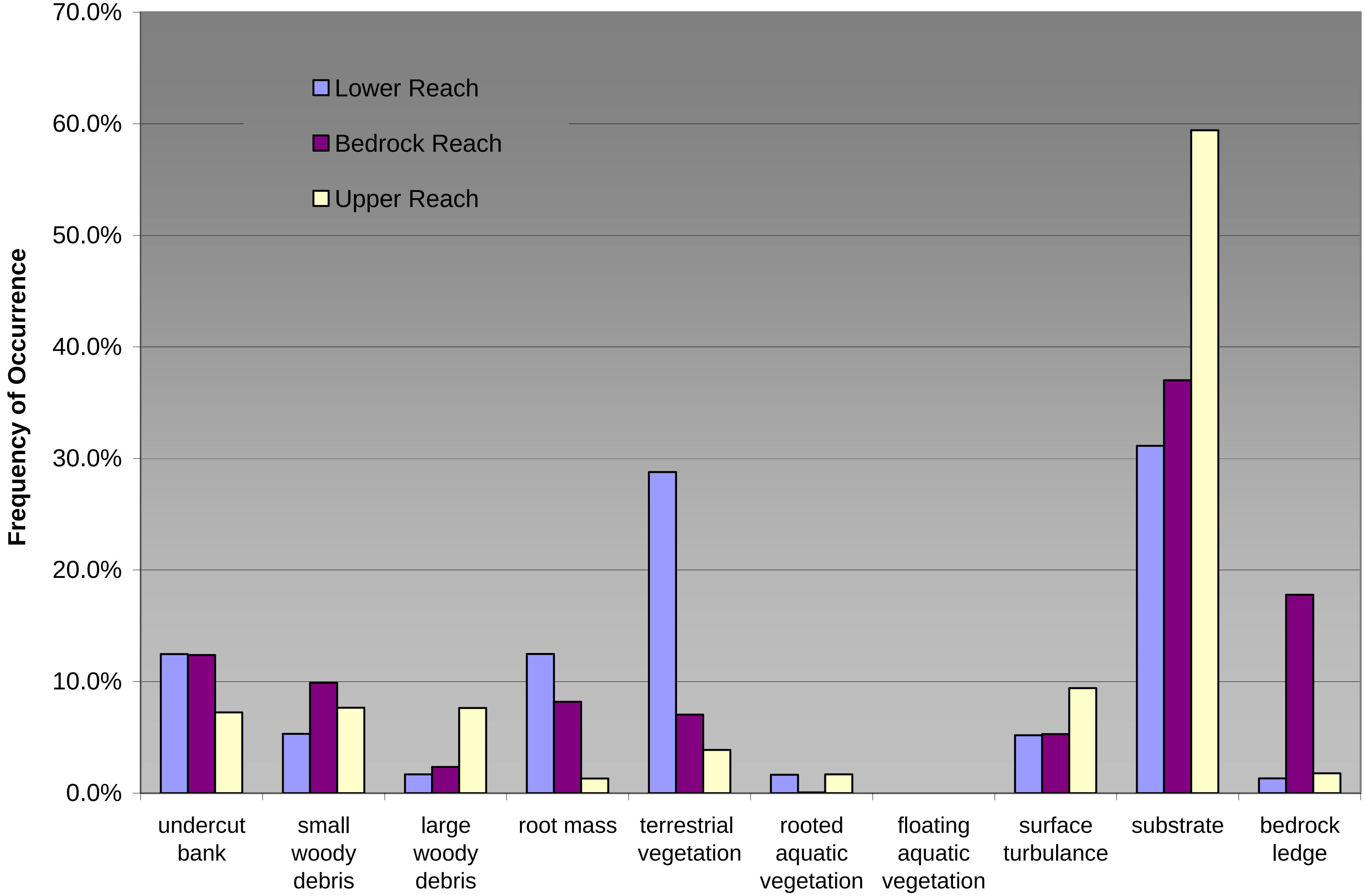


Figure 7. Frequency of occurrence of cover type by reach

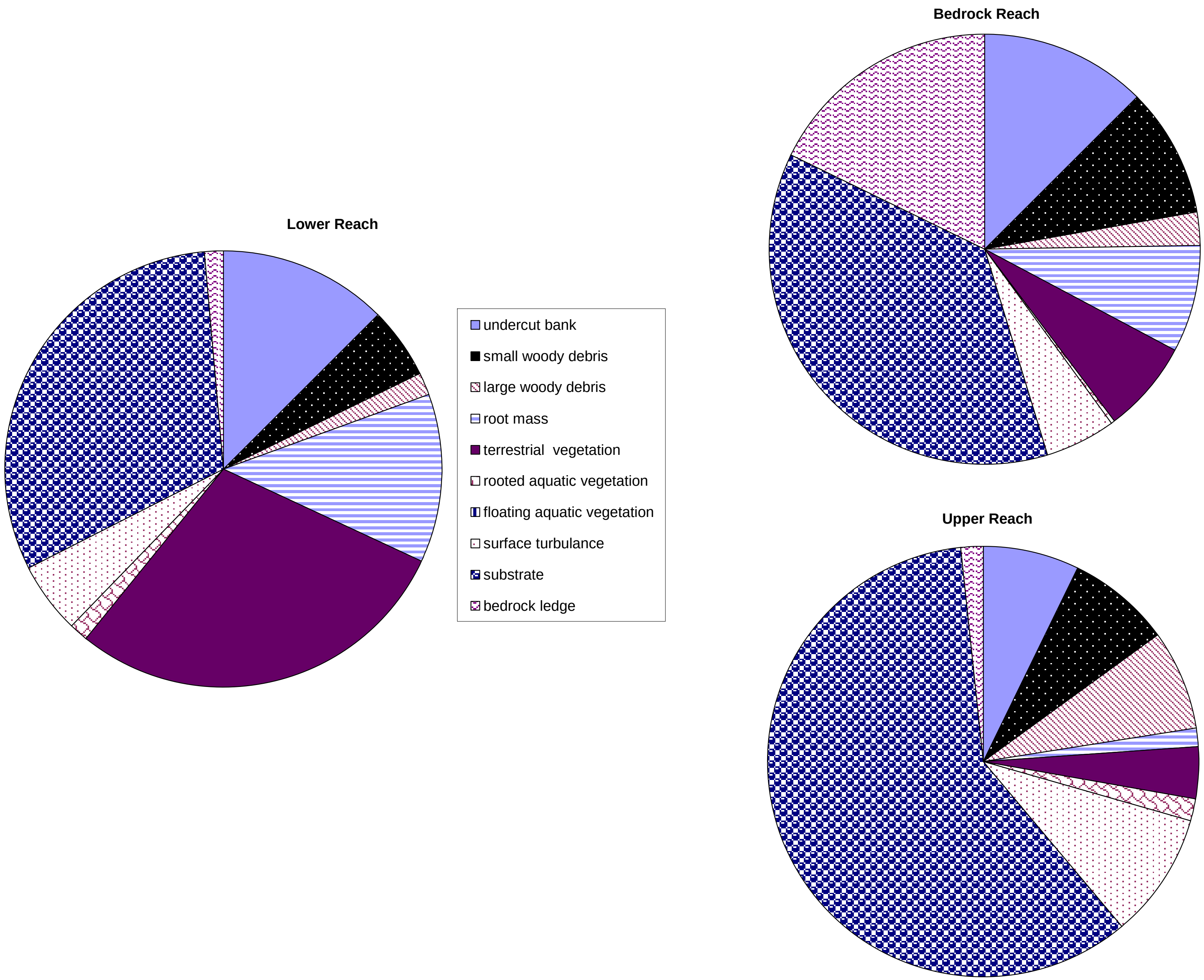


Figure 8. Relative extent of cover types

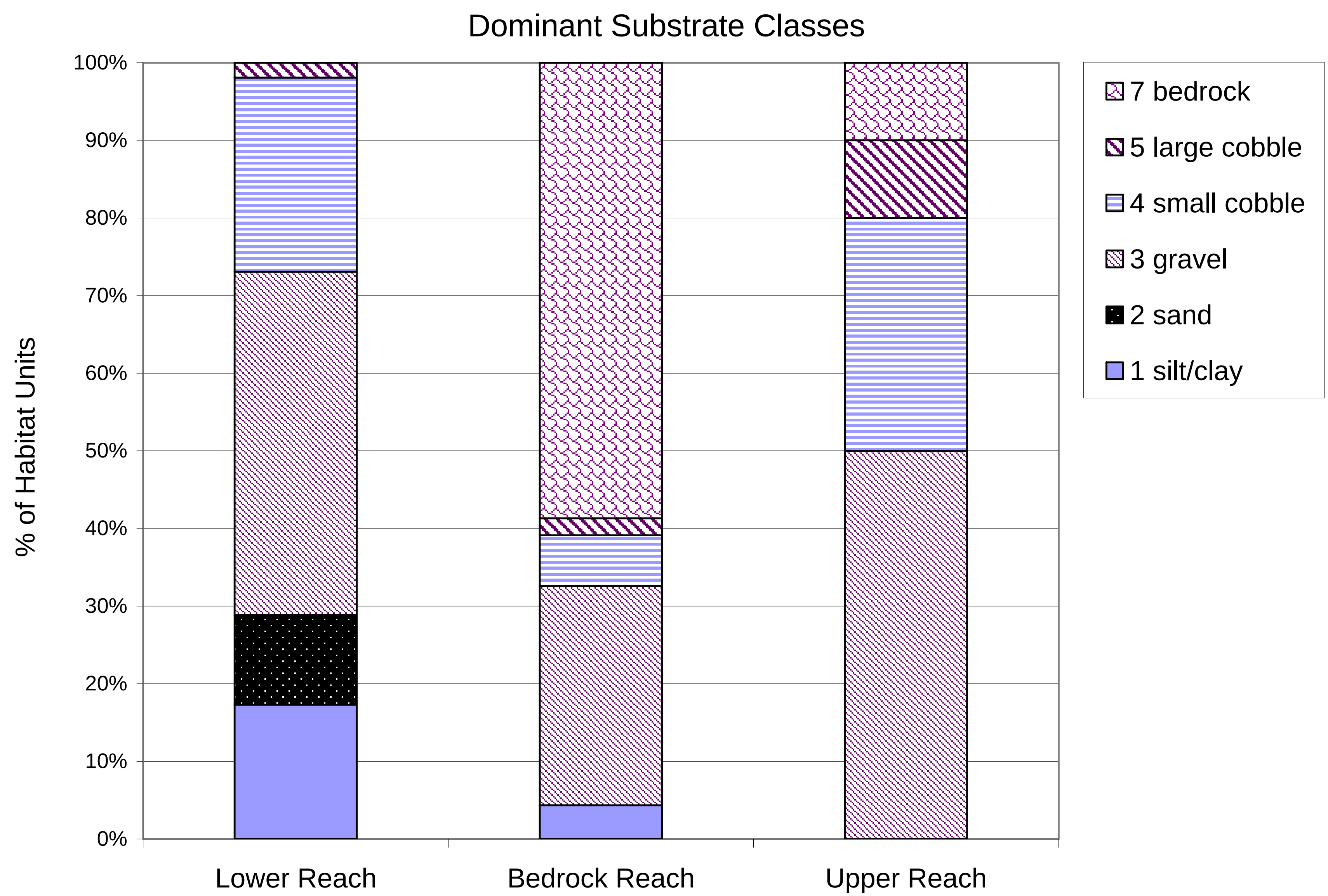


Figure 9. Dominant substrate by reach

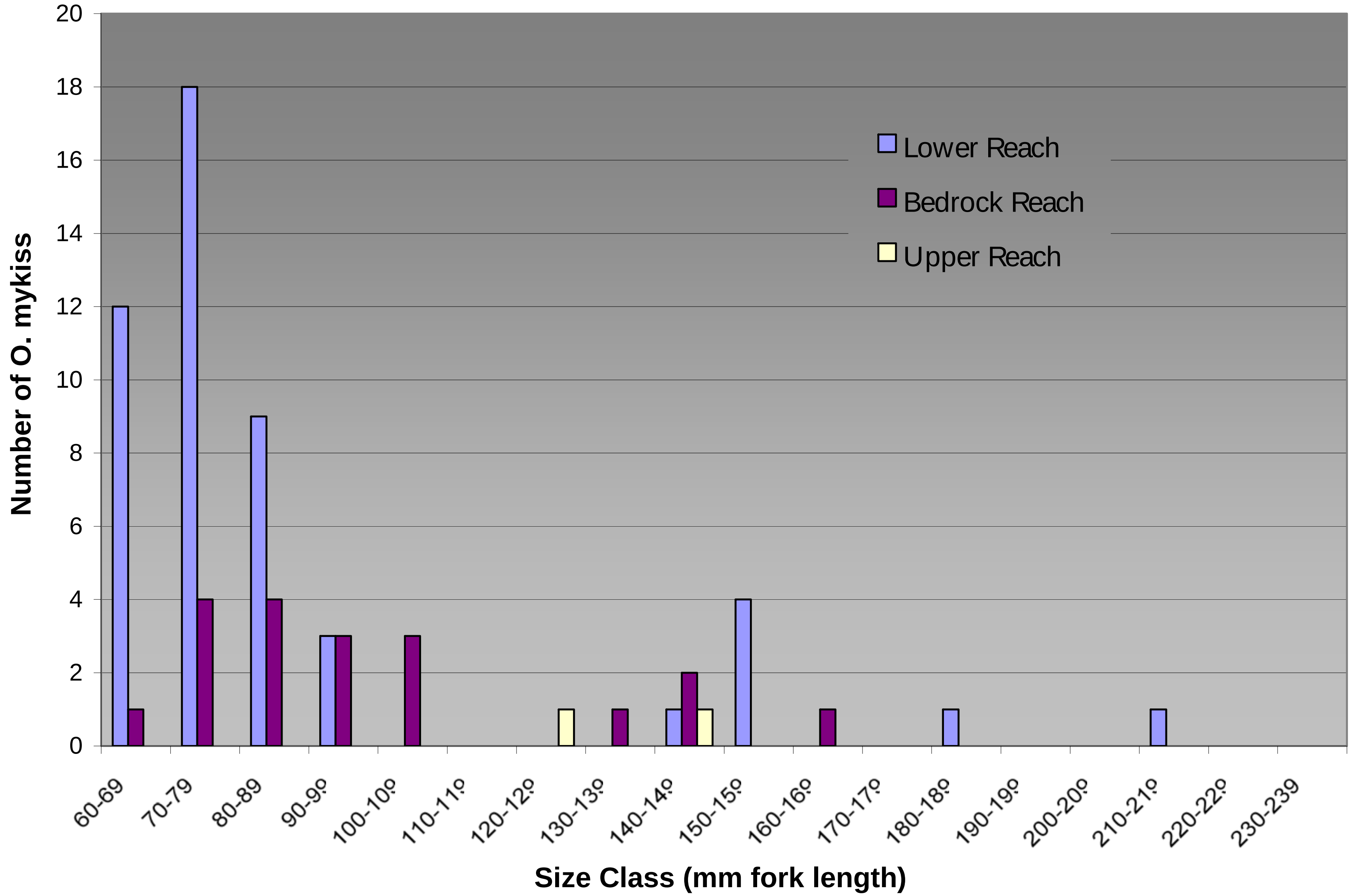
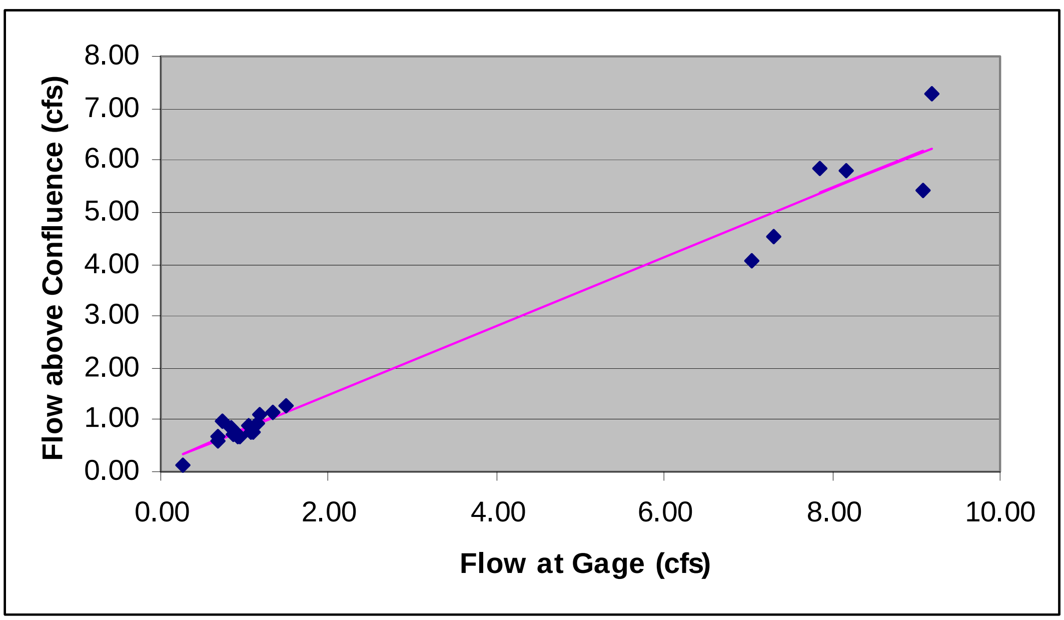


Figure 10. Size Distribution of *O. mykiss* by reach

Appendix D

Liddell Flow above West Branch Confluence

Data Source	Location	Date/Time	Flow at Gage (cfs)	Flow Above Confluence (cfs)
City		4/8/2003	1.18	1.09
City		5/22/2003	1.08	0.77
City		6/17/2003	0.84	0.83
City		7/22/2003	0.87	0.79
City		8/19/2003	0.95	0.68
City		9/23/2003	0.90	0.74
City		10/28/2003	1.15	0.91
City		11/18/2003	1.34	1.14
City		12/16/2003	1.10	0.77
City		5/20/2004	1.06	0.88
City		6/24/2004	0.85	0.73
City		7/21/2004	0.91	0.69
City		8/27/2004	0.68	0.67
City		9/22/2004	0.68	0.61
City		9/25/2007	0.26	0.15
Flow Study	LD R-6	10/25/06 14:05	0.73	0.98
Flow Study	LD R-6	12/14/06 13:35	1.48	1.29
Flow Study	LD R-4	2/12/07 14:38	7.05	4.07
Flow Study	LD S-3	2/12/07 10:34	7.30	4.54
Flow Study	LD R-6	2/12/07 13:08	9.08	5.43
Flow Study	LD-P2	2/12/07 11:55	8.18	5.78
Flow Study	LD S-4	2/12/07 11:08	7.86	5.86
Flow Study	LD R-5	2/12/07 13:59	9.18	7.29



LINEAR REGRESSION
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.985593
R Square	0.971394
Adjusted R Square	0.970032
Standard Error	0.378048
Observations	23

ANOVA

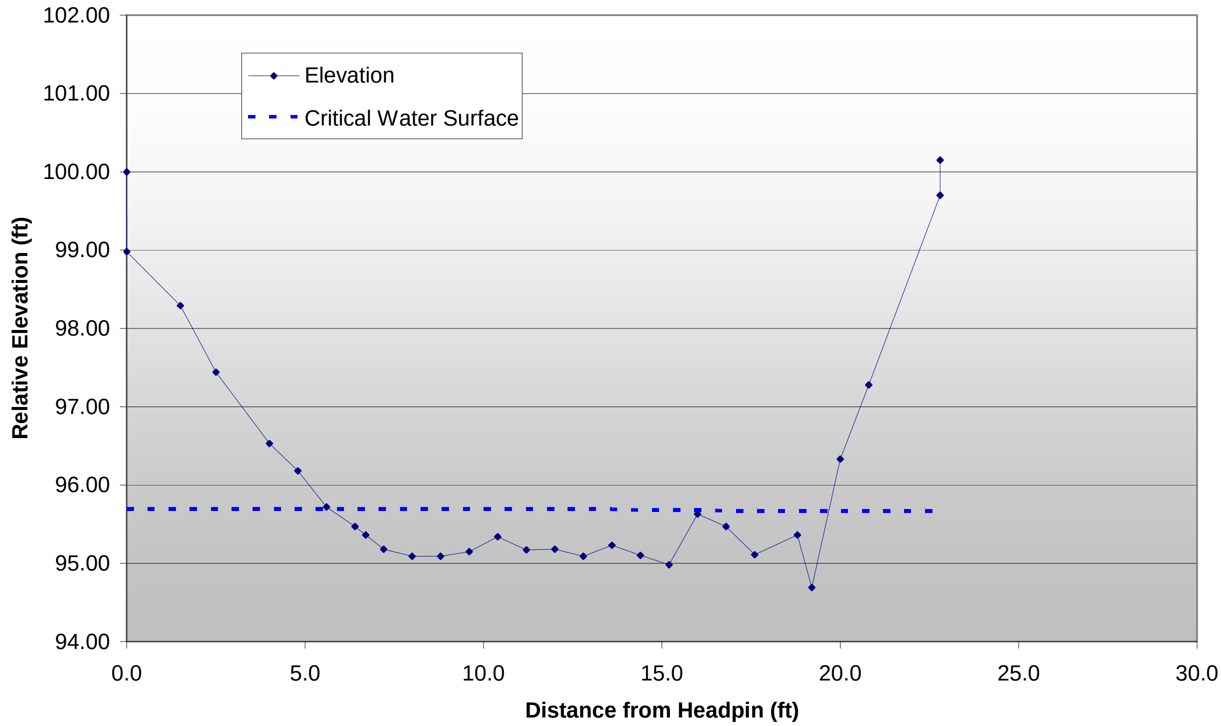
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	101.919	101.919	713.1187	1.08E-17
Residual	21	3.001323	0.14292		
Total	22	104.9204			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.169407	0.105214	1.610108	0.122304	-0.0494	0.388212	-0.0494	0.388212
X Variable 1	0.661603	0.024775	26.70428	1.08E-17	0.610081	0.713126	0.610081	0.713126

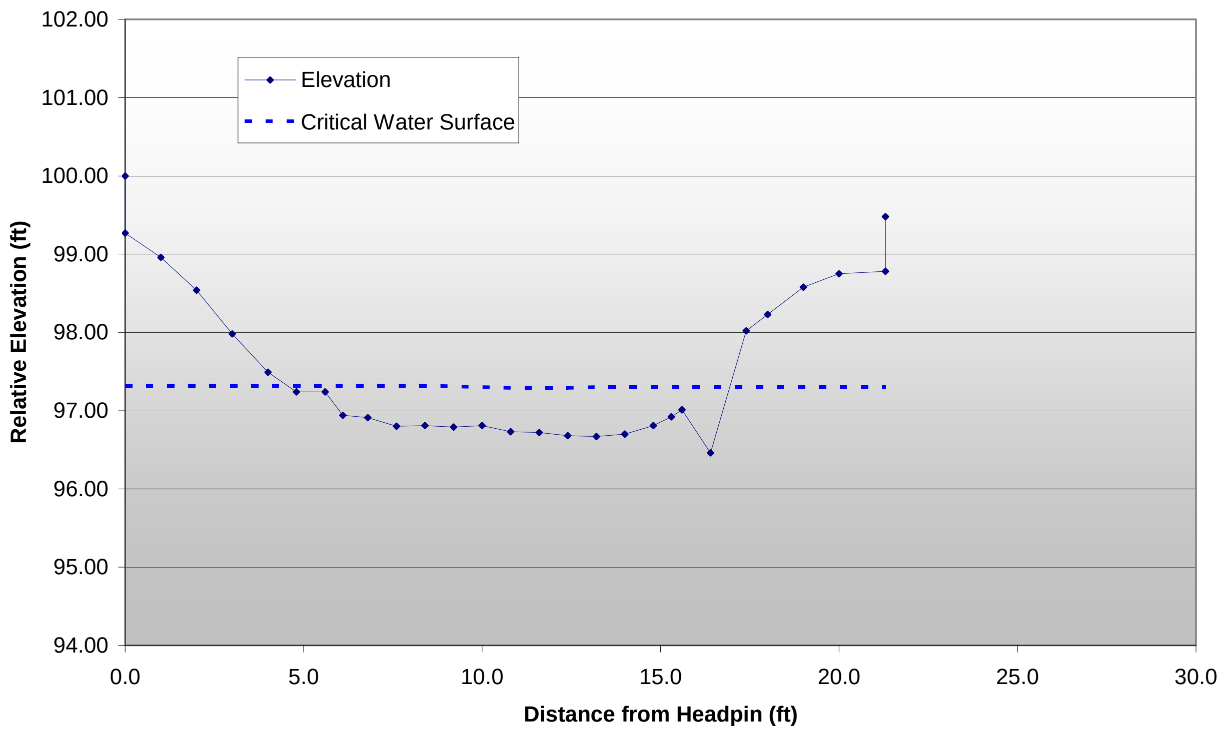
Appendix E

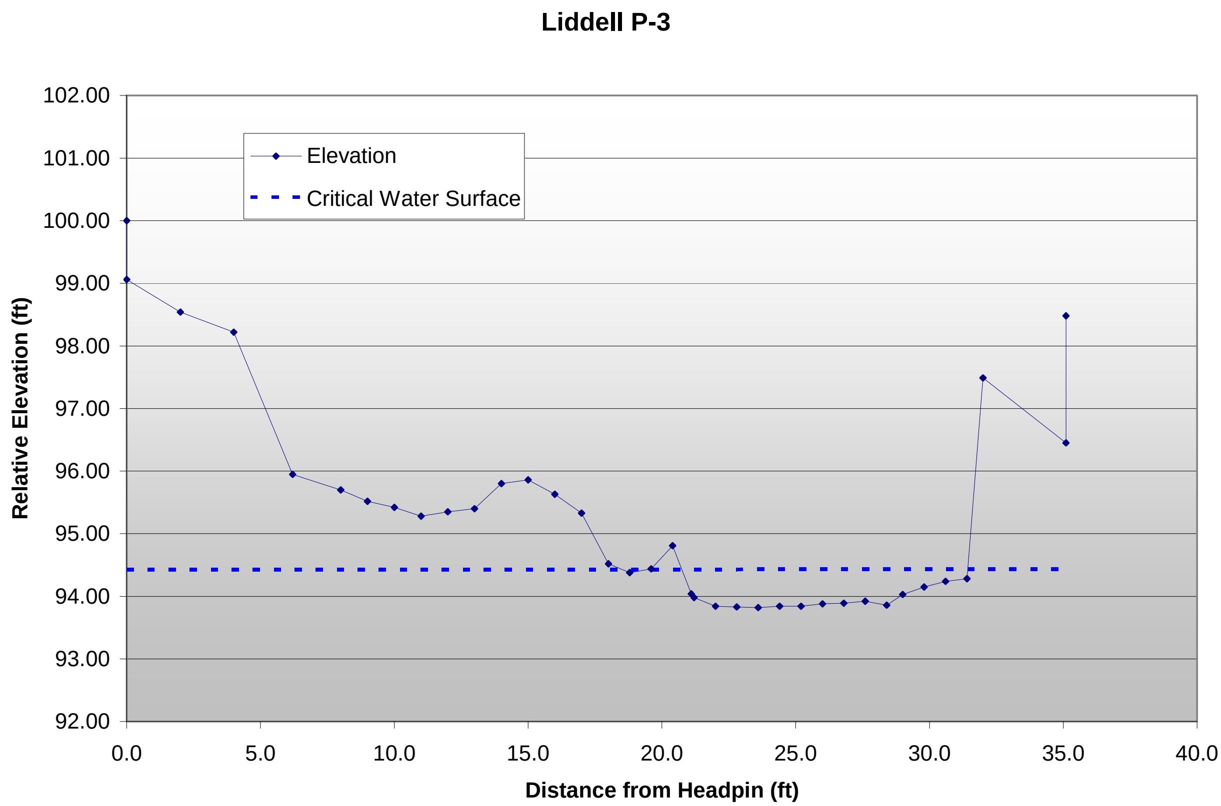
Critical Riffle Cross-sections

Liddell P-1

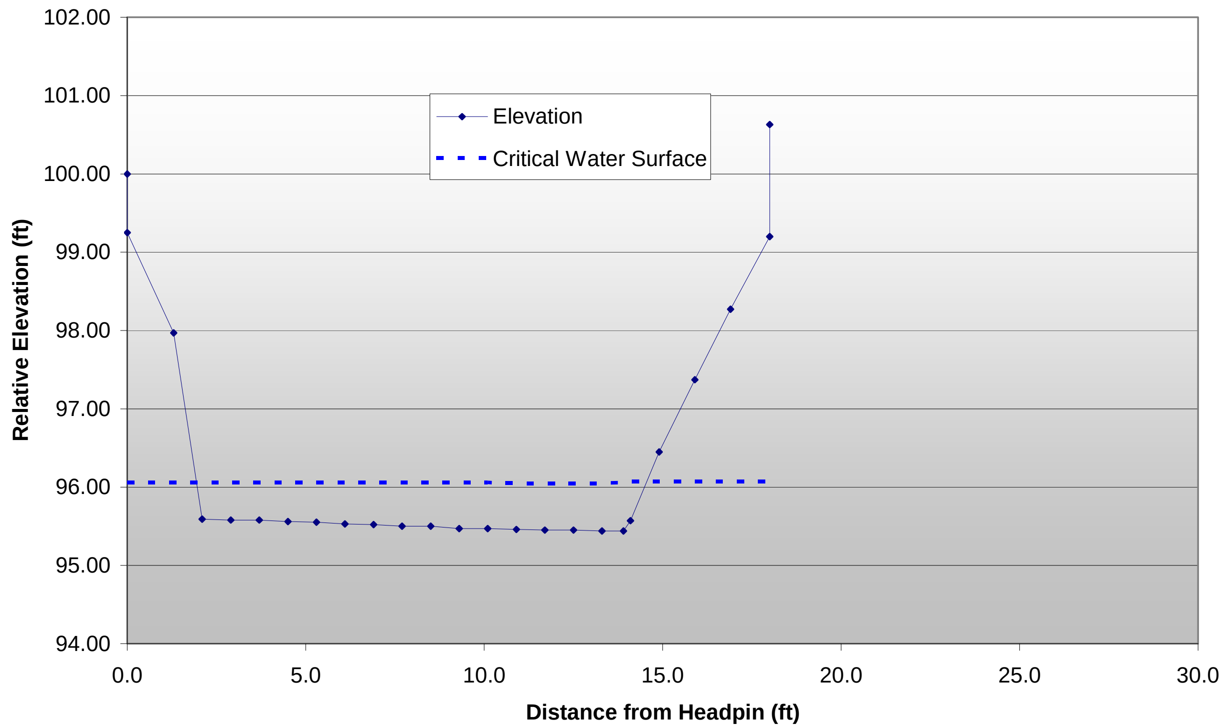


Liddell P-2

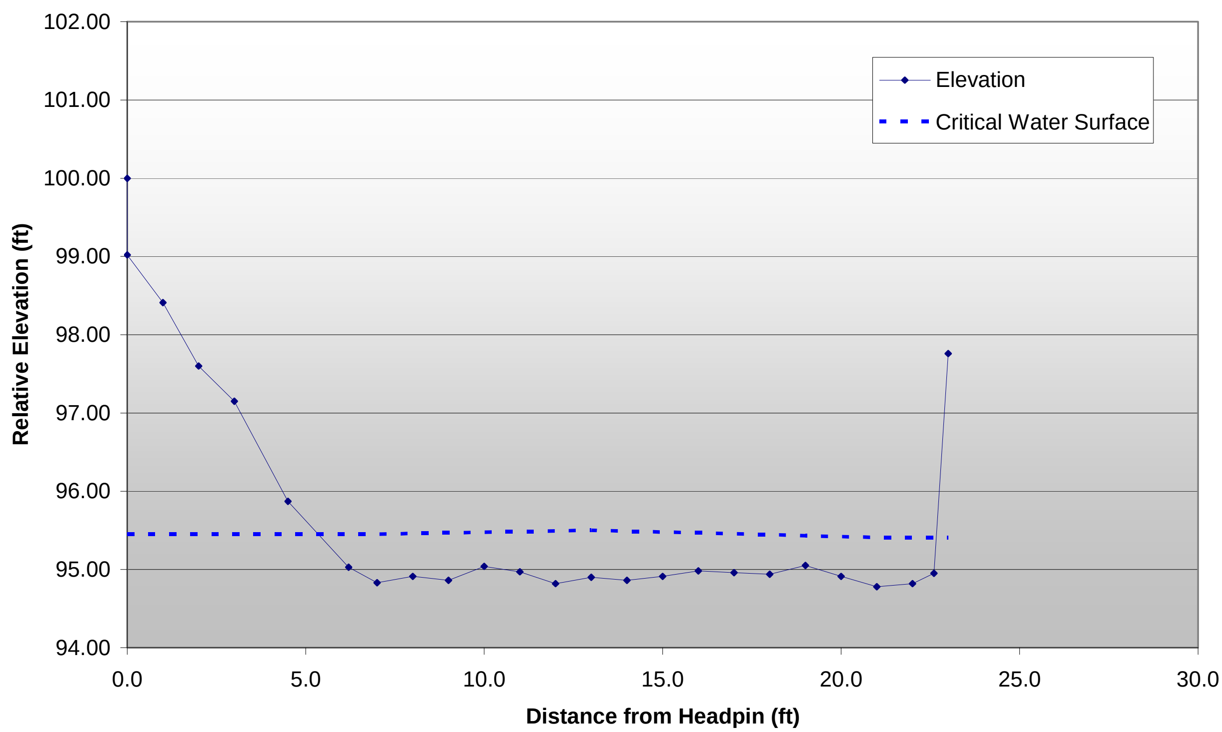



Liddell P-3
Elevation
Critical Water Surface
Relative Elevation (ft)
Distance from Headpin (ft)
102.00
101.00
100.00
99.00
98.00
97.00
96.00
95.00
94.00
93.00
92.00
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0

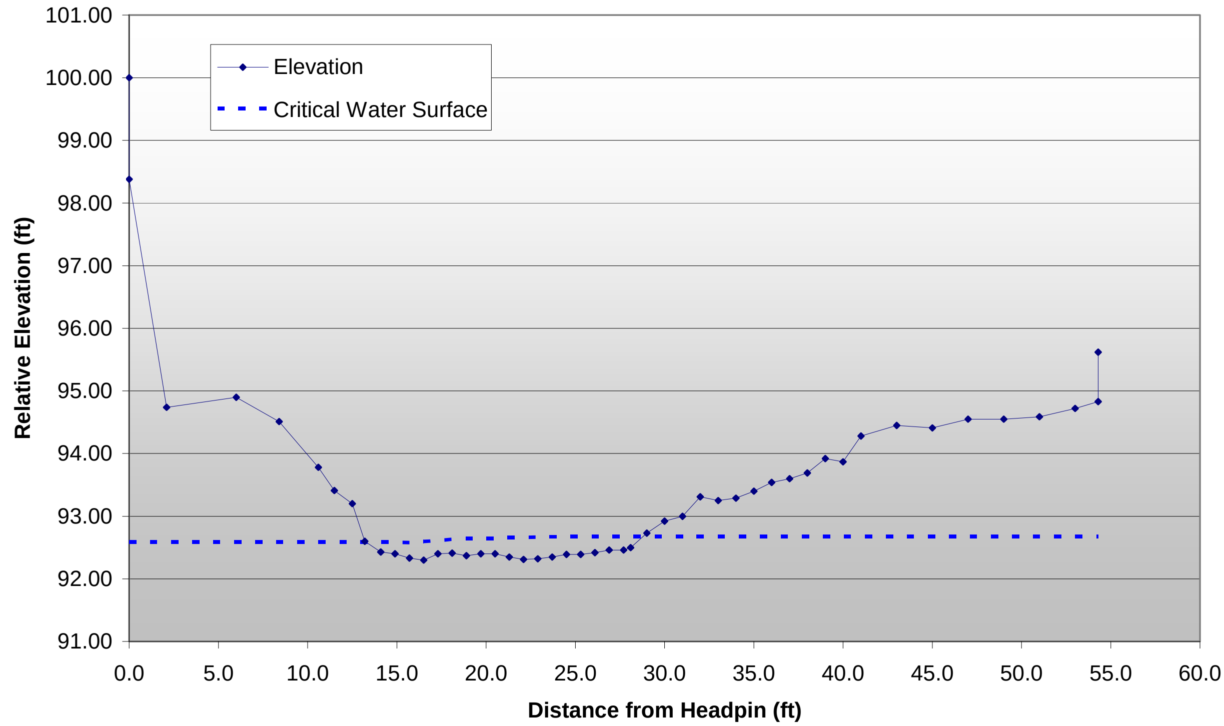
Laguna P-1



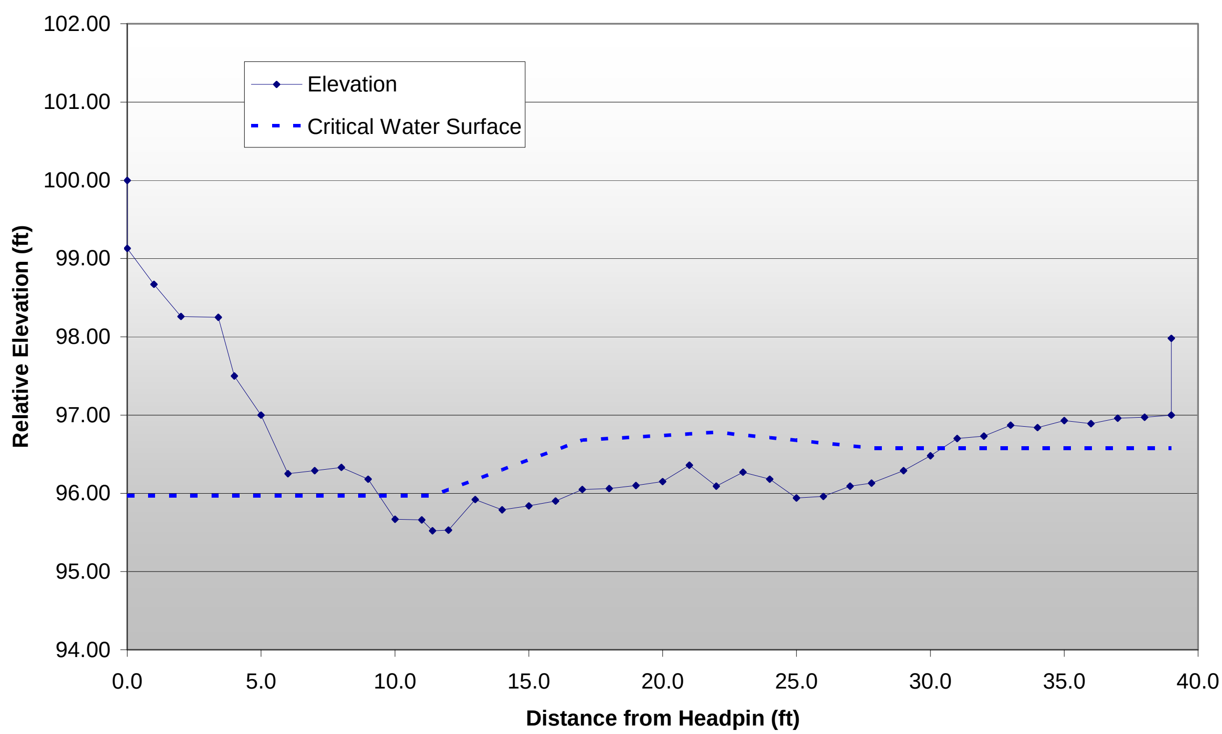
Laguna P-2



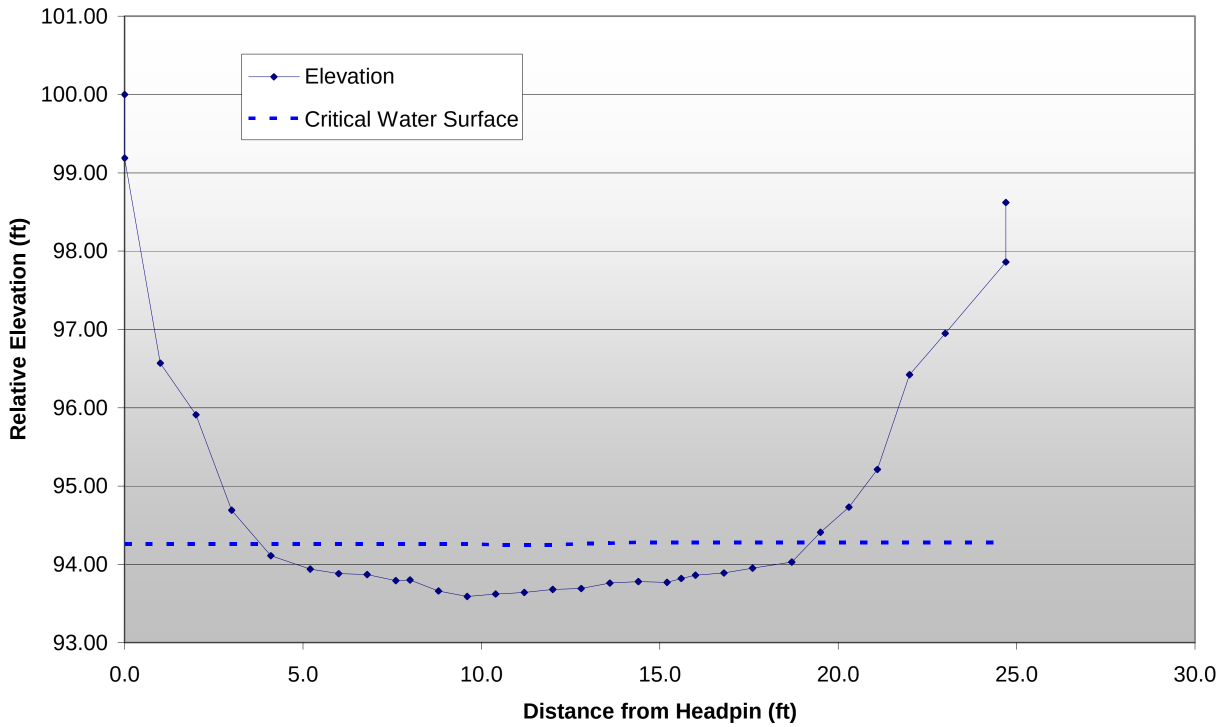
Laguna P-3



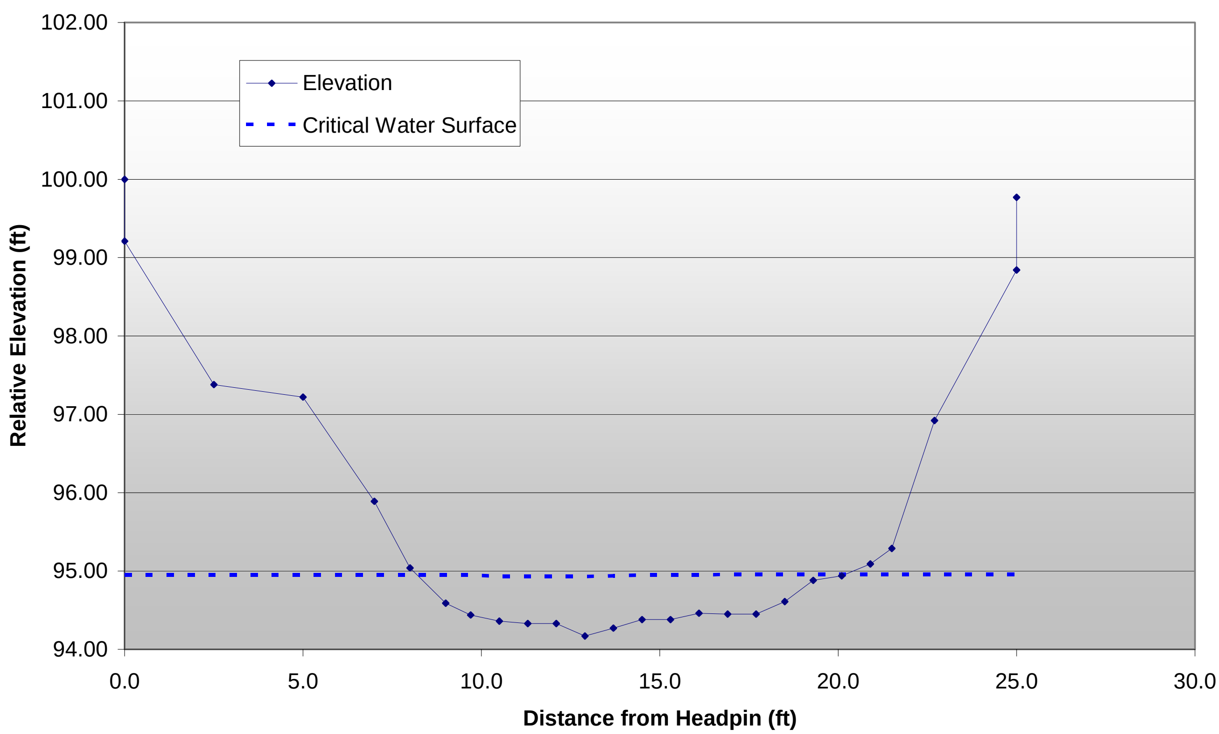
Laguna P-4

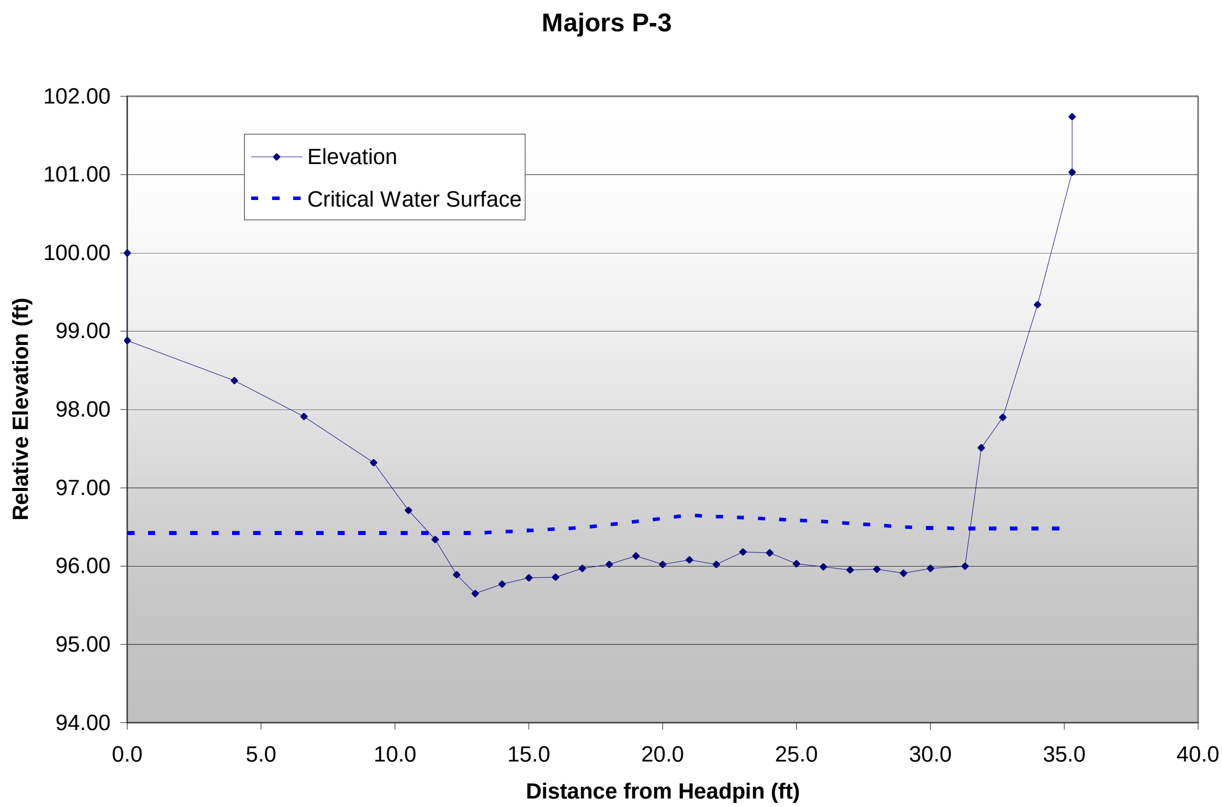


Majors P-1



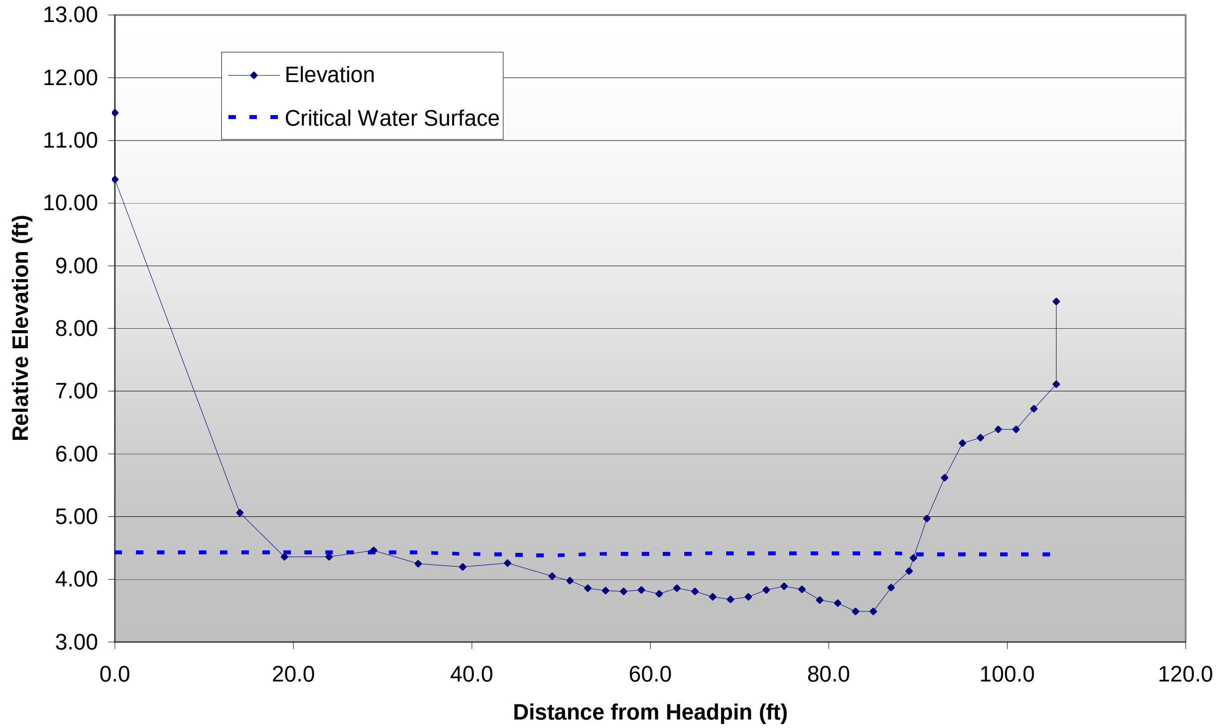
Majors P-2



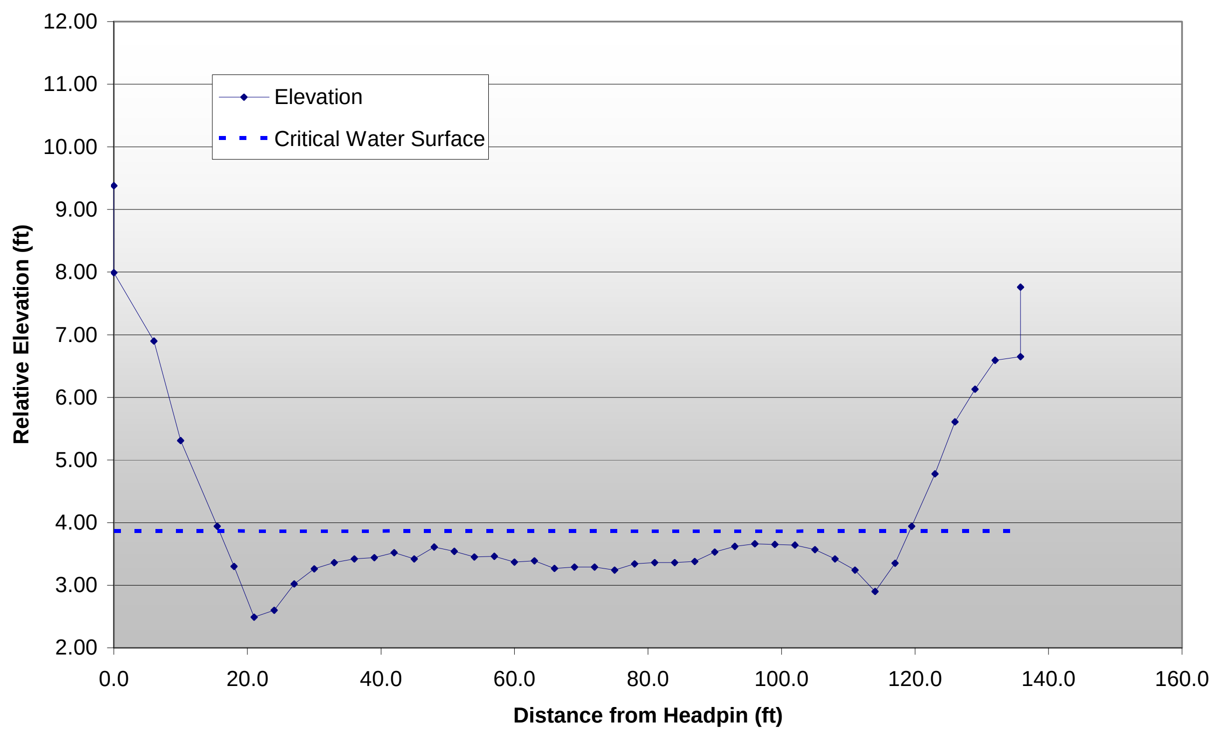


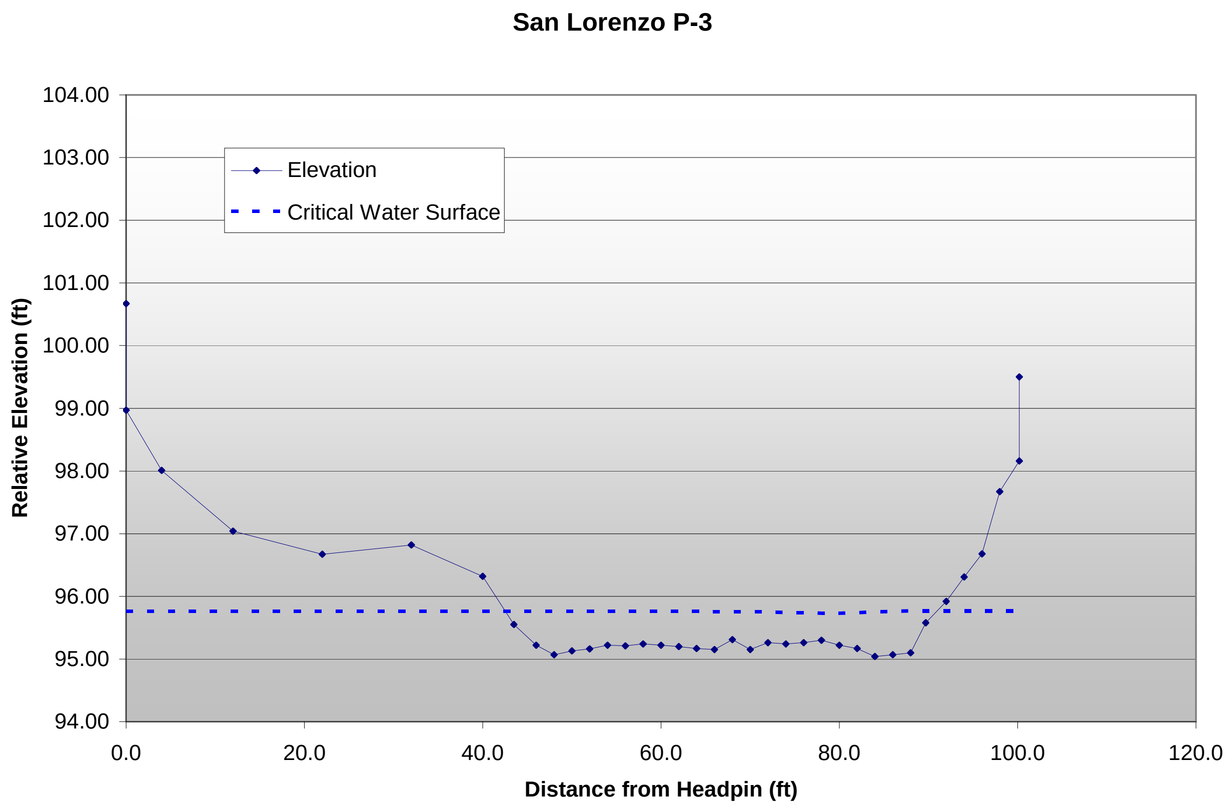
Majors P-3
102.00
101.00
100.00
99.00
98.00
97.00
96.00
95.00
94.00
Relative Elevation (ft)
Elevation
Critical Water Surface
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Distance from Headpin (ft)

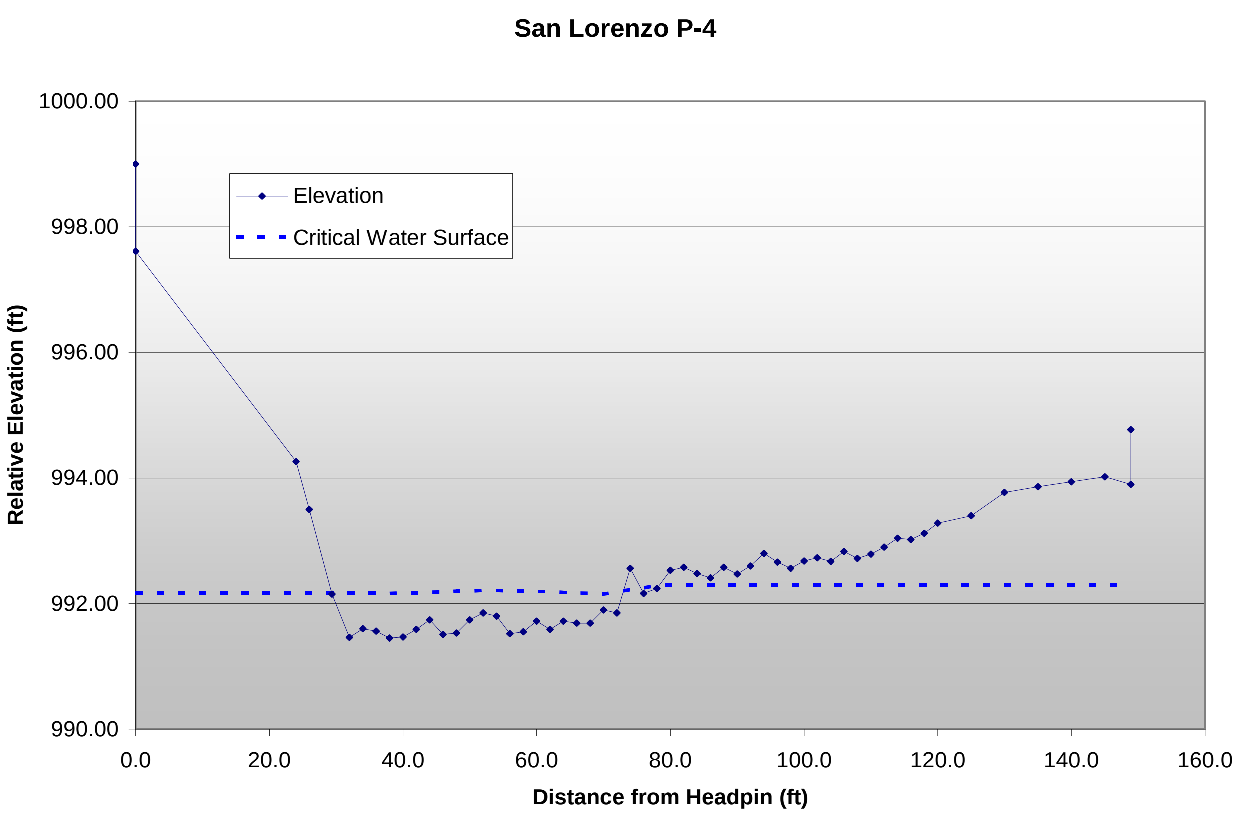
San Lorenzo P-1



San Lorenzo P-2




San Lorenzo P-3
104.00
103.00
102.00
101.00
100.00
99.00
98.00
97.00
96.00
95.00
94.00
Relative Elevation (ft)
Elevation
Critical Water Surface
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Distance from Headpin (ft)


San Lorenzo P-4
1000.00
998.00
996.00
994.00
992.00
990.00
Relative Elevation (ft)
Elevation
Critical Water Surface
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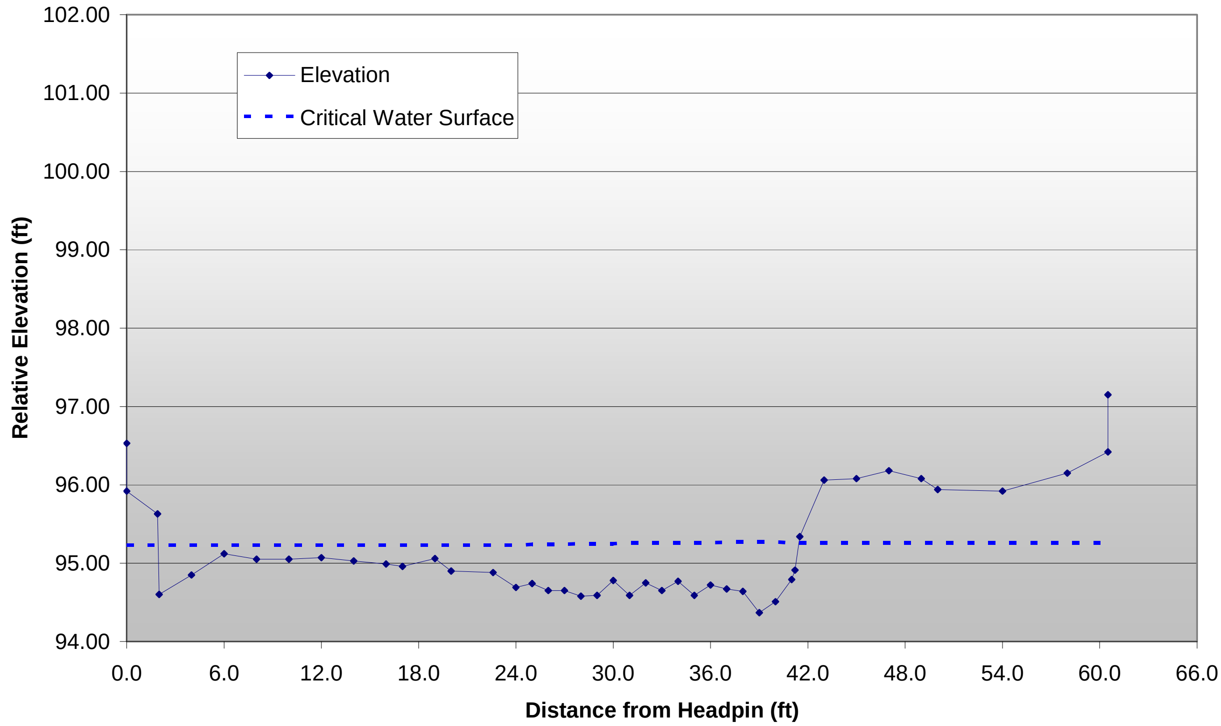
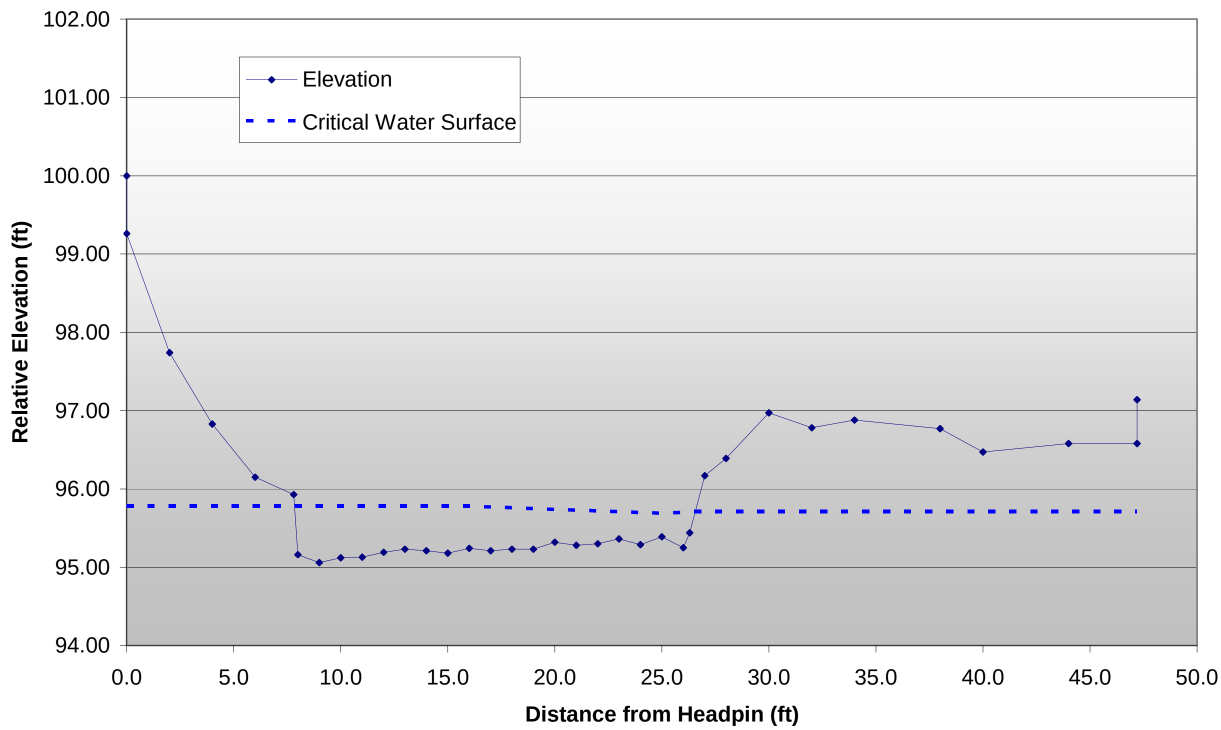
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
Distance from Headpin (ft)

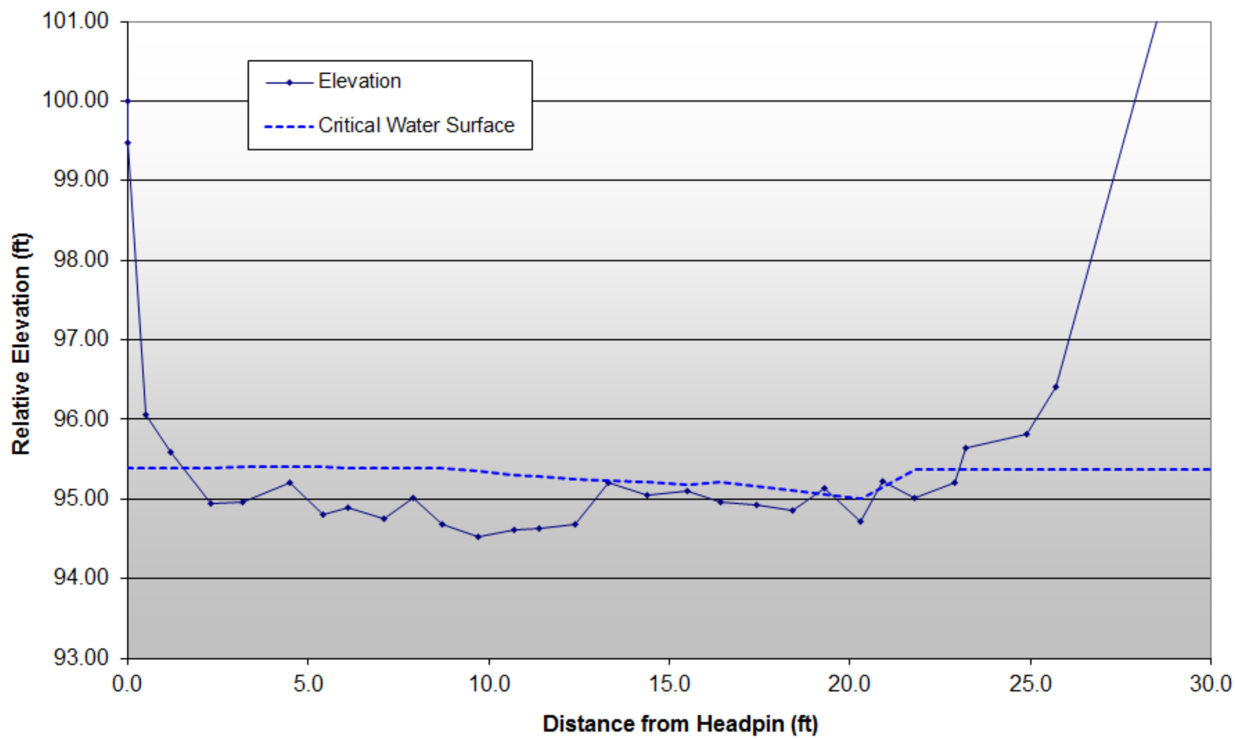
Newell P-1



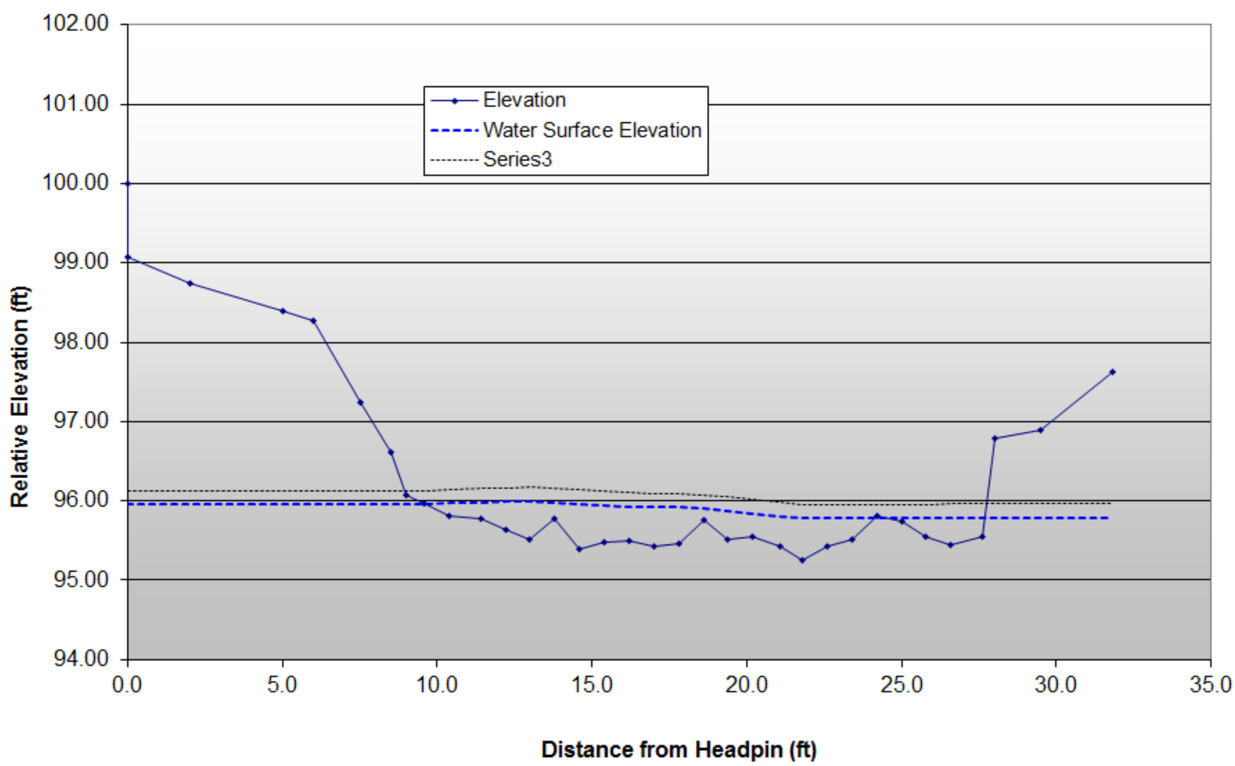
Newell P-2



Newell P-A1



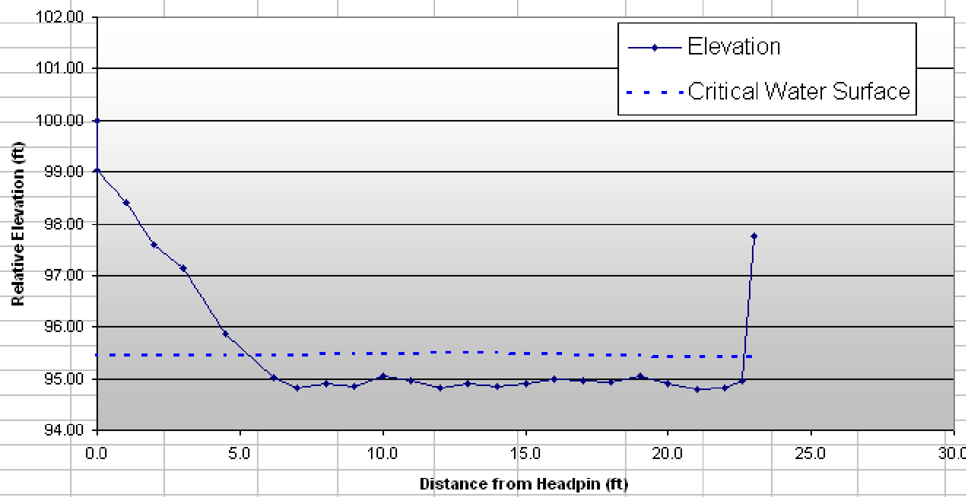
Newell P-A2



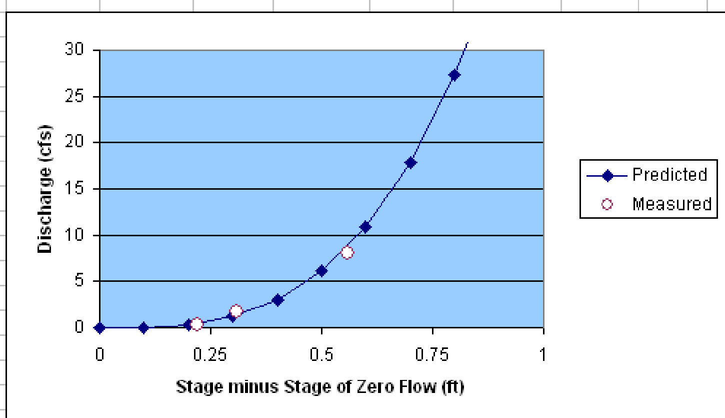
Appendix F

Analytical Data for Adult Extreme Critical Riffles

Laguna P-2

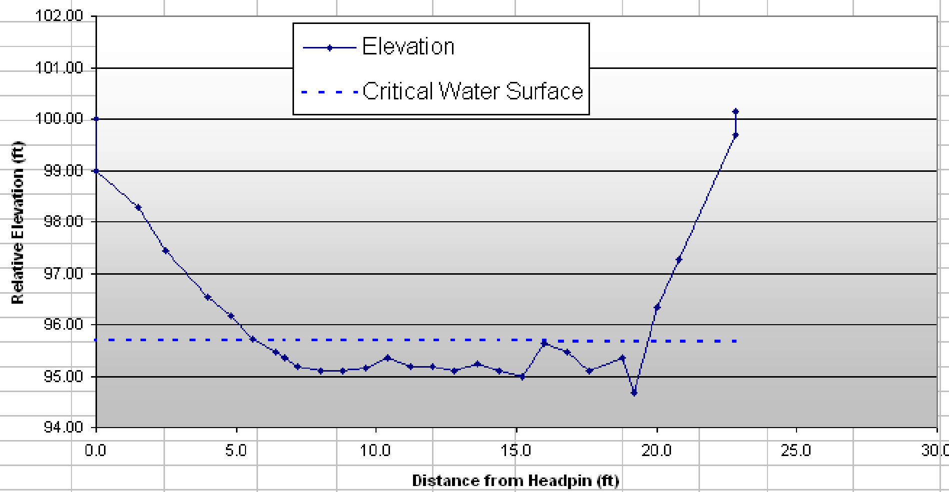


Date	Stage (ft)	Stage minus zero flow (ft)	Discharge (cfs)	Cross-Section nadir (ft)	Stage Zero Flow (ft)
17-Oct-06	95.00	0.22	0.39	94.78	94.78
12-Mar-07	95.09	0.31	1.75		
12-Dec-06	95.34	0.56	8.00		

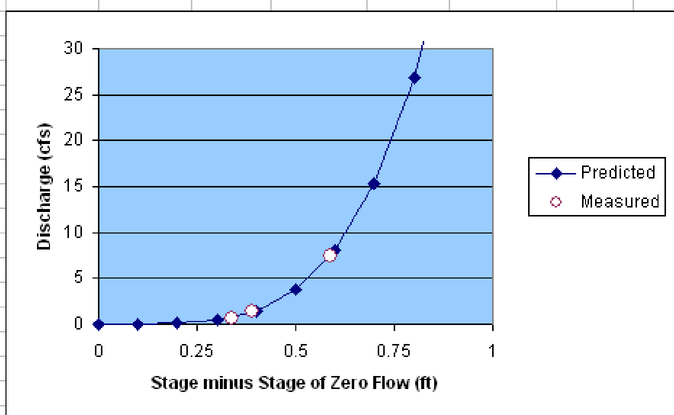


				Depth Criteria = 0.6 feet						
Stage (ft)	Stage Above Zero Flow (ft)	Discharge (cfs)	Wetted Width (ft)	Wetted Width >= Critical Depth (ft)	Percent >= Critical Depth	Longest Continuous Portion >= Critical Depth (ft)	Percent LCP	**Depth Criteria (ft)**	Stage for LCP = 10% of WW (ft)	Discharge (cfs)
94.98	0.2	0.3	13.7	0.0	0%	0.0	0%	**0.2**	95.05	0.9
95.08	0.3	1.2	17.5	0.0	0%	0.0	0%	**0.4**	95.25	5.0
95.18	0.4	3.0	17.5	0.0	0%	0.0	0%	**0.6**	95.45	15.5
95.28	0.5	6.1	17.5	0.0	0%	0.0	0%	**0.8**	95.65	35.5
95.38	0.6	10.9	17.5	1.0	6%	1.0	6%	**1**	95.85	68.5
95.45	0.67	15.5	17.5	5.9	34%	3.0	17%			
95.48	0.7	17.8	17.5	7.7	44%	4.0	23%			
95.58	0.8	27.2	17.5	13.7	79%	8.0	46%			
95.68	0.9	39.6	17.5	17.5	100%	17.5	100%			

Liddell P-1

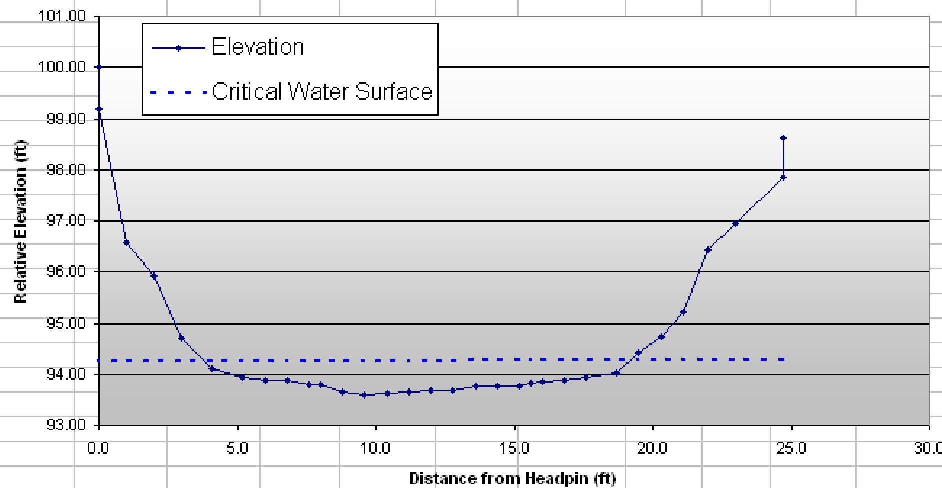


Date	Stage	Stage minus zero flow	Discharge	Cross-Section nadir	Stage Zero Flow
24-Oct-06	95.38	0.34	0.70	94.69	95.04
14-Dec-06	95.43	0.39	1.44		
12-Feb-07	95.63	0.59	7.35		

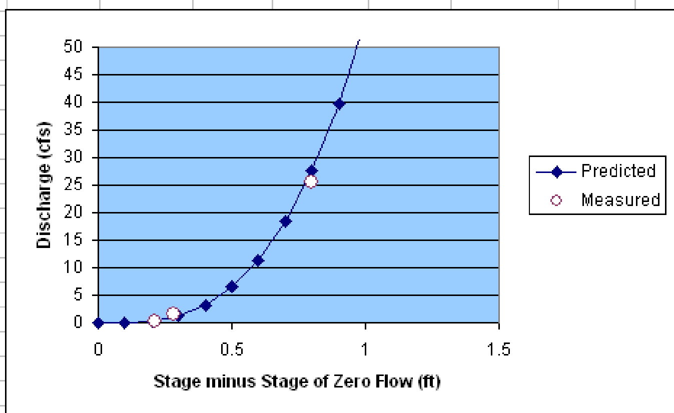


				Depth Criteria = 0.6 feet						
Stage (ft)	Stage Above Zero Flow (ft)	Discharge (cfs)	Wetted Width (ft)	Wetted Width >= Critical Depth (ft)	Percent >= Critical Depth	Longest Continuous Portion >= Critical Depth (ft)	Percent LCP	**Depth Criteria (ft)**	Stage for LCP = 10% of WW (ft)	Discharge (cfs)
95.14	0.1	0.0	5.6	0.0	0%	0.0	0%	**0.2**	95.29	0.2
95.24	0.2	0.1	9.5	0.0	0%	0.0	0%	**0.4**	95.49	2.4
95.34	0.3	0.4	9.5	0.6	6%	0.6	6%	**0.6**	95.69	11.3
95.44	0.4	1.5	11.5	0.6	5%	0.6	5%	**0.8**	95.89	34.6
95.54	0.5	3.8	12.8	0.6	5%	0.6	5%	**1**	96.09	84.0
95.64	0.6	8.1	12.8	1.4	11%	0.8	6%			
95.69	0.65	11.3	13.6	3.8	28%	1.6	12%			
95.74	0.7	15.4	14.4	5.6	39%	1.6	11%			
95.84	0.8	26.9	14.4	9.5	66%	4.8	33%			
95.94	0.9	44.0	14.4	10.3	71%	8.7	60%			

Majors P-1



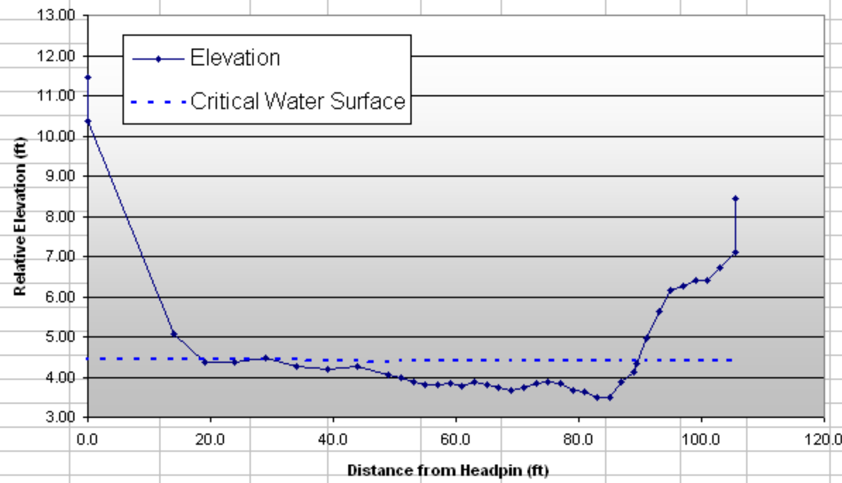
Date	Stage	Stage minus zero flow	Discharge	Cross-Section nadir	Stage Zero Flow
20-Oct-06	93.80	0.21	0.34	93.59	93.59
12-Dec-06	94.39	0.80	25.62		
8-Mar-07	93.87	0.28	1.56		



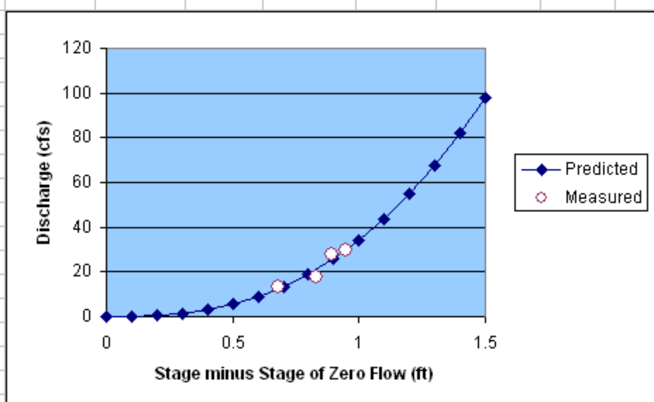
Stage (ft)	Stage Above Zero Flow (ft)	Discharge (cfs)	Wetted Width (ft)	Depth Criteria = 0.6 feet: Wetted Width >= Critical Depth (ft)	Percent >= Critical Depth	Longest Continuous Portion >= Critical Depth (ft)	Percent LCP
93.69	0.1	0.0	3.2	0	0%	0	0%
93.79	0.2	0.4	7.0	0	0%	0	0%
93.89	0.3	1.3	11.6	0	0%	0	0%
93.99	0.4	3.3	13.5	0	0%	0	0%
94.09	0.5	6.5	14.5	0	0%	0	0%
94.19	0.6	11.4	15.6	0.8	5%	0.8	5%
94.26	0.67	16.0	15.6	3.2	21%	3.2	21%
94.29	0.7	18.3	15.6	4.8	31%	4.8	31%
94.39	0.8	27.7	15.6	7.6	49%	7	45%
94.49	0.9	39.8	16.4	11.6	71%	11.6	71%

Depth Criteria (ft)	Stage for LCP = 10% of WW (ft)	Discharge (cfs)
0.2	93.85	0.9
0.4	94.09	6.5
0.6	94.26	16.0
0.8	94.46	35.9
1	94.66	67.9

San Lorenzo P-1



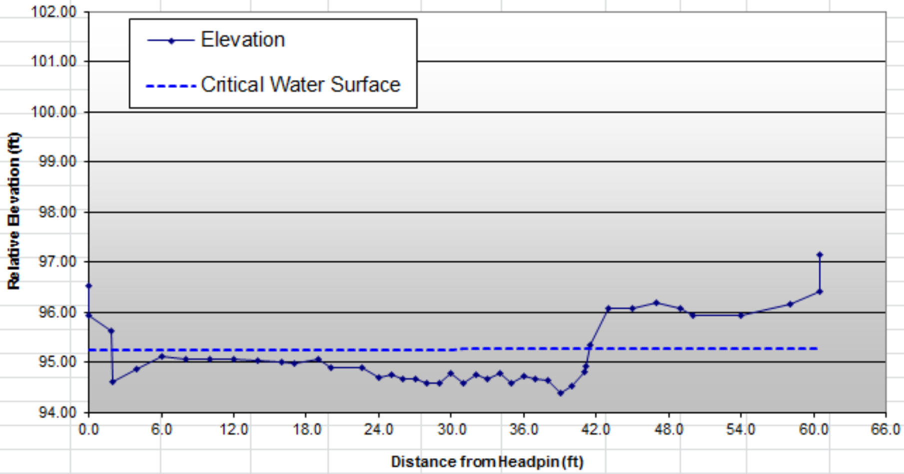
Date	Stage (ft)	Stage minus zero flow (ft)	Discharge (cfs)	Cross-Section nadir (ft)	Stage Zero Flow (ft)
12-Oct-05	4.34	4.34	18.00	3.49	3.51
20-Oct-05	4.19	4.19	13.00		
6-Dec-05	4.40	4.40	28.00		
6-Dec-05	4.46	4.46	30.00		



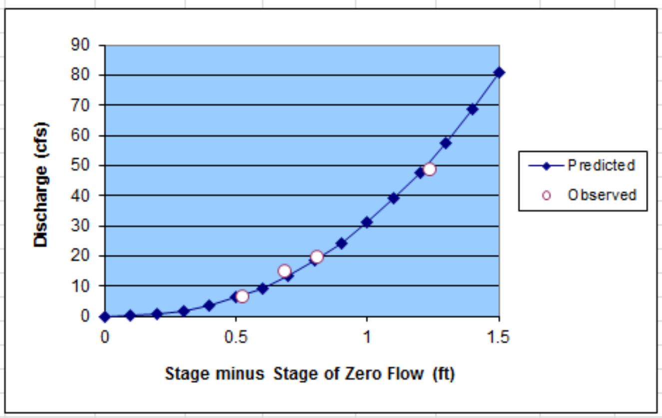
				Depth Criteria = 0.6 feet			
Stage (ft)	Stage Above Zero Flow (ft)	Discharge (cfs)	Wetted Width (ft)	Wetted Width >= Critical Depth (ft)	Percent >= Critical Depth	Longest Continuous Portion >= Critical Depth (ft)	Percent LCP
3.71	0.2	0.5	14.0	0.0	0%	0.0	0%
3.81	0.3	1.5	20.0	0.0	0%	0.0	0%
3.91	0.4	3.1	36.0	0.0	0%	0.0	0%
4.01	0.5	5.6	38.0	0.0	0%	0.0	0%
4.11	0.6	9.0	41.5	4.0	10%	4.0	10%
4.21	0.7	13.5	47.8	6.0	13%	6.0	13%
4.31	0.8	19.1	57.8	14.0	24%	8.0	14%
4.40	0.89	25.2	68.8	20.0	29%	8.0	12%
4.41	0.9	34.1	68.8	24.0	35%	10.0	15%
4.51	1	43.7	73.8	36.0	49%	36.0	49%
4.61	1.1	54.86	73.75	38.0	52%	38.0	52%

Depth Criteria (ft)	Stage for LCP = 10% of WW (ft)	Discharge (cfs)
0.2	3.67	0.3
0.4	4.1	8.6
0.6	4.4	25.2
0.8	4.6	42.7
1	4.8	66.2

Newell P-1



Date	Stage (ft)	Stage minus zero flow (ft)	Discharge (cfs)	Cross-Section nadir (ft)	Stage Zero Flow (ft)
25-Feb-08	95.61	1.24	48.59	94.37	94.37
26-Feb-08	95.18	0.81	19.74		
27-Feb-08	95.06	0.69	15.01		
3-Mar-08	94.90	0.53	6.27		



				Depth Criteria = 0.6 feet						
Stage (ft)	Stage Above Zero Flow (ft)	Discharge (cfs)	Wetted Width (ft)	Wetted Width >= Critical Depth (ft)	Percent >= Critical Depth	Longest Continuous Portion >= Critical Depth (ft)	Percent LCP	**Depth Criteria (ft)**	Stage for LCP = 10% of WW (ft)	Discharge (cfs)
94.57	0.2	0.7	2.0	0.0	0%	0.0	0%	**0.2**	94.8	4.3
94.67	0.3	1.8	9.1	0.0	0%	0.0	0%	**0.4**	95.04	12.2
94.77	0.4	3.6	15.3	0.0	0%	0.0	0%	**0.6**	95.27	24.4
94.87	0.5	6.1	18.9	0.0	0%	0.0	0%	**0.8**	95.47	39.0
94.97	0.6	9.4	24.9	1.0	4%	1.0	4%	**1**	95.67	57.8
95.07	0.7	13.5	27.9	1.0	4%	1.0	4%			
95.17	0.8	18.5	39.4	2.0	5%	2.0	5%			
95.27	0.9	24.4	39.4	10.1	26%	4.0	10%			
95.37	1	31.2	40.3	16.3	40%	6.2	15%			
95.47	1.1	39.0	40.3	18.9	47%	17.8	44%			

Appendix G

WUA vs. Discharge Data

Table G-1. WUA vs. Discharge for Steelhead Spawning in Liddell Creek.

Simulated Flow	Equivalent Flow above West Branch	WUA below West Branch	WUA above West Branch	WUA combined	Percent of Peak WUA
1.0	0.83	540	358	898	15.7%
2.0	1.49	923	568	1491	26.1%
3.0	2.15	1305	812	2117	37.0%
4.0	2.82	1718	1094	2812	49.1%
5.0	3.48	2033	1385	3419	59.7%
6.0	4.14	2260	1702	3962	69.2%
7.0	4.8	2483	2012	4495	78.6%
8.0	5.46	2688	2285	4973	86.9%
8.5	5.79	2785	2409	5194	90.8%
9.0	6.12	2811	2509	5320	93.0%
9.5	6.45	2825	2600	5425	94.8%
10.0	6.79	2809	2690	5499	96.1%
10.5	7.12	2802	2770	5571	97.4%
11.0	7.45	2809	2828	5637	98.5%
11.5	7.78	2803	2881	5683	99.3%
12.0	8.11	2785	2923	5709	99.8%
13.0	8.77	2720	3002	5722	100.0%
14.0	9.43	2658	3061	5719	99.9%
15.0	10.09	2584	3087	5670	99.1%
16.0	10.76	2504	3085	5588	97.7%
17.0	11.42	2413	3068	5481	95.8%
18.0	12.08	2341	3027	5368	93.8%
19.0	12.74	2272	2958	5231	91.4%
20.0	13.4	2199	2866	5065	88.5%
21.0	14.06	2114	2778	4892	85.5%
23.0	15.39	1917	2576	4493	78.5%
25.0	16.71	1740	2404	4144	72.4%
27.0	18.03	1590	2213	3803	66.5%
29.0	19.36	1432	2055	3487	60.9%
31.0	20.68	1302	1921	3223	56.3%

Table G-2. WUA vs. Discharge for Coho Salmon Spawning in Liddell Creek.

Simulated Flow	Equivalent Flow above West Branch	WUA below West Branch	WUA above West Branch	WUA combined	Percent of Peak WUA
1.0	1.1	667	164	830	23.2%
2.0	1.7	1326	343	1669	46.6%
3.0	2.2	1763	506	2269	63.3%
4.0	2.8	2069	654	2723	76.0%
5.0	3.4	2241	792	3033	84.6%
6.0	3.9	2367	928	3295	91.9%
7.0	4.5	2459	1055	3514	98.0%
8.0	5.1	2432	1147	3579	99.8%
8.5	5.3	2405	1179	3585	100.0%
9.0	5.6	2377	1199	3576	99.7%
9.5	5.9	2351	1219	3570	99.6%
10.0	6.2	2330	1242	3572	99.7%
10.5	6.5	2287	1254	3541	98.8%
11.0	6.8	2237	1263	3500	97.6%
11.5	7.0	2177	1258	3434	95.8%
12.0	7.3	2130	1255	3386	94.4%
13.0	7.9	2038	1259	3298	92.0%
14.0	8.4	1907	1251	3158	88.1%
15.0	9.0	1807	1216	3024	84.3%
16.0	9.6	1734	1182	2916	81.3%
17.0	10.1	1662	1132	2794	77.9%
18.0	10.7	1585	1087	2672	74.5%
19.0	11.3	1517	1046	2563	71.5%
20.0	11.8	1438	1012	2450	68.4%
21.0	12.4	1354	981	2336	65.2%
23.0	13.5	1195	901	2096	58.5%
25.0	14.7	1060	812	1872	52.2%
27.0	15.8	919	727	1646	45.9%
29.0	16.9	806	640	1446	40.3%
31.0	18.0	689	592	1281	35.7%

Table G-3. WUA vs. Discharge for Steelhead and Coho Salmon Spawning in Laguna Creek.

Simulated Flow	Steelhead WUA	Percent of Peak	Coho WUA	Percent of Peak
0.2	296	4.7%	133	2.8%
0.5	459	7.3%	485	10.2%
0.6	489	7.8%	554	11.6%
2.0	1221	19.5%	1805	37.9%
2.1	1251	20.0%	1850	38.8%
4.0	2275	36.3%	3088	64.8%
6.0	3359	53.7%	3942	82.7%
8.0	4408	70.4%	4478	94.0%
8.9	4832	77.2%	4600	96.5%
10.0	5313	84.9%	4693	98.5%
12.0	5889	94.1%	4765	100.0%
14.0	6146	98.2%	4760	99.9%
16.0	6261	100.0%	4720	99.0%
18.0	6254	99.9%	4612	96.8%
18.5	6240	99.7%	4585	96.2%
20.0	6191	98.9%	4482	94.1%
22.0	6017	96.1%	4351	91.3%
24.0	5803	92.7%	4212	88.4%
26.0	5594	89.3%	4068	85.4%
28.0	5431	86.7%	3923	82.3%
30.0	5304	84.7%	3803	79.8%
32.0	5181	82.7%	3685	77.3%
34.0	5057	80.8%	3560	74.7%
36.0	4949	79.0%	3439	72.2%
38.0	4804	76.7%	3340	70.1%
40.0	4658	74.4%	3252	68.2%
42.0	4515	72.1%	3182	66.8%
44.0	4365	69.7%	3118	65.4%
46.0	4200	67.1%	3041	63.8%

Table G-4. WUA vs. Discharge for Steelhead and Coho Salmon Spawning in Majors Creek.

Simulated Flow	Steelhead WUA	Percent of Peak	Coho WUA	Percent of Peak
0.2	275	4.2%	26	0.5%
0.5	505	7.7%	456	8.6%
2.0	1390	21.1%	1751	33.1%
4.0	2232	33.8%	2631	49.8%
6.0	3055	46.3%	3398	64.3%
8.0	3854	58.4%	3996	75.7%
10.0	4582	69.4%	4534	85.8%
12.0	5250	79.6%	4945	93.6%
14.0	5813	88.1%	5207	98.6%
16.0	6285	95.3%	5282	100.0%
18.0	6548	99.3%	5124	97.0%
20.0	6598	100.0%	4861	92.0%
22.0	6432	97.5%	4547	86.1%
24.0	6168	93.5%	4173	79.0%
26.0	5913	89.6%	3804	72.0%
28.0	5674	86.0%	3466	65.6%
30.0	5472	82.9%	3189	60.4%
32.0	5328	80.7%	2937	55.6%
34.0	5169	78.3%	2748	52.0%
36.0	4951	75.0%	2601	49.3%
38.0	4710	71.4%	2474	46.8%
40.0	4457	67.6%	2362	44.7%
42.0	4236	64.2%	2266	42.9%
44.0	4037	61.2%	2171	41.1%
46.0	3847	58.3%	2091	39.6%

Table G-5. WUA vs. Discharge for Steelhead and Coho Salmon Spawning in Newell Creek.

Simulated Flow	Steelhead WUA	Percent of Peak	Coho WUA	Percent of Peak
1.00	917	8.5%	1069	11.8%
2.00	1534	14.1%	2741	30.3%
3.00	2331	21.5%	3875	42.8%
4.00	3191	29.4%	4743	52.4%
5.00	4057	37.4%	5440	60.1%
6.00	4909	45.2%	6032	66.6%
7.00	5695	52.5%	6505	71.8%
8.00	6392	58.9%	6901	76.2%
9.00	6941	63.9%	7217	79.7%
10.00	7422	68.4%	7488	82.7%
12.00	8217	75.7%	7968	88.0%
14.00	8870	81.7%	8380	92.6%
16.00	9441	87.0%	8759	96.7%
18.00	9912	91.3%	8947	98.8%
20.00	10315	95.0%	9054	100.0%
22.00	10639	98.0%	9047	99.9%
24.00	10805	99.5%	8974	99.1%
26.00	10855	100.0%	8872	98.0%
28.00	10846	99.9%	8650	95.5%
30.00	10692	98.5%	8383	92.6%
32.00	10453	96.3%	8054	89.0%
34.00	10153	93.5%	7713	85.2%
36.00	9794	90.2%	7375	81.5%
38.00	9379	86.4%	6989	77.2%
40.00	8900	82.0%	6598	72.9%
50.00	6705	61.8%	4778	52.8%
60.00	5218	48.1%	3527	39.0%
80.00	3626	33.4%	1729	19.1%
100.00	2317	21.3%	1024	11.3%
120.00	1364	12.6%	717	7.9%

Table G-6. WUA vs. Discharge for Steelhead Juvenile Rearing in Liddell Creek.

Simulated Flow	Equivalent Flow above West Branch	WUA below West Branch	WUA above West Branch	WUA combined	Percent of Peak WUA
0.10	0.24	762	623	1385	23.1%
0.25	0.33	954	688	1642	27.4%
0.50	0.5	1224	783	2007	33.6%
0.75	0.67	1429	859	2289	38.3%
1.00	0.83	1616	923	2539	42.4%
1.25	1	1779	987	2766	46.2%
1.50	1.16	1892	1046	2938	49.1%
1.75	1.33	1992	1107	3098	51.8%
2.00	1.49	2082	1162	3244	54.2%
2.25	1.66	2164	1219	3383	56.6%
2.50	1.82	2236	1272	3508	58.6%
2.75	1.99	2300	1327	3627	60.6%
3.00	2.15	2353	1379	3733	62.4%
3.25	2.32	2402	1432	3834	64.1%
3.50	2.49	2449	1483	3932	65.7%
3.75	2.65	2493	1530	4023	67.2%
4.00	2.82	2536	1577	4113	68.8%
4.50	3.15	2619	1664	4283	71.6%
5.00	3.48	2696	1748	4444	74.3%
5.50	3.81	2768	1831	4599	76.9%
6.00	4.14	2835	1907	4742	79.3%
6.50	4.47	2899	1979	4878	81.5%
7.00	4.8	2959	2049	5007	83.7%
8.00	5.46	3072	2180	5252	87.8%
9.00	6.12	3163	2290	5453	91.2%
10.00	6.79	3202	2370	5572	93.1%
12.00	8.11	3280	2486	5767	96.4%
14.00	9.43	3323	2567	5890	98.5%
20.00	13.4	3196	2730	5926	99.1%
28.00	18.69	3025	2957	5982	100.0%

Table G-7. WUA vs. Discharge for Coho Salmon Juvenile Rearing in Liddell Creek.

Simulated Flow	Equivalent Flow above West Branch	WUA below West Branch	WUA above West Branch	WUA combined	Percent of Peak WUA
0.10	0.24	2282	1477	3759	71.7%
0.25	0.33	2562	1566	4128	78.7%
0.50	0.5	2834	1701	4535	86.5%
0.75	0.67	3004	1790	4794	91.4%
1.00	0.83	3107	1865	4973	94.8%
1.25	1	3175	1906	5081	96.9%
1.50	1.16	3202	1936	5137	98.0%
1.75	1.33	3216	1967	5183	98.9%
2.00	1.49	3220	1995	5215	99.5%
2.25	1.66	3214	2019	5233	99.8%
2.50	1.82	3203	2040	5242	100.0%
2.75	1.99	3180	2063	5243	100.0%
3.00	2.15	3158	2079	5237	99.9%
3.25	2.32	3139	2095	5234	99.8%
3.50	2.49	3123	2102	5225	99.6%
3.75	2.65	3099	2103	5202	99.2%
4.00	2.82	3084	2103	5187	98.9%
4.50	3.15	3074	2097	5171	98.6%
5.00	3.48	3064	2096	5160	98.4%
5.50	3.81	3042	2108	5150	98.2%
6.00	4.14	3002	2127	5129	97.8%
6.50	4.47	2939	2143	5082	96.9%
7.00	4.8	2868	2162	5030	95.9%
8.00	5.46	2719	2214	4933	94.1%
9.00	6.12	2611	2263	4874	93.0%
10.00	6.79	2521	2322	4843	92.4%
12.00	8.11	2427	2421	4848	92.5%
14.00	9.43	2364	2515	4879	93.0%
20.00	13.4	2121	2758	4879	93.1%
28.00	18.69	1917	2847	4765	90.9%

Table G-8. WUA vs. Discharge for Steelhead and Coho Salmon Juvenile Rearing in Laguna Creek.

Simulated Flow	Steelhead WUA	Percent of Peak	Coho WUA	Percent of Peak
0.10	1474	21.6%	5088	80.9%
0.25	1721	25.2%	5401	85.9%
0.50	2060	30.2%	5687	90.4%
0.75	2358	34.5%	5861	93.2%
1.00	2628	38.5%	5990	95.3%
1.25	2870	42.0%	6087	96.8%
1.50	3086	45.2%	6166	98.1%
1.75	3283	48.1%	6220	98.9%
2.00	3460	50.7%	6245	99.3%
2.25	3625	53.1%	6267	99.7%
2.50	3776	55.3%	6279	99.9%
2.75	3910	57.3%	6284	100.0%
3.00	4037	59.1%	6287	100.0%
3.25	4157	60.9%	6280	99.9%
3.50	4269	62.5%	6267	99.7%
3.75	4374	64.1%	6239	99.2%
4.00	4474	65.5%	6204	98.7%
4.50	4662	68.3%	6130	97.5%
5.00	4841	70.9%	6052	96.3%
5.50	5002	73.3%	5967	94.9%
6.00	5150	75.4%	5883	93.6%
6.50	5284	77.4%	5805	92.3%
7.00	5406	79.2%	5732	91.2%
8.00	5613	82.2%	5596	89.0%
9.00	5785	84.7%	5443	86.6%
10.00	5944	87.1%	5267	83.8%
12.00	6190	90.7%	4899	77.9%
14.00	6385	93.5%	4603	73.2%
20.00	6717	98.4%	3908	62.2%
28.00	6828	100.0%	3411	54.3%

Table G-9. WUA vs. Discharge for Steelhead and Coho Salmon Juvenile Rearing in Majors Creek.

Simulated Flow	Steelhead WUA	Percent of Peak	Coho WUA	Percent of Peak
0.05	851	21.3%	3719	74.5%
0.25	1061	26.5%	4097	82.1%
0.50	1247	31.2%	4315	86.4%
0.75	1402	35.1%	4466	89.5%
1.00	1542	38.6%	4583	91.8%
1.25	1672	41.8%	4675	93.7%
1.50	1788	44.7%	4752	95.2%
1.75	1896	47.4%	4812	96.4%
2.00	1988	49.7%	4864	97.4%
2.25	2071	51.8%	4909	98.3%
2.50	2149	53.8%	4946	99.1%
2.75	2220	55.5%	4975	99.7%
3.00	2287	57.2%	4992	100.0%
3.50	2404	60.1%	4991	100.0%
4.00	2509	62.8%	4968	99.5%
4.50	2608	65.2%	4926	98.7%
5.00	2703	67.6%	4878	97.7%
5.50	2794	69.9%	4821	96.6%
6.00	2882	72.1%	4756	95.3%
6.50	2967	74.2%	4697	94.1%
7.00	3048	76.3%	4639	92.9%
7.50	3126	78.2%	4588	91.9%
8.00	3201	80.1%	4529	90.7%
9.00	3346	83.7%	4434	88.8%
10.00	3469	86.8%	4344	87.0%
12.00	3674	91.9%	4202	84.2%
14.00	3823	95.6%	4066	81.5%
16.00	3901	97.6%	3943	79.0%
18.00	3961	99.1%	3851	77.1%
20.00	3998	100.0%	3791	75.9%

Table G-10. WUA vs. Discharge for Steelhead and Coho Salmon Juvenile Rearing in the San Lorenzo River Downstream of Tait Street.

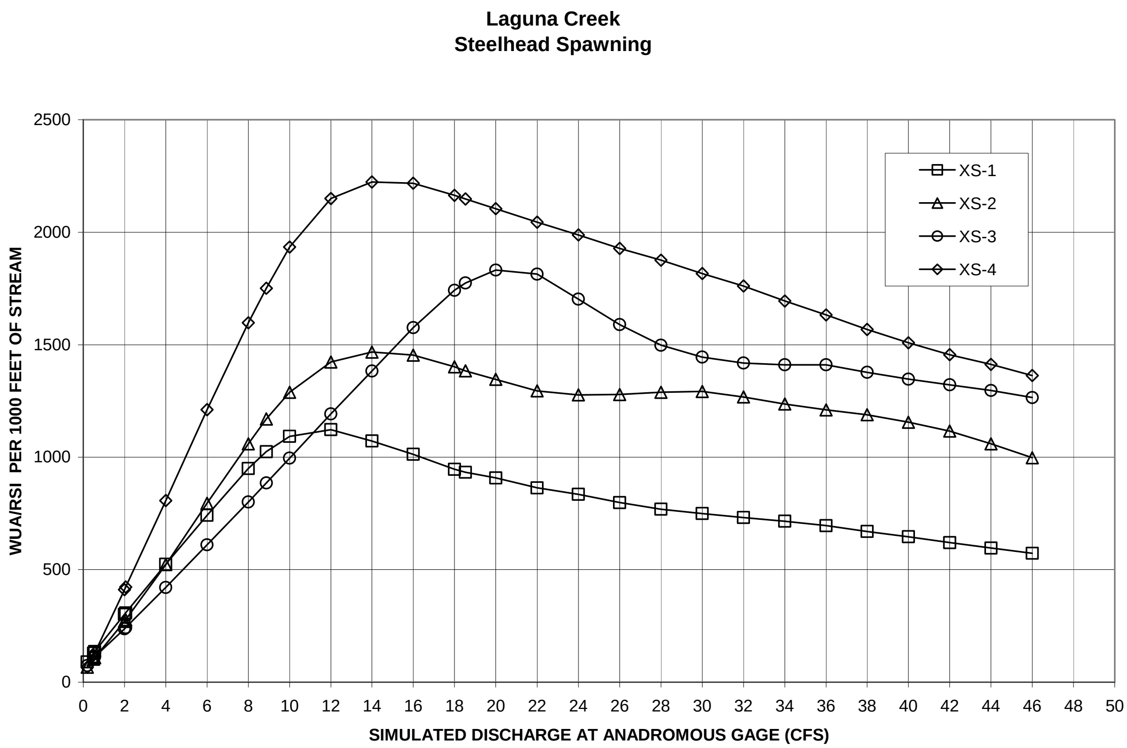
Simulated Flow	Steelhead WUA	Percent of Peak	Coho WUA	Percent of Peak
0	3220	23%	14691	89%
1	4122	29%	15340	93%
2	5024	35%	15990	97%
3	5821	41%	16280	99%
4	6506	46%	16432	100%
5	7108	50%	16490	100%
6	7636	54%	16461	100%
7	8118	57%	16373	99%
8	8558	60%	16289	99%
9	8947	63%	16210	98%
10	9295	66%	16120	98%
11	9604	68%	16034	97%
12	9892	70%	15945	97%
14	10400	73%	15771	96%
16	10828	76%	15596	95%
18	11215	79%	15436	94%
20	11570	82%	15286	93%
24	12201	86%	15031	91%
28	12735	90%	14833	90%
32	13191	93%	14613	89%
36	13538	95%	14376	87%
40	13803	97%	14126	86%
44	13996	99%	13894	84%
48	14107	99%	13677	83%
52	14110	99%	13503	82%
56	14101	99%	13355	81%
60	14125	100%	13227	80%
64	14166	100%	13123	80%
68	14184	100%	13044	79%
72	14169	100%	12992	79%

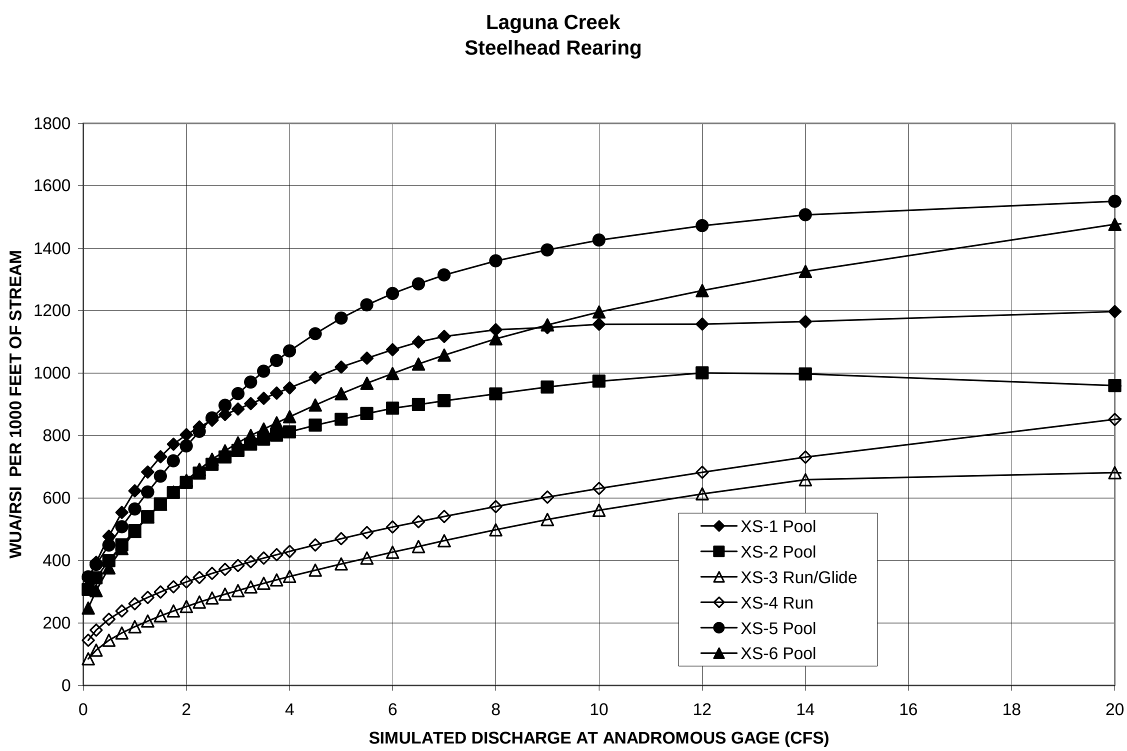
Table G-11. WUA vs. Discharge for Steelhead and Coho Salmon Rearing in Newell Creek.

Simulated Flow	Steelhead WUA	Percent of Peak	Coho WUA	Percent of Peak
0.10	2207	23.2%	8807	86.1%
0.20	2393	25.1%	9084	88.8%
0.30	2557	26.9%	9275	90.7%
0.40	2707	28.4%	9425	92.2%
0.50	2851	29.9%	9547	93.3%
0.60	2990	31.4%	9651	94.4%
0.70	3123	32.8%	9740	95.2%
0.80	3251	34.1%	9818	96.0%
0.90	3374	35.4%	9887	96.7%
1.00	3493	36.7%	9950	97.3%
1.50	4018	42.2%	10151	99.2%
2.00	4471	46.9%	10228	100.0%
3.00	5202	54.6%	10171	99.4%
4.00	5780	60.7%	10022	98.0%
5.00	6235	65.5%	9885	96.6%
6.00	6608	69.4%	9760	95.4%
7.00	6927	72.8%	9644	94.3%
8.00	7201	75.6%	9531	93.2%
9.00	7448	78.2%	9394	91.8%
10.00	7672	80.6%	9236	90.3%
12.00	8071	84.8%	8913	87.1%
14.00	8414	88.4%	8603	84.1%
16.00	8714	91.5%	8292	81.1%
18.00	8972	94.2%	8020	78.4%
20.00	9189	96.5%	7768	76.0%
22.00	9350	98.2%	7538	73.7%
24.00	9445	99.2%	7331	71.7%
26.00	9498	99.7%	7138	69.8%
28.00	9522	100.0%	6956	68.0%
30.00	9510	99.9%	6786	66.3%

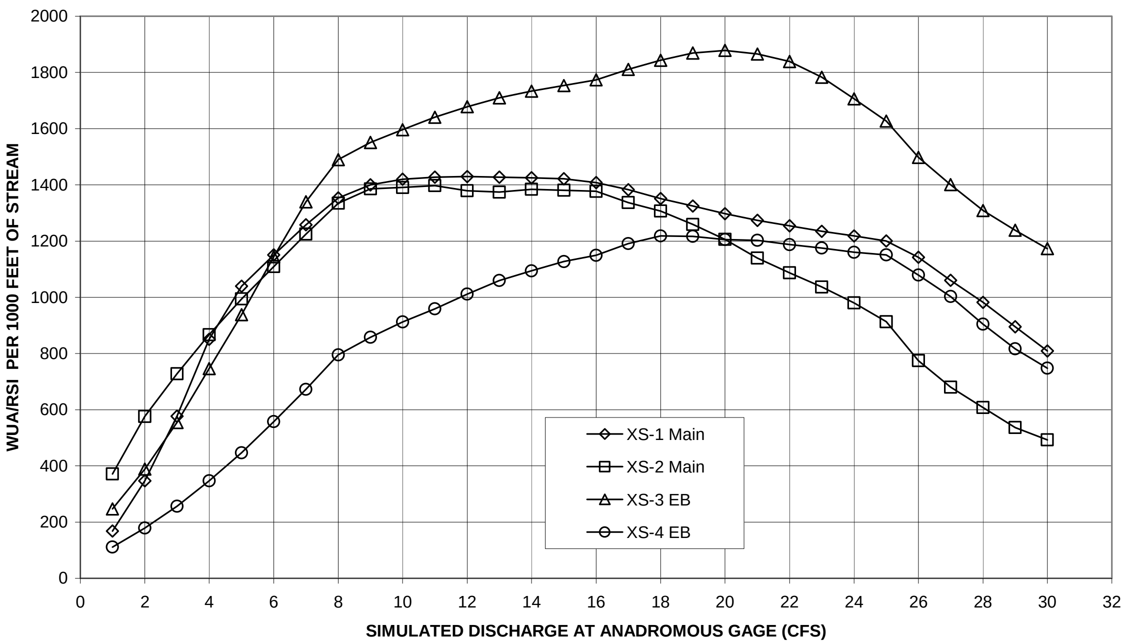
Appendix H

WUA vs. Discharge for Individual Study Transects

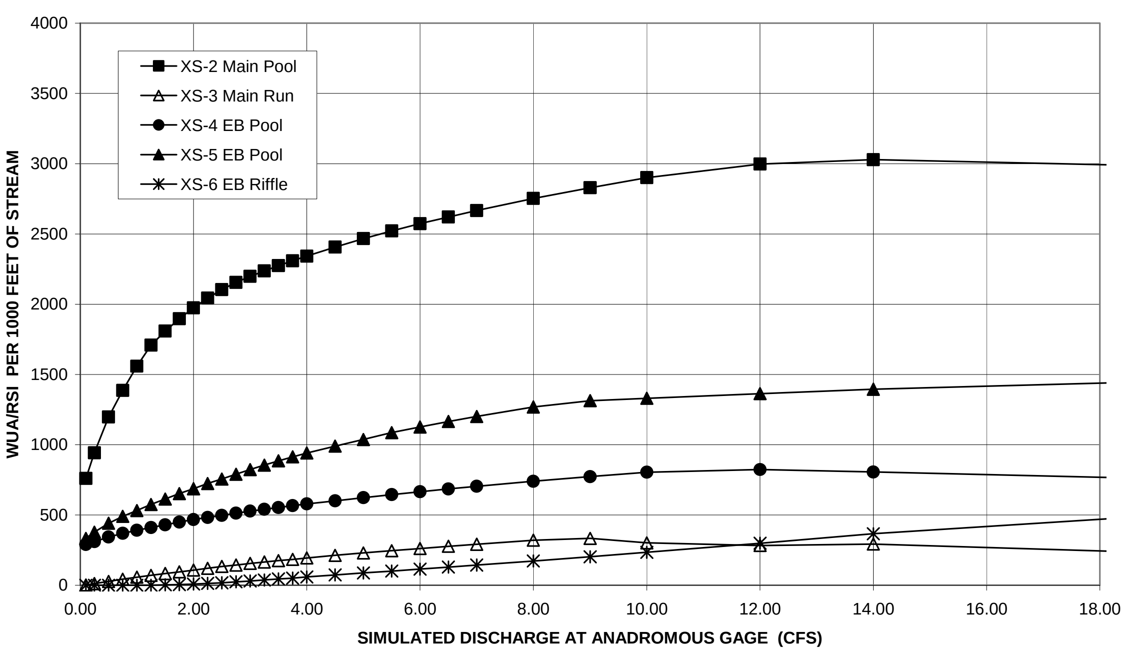

Laguna Creek
Steelhead Spawning
WUA/RSI PER 1000 FEET OF STREAM
SIMULATED DISCHARGE AT ANADROMOUS GAGE (CFS)
XS-1
XS-2
XS-3
XS-4
0
500
1000
1500
2000
2500
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50


Laguna Creek
Steelhead Rearing
WUA/RSI PER 1000 FEET OF STREAM
SIMULATED DISCHARGE AT ANADROMOUS GAGE (CFS)
XS-1 Pool
XS-2 Pool
XS-3 Run/Glide
XS-4 Run
XS-5 Pool
XS-6 Pool
0
200
400
600
800
1000
1200
1400
1600
1800
0 2 4 6 8 10 12 14 16 18 20

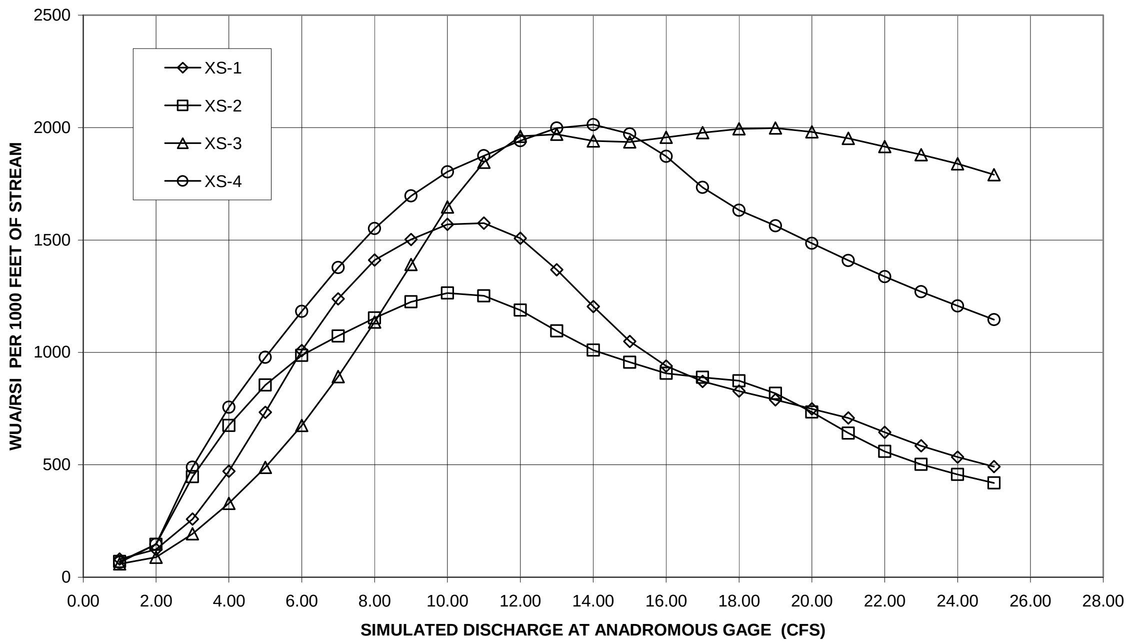
Liddell Creek
Steelhead Spawning



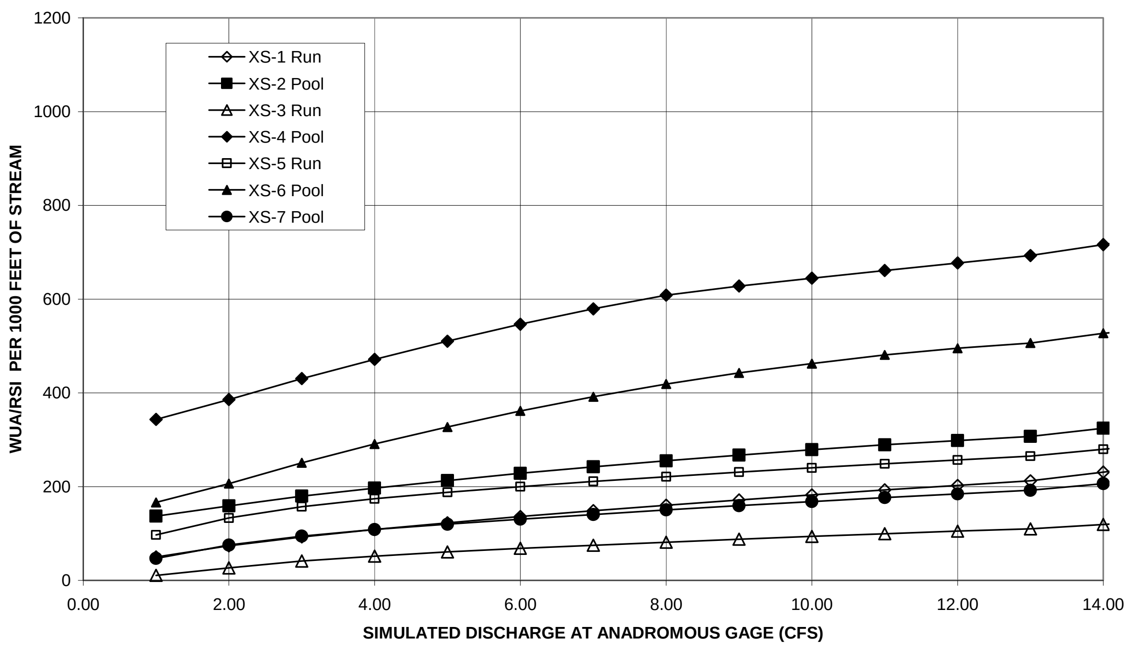
Liddell Creek
Steelhead Rearing



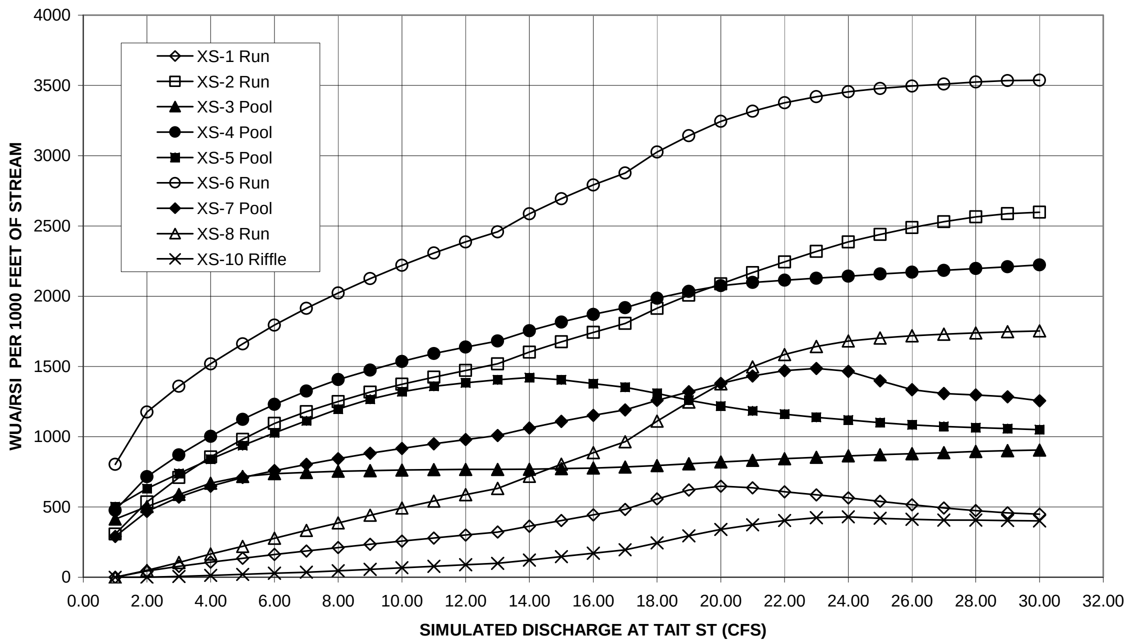
Majors Creek
Steelhead Spawning

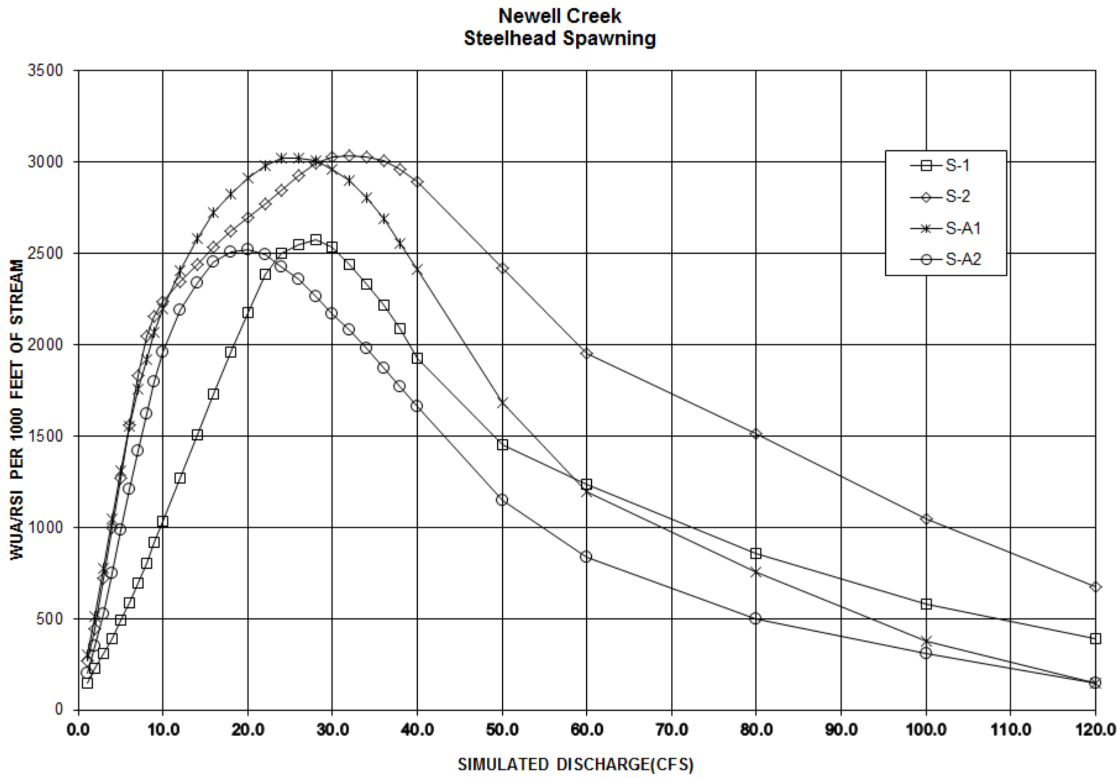


Majors Creek
Steelhead Rearing

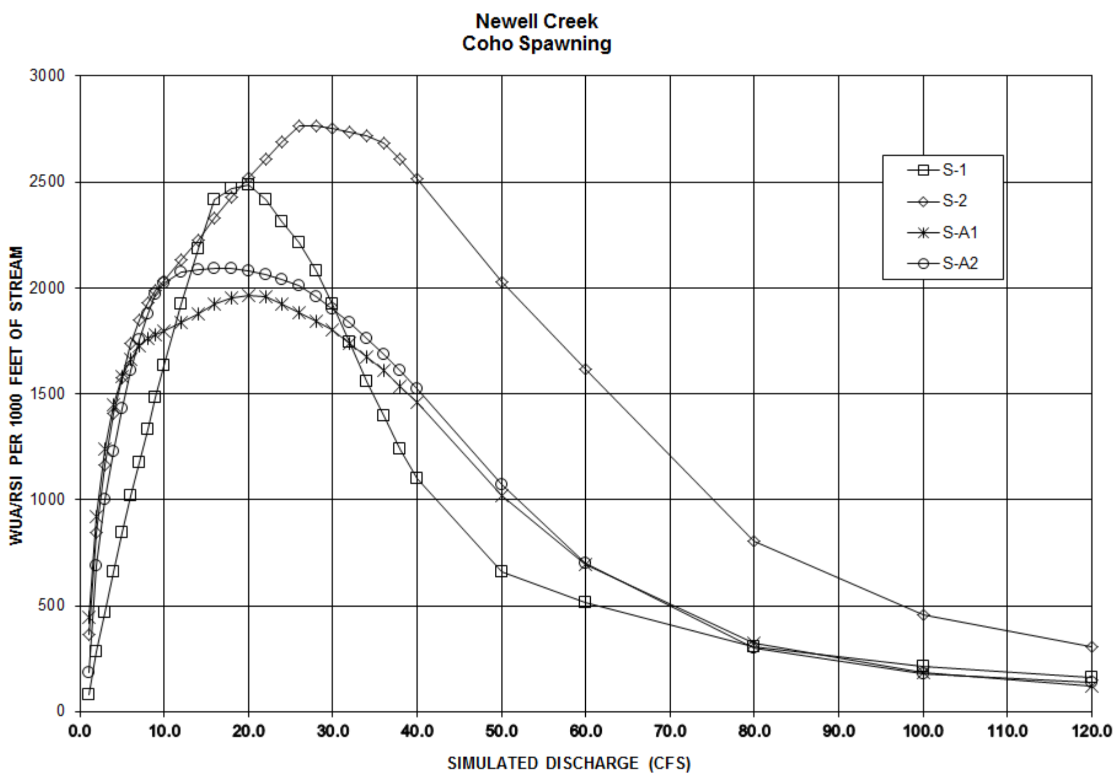


San Lorenzo River Downstream of Tait Street Diversion
Steelhead Rearing



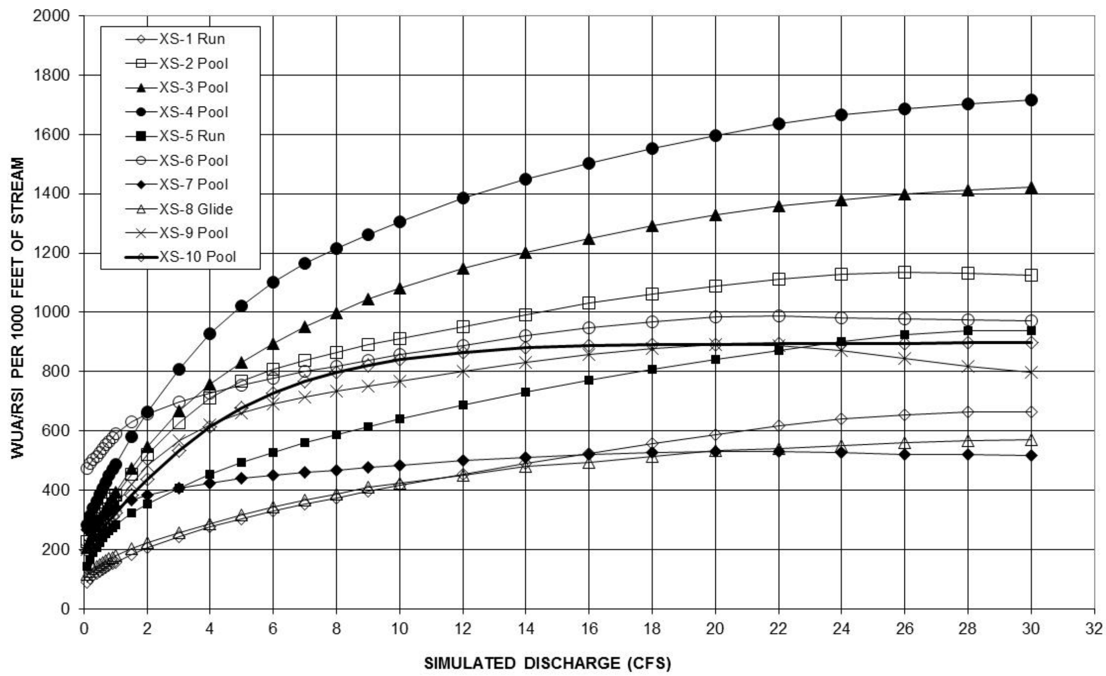


Newell Creek
Steelhead Spawning
WUA/RSI PER 1000 FEET OF STREAM
SIMULATED DISCHARGE(CFS)
S-1
S-2
S-A1
S-A2
0
500
1000
1500
2000
2500
3000
3500
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0



Newell Creek
Coho Spawning
WUA/RSI PER 1000 FEET OF STREAM
SIMULATED DISCHARGE (CFS)
S-1
S-2
S-A1
S-A2
0
500
1000
1500
2000
2500
3000
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0

Newell Creek
Steelhead Rearing



Newell Creek
Coho Rearing