TECHNICAL MEMORANDUM

STREAMFLOW THRESHOLDS FOR JUVENILE SALMONID REARING HABITAT IN THE MATTOLE HEADWATERS SOUTHERN SUB-BASIN

March 31, 2012

PREPARED FOR:

TROUT UNLIMITED CALIFORNIA CHAPTER

PREPARED BY:

MCBAIN & TRUSH, INC.

TABLE OF CONTENTS PAGE

1 INTRODUCTION

In a Mediterranean climate, summers are hot and dry. Baseflows in even large rivers such as the Mattole River can recede to intermittent surface streamflows by mid-summer in drier years. We define the Summer Doldrums as the one to two-and-a-half month period (depending on water year type) of very low seasonal baseflows occurring in almost all summers on the Mattole Headwaters. A juvenile steelhead's goal during the Summer Doldrums is to survive it, and if fortunate, to minimize weight loss and remain healthy. If a juvenile survives, it can rear through the winter and migrate to the Pacific Ocean as a pre-smolt or smolt the following spring.

For a steelhead, the chance of returning as a spawning adult is very much a function of its smolt size upon entering the Pacific Ocean. But Mattole lower mainstem and estuarine rearing habitats have been significantly degraded (MRRP 2009). Steelhead juveniles cannot rely on additional growth during their pre-smolt and smolt outmigration, as they once did throughout the Mattole's lower mainstem and estuary, to significantly improve their chances of returning as adults. The Mattole Headwaters, and particularly its Southern Sub-Basin (Figure 1), maintains the coolest summer temperatures in the watershed (NMFS 2012), making it the best candidate for sustaining juveniles through the Summer Doldrums and subsequently growing large smolts (> 170 mm Fork Length) by the following spring. Maintaining this key life history tactic is essential, because recovery of the mainstem Mattole River and Estuary is going to take time.

The transition from productive to stressful rearing habitat conditions through the summer was a common and natural occurrence when the Mattole watershed was unimpaired, but it could now be occurring earlier, more intensely, and more frequently as a result of a cumulative effect from multiple streamflow diversions. Small individual diversions that might appear inconsequential in winter and spring, or even early summer in wetter years, cumulatively can become highly consequential mid-summer through early-fall. To improve streamflows during receding summer baseflows, but particularly during the highly stressful Summer Doldrums, Trout Unlimited and the Center for Ecosystem Management and Restoration (TU/CEMAR) have partnered with the Mattole River's Sanctuary Forest and local non-residential water users to increase winter water storage as an alternative to direct summertime diversions. TU and CEMAR are assisting Sanctuary Forest with: (1) their ongoing residential tanks program, (2) investigating options for water recharge projects, and (3) developing a long-term Water Diversion and Streamflow Protection Plan for local water users, which includes this instream flow needs (IFN) study.

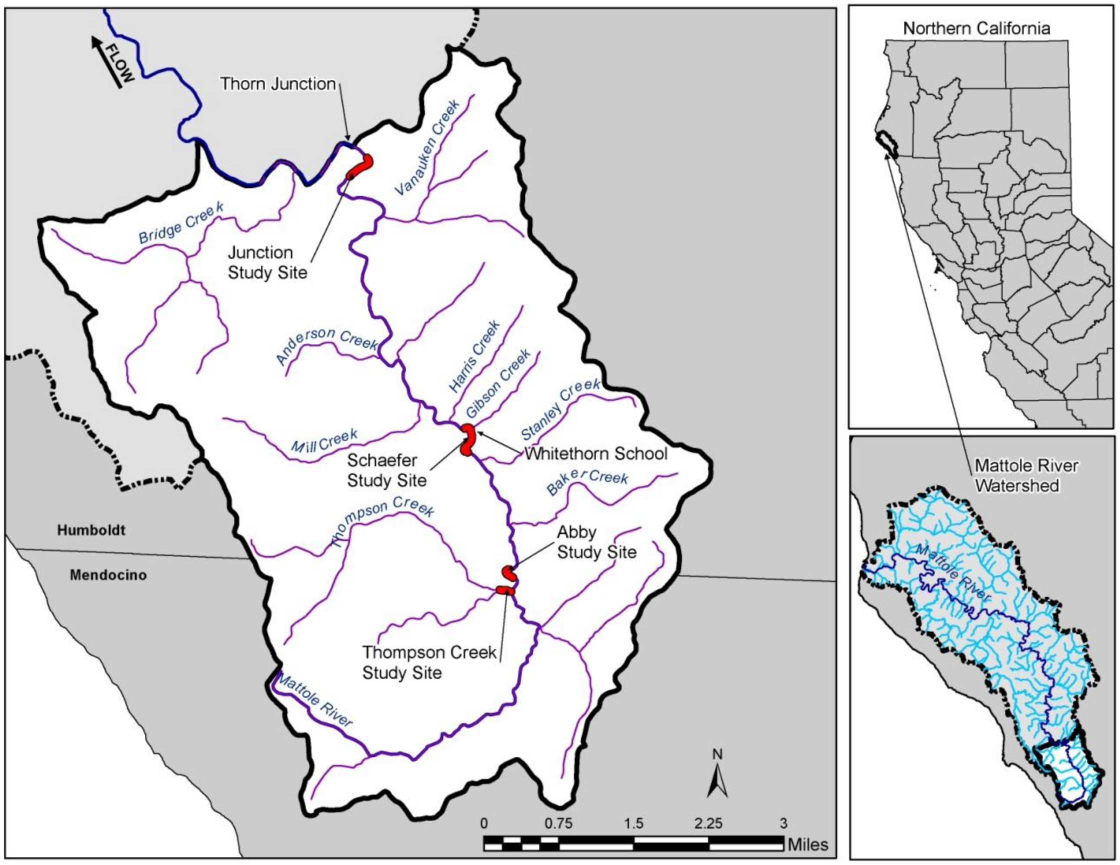

Figure 1. The Mattole Headwaters Southern Sub-Basin (Downie et al. 2003).

2 STUDY GOALS

In an instream flow (ISF) study the term "threshold" is used to imply a significant, abrupt change in habitat or ecological function as a direct response to a small change in streamflow. Our primary study goal was to identify the instream flow threshold for the Summer Doldrums in the Mattole Headwaters. Streamflows less than this low-flow threshold will be highly stressful and will result in poor to negative growth, higher risks from disease, predation, shrinking habitat area, and heightened competition for limited food. Extended durations with streamflows below the Summer Doldrums threshold will substantially decrease chances of a juvenile salmonid surviving the summer. But survival through the Doldrums will also depend on a juvenile's condition and health upon entering the Doldrums. Cumulative diversions during receding baseflows leading up to the Doldrums, could still degrade juvenile steelhead rearing habitat and lower overall stream productivity. From a management perspective, cumulative diversions during the Doldrums could be curtailed, but juvenile steelhead success would still be compromised if cumulative diversions preceding the Doldrums were significant. A secondary study goal, therefore, was to identify streamflow thresholds higher than the summer doldrums, but below which diversions would likely affect juveniles chances of surviving the Summer Doldrums. Also, recession streamflows may begin when adult steelhead are still spawning, particularly in drier water years. A third study goal, therefore, was to estimate streamflow thresholds for spawning habitat availability.

Collectively, these streamflow thresholds will be necessary in developing a cumulative diversion strategy for the Mattole Southern Sub-Basin that will be accepted by the State Water Resources Control Board and state/federal resource agencies.

Study Goal No. 1 - Estimate the instream flow threshold for the Summer Doldrums in the Mattole Headwaters.

Study Goal No. 2 – Estimate instream flow thresholds below which diversions would likely affect a juveniles chances of surviving the Summer Doldrums in the Mattole Headwaters..

Study Goal No. 3 – Estimate streamflow thresholds for adult steelhead spawning habitat availability in the Mattole Headwaters..

3 ANALYTICAL FRAMEWORK

3.1 Streamflow Thresholds for Smolt and Juvenile Salmonid Habitat

To meet Study Goals No.1 and No. 2, three temporal phases of juvenile salmonid rearing and growth are identified during the spring recession hydrograph: (1) highly productive, (2) maintenance, and (3) survival. From mid-March to mid-May, juvenile salmonids and pre-smolts/smolts need to grow rapidly when riffle habitat with high benthic macroinvertebrate productivity (BMI) is abundant, low water temperatures favor growth of fish and macroinvertebrates, and physical rearing habitat is abundant and diverse. From early June through mid-July (depending on the water year (WY) type), juvenile salmonids must at least maintain their weight and health as riffles shift from being productive to simply maintaining BMI biomass, water temperatures are less than that desired for rapid growth, and rearing habitat begins to be confined to pools/runs because riffles are becoming too shallow and losing complexity. Finally, beginning late July to late August (again, depending on the WY type) and lasting through early October, resident juveniles must survive the considerably more adverse conditions of the Summer Doldrums. During the Summer Doldrums streamflows through the riffles can go sub-surface, effectively isolating pools with no chance of escape, resulting in shrinking habitat area, scarce prey, and higher water temperatures that demand even greater food consumption to maintain weight. Some mainstem segments may dry up entirely.

To meet Study Goals No. 1 and No. 2, three streamflow thresholds corresponding to the three juvenile rearing phases were identified for steelhead juvenile and smolt rearing conditions: EXCELLENT, GOOD, and FAIR. Daily average streamflows dropping below the FAIR threshold were considered the Summer Doldrums. A fourth streamflow threshold, CONNECTIVITY, identified when very low baseflows within the Summer Doldrums became intermittent.

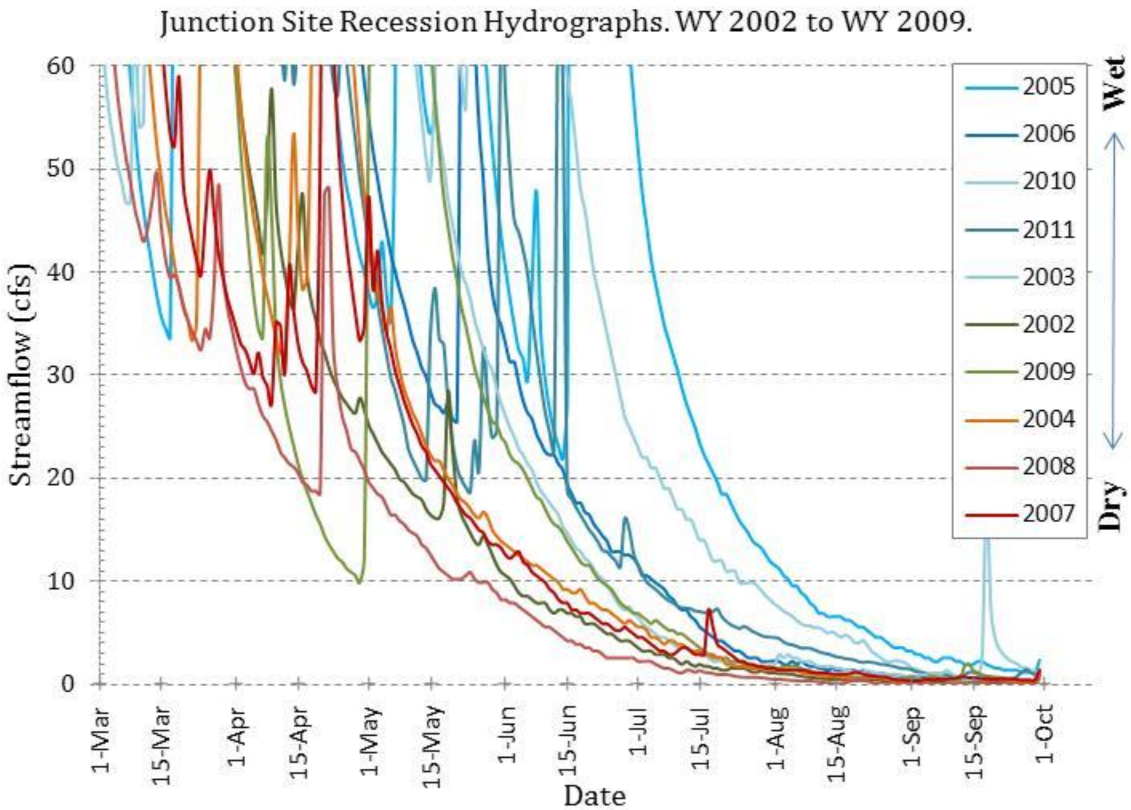

Figure 2 Modeled impaired annual hydrographs showing spring/summer recession at Junction Study Site in Mattole Headwaters. Streamflow modeled by CEMAR (for a discussion of flow modeling assumptions see Section 5.1)

3.2 **Hydraulic Units are Basic Habitat Units**

In this study streamflow thresholds were first identified in individual hydraulic units, and then for a study site. An hydraulic unit (HU) is the basic bar-pool morphology typical of alluvial and depositional streams (Dietrich, 1987). Although bedrock hydraulic controls are prominent in the Mattole Headwaters, this depositional bar-pool sequence is expressed throughout our study sites. Hydraulic units are naturally delineated by an upstream and a downstream riffle crest. Often, HUs correspond to the meander of the thalweg, beginning where the thalweg crosses from one side of the channel to the other and lasting to the next cross-over downstream.

Each hydraulic unit contains an upstream riffle or cascade, and a downstream pool or run. In traditional mesohabitat typing, the riffles/cascades are inventoried and assessed separately from the pools and from the runs. But juveniles or smolts in a pool are significantly affected by the extent and quality of the riffle/cascade/waterfall immediately upstream. Therefore we use these naturally delineated hydraulic units as analytical segments to address the transition from good to poor habitat conditions longitudinally through a reach. For a smolt migrating to the sea, the ideal environment would be to encounter one hydraulic unit after another excelling at meeting all its needs. For an individual over-summering juvenile steelhead, the sequence may not be as important. But the better an entire sequence of hydraulic units collectively performs at rearing juveniles, the greater the number and size of smolts likely to be produced.

Instream flow thresholds for juvenile rearing and adult steelhead spawning were identified in each hydraulic unit. Four parameters were used to rate the hydraulic units as EXCELLENT, GOOD, or FAIR for juveniles salmonid rearing conditions in each hydraulic unit: (1) rearing habitat abundance and (2) quality, (3) BMI habitat productivity, and (4) connectivity via the riffles (upstream and downstream) to adjacent hydraulic units.

3.3 The IFN Assessment Strategy behind Hydraulic Habitat Thresholds

Hydraulic Habitat Thresholds (HHTs) were used identify instream flow thresholds for each of the four parameters of juvenile rearing conditions. Like traditional PHABSIM, HHTs rely on a small set of physical variables to quantify habitat for a given species and life-stage. Both PHABSIM and HHTs employ suitability criteria to quantify habitat abundance. However, in an HHT study, the relationships between streamflow and suitability criteria are quantified at specific, ecologically relevant locations and/or cross-sections within each hydraulic unit. By linking the relationship between streamflow and habitat suitability to a sequence of ecologically relevant locations, multiple HHTs can 'work together' to indicate thresholds in ecological processes, as well as habitat abundance and quality. An HHT, therefore, is a threshold streamflow, identified using physical criteria at a location indicative of the habitat or process being addressed.

For example, benthic macroinvertebrate (BMI) productivity in riffles is an important food source for growing juvenile steelhead and smolts. Measurement of BMI productivity in one or a few riffles over a range of baseflows could take years. A more direct approach (relative to juvenile salmonid needs) would be the measurement of BMI drift. But even this would be difficult to accomplish. An HHT approach would be to define productive BMI habitat using physical thresholds identified at a riffle cross-section that provides BMI habitat. Thresholds for: streamflow depth inundating the coarse substrate, mean column velocity, minimum duration of inundation, and a desirable temperature range are all required to quantify whether a riffle is productive BMI habitat. If the threshold criteria for all five variables are met, the riffle at that streamflow could support a highly productive BMI community. Measurement of depth, velocity, and inundation duration at a representative point(s) or better, along a cross section in the riffle, can be interpreted as a measure of productive BMI habitat. Many riffles can be monitored in this fashion to discern broad relationships between streamflow and BMI riffle habitat and to estimate important streamflow thresholds relevant to rearing smolts and juvenile salmonids.

No two hydraulic units provide the same amount or quality of salmonid habitat for the same streamflow and, therefore, each has unique habitat streamflow thresholds . Using HHTs juvenile rearing parameters for: habitat abundance, quality, and BMI productivity, were ranked as EXCELLENT, GOOD, or FAIR for each hydraulic unit at every observed streamflow. This process produces a mosaic of habitat conditions throughout a study site. However, to identify a single flow threshold for the study site a further, composite analysis was required. To accomplish this each HU also received a ranking of EXCELLENT, GOOD, or FAIR based on the habitat parameters within that unit. The lowest ranked habitat parameter in a hydraulic unit determines the HU's rank at any given streamflow. For example: HU-1 at 8 cfs has GOOD habitat abundance and quality but only FAIR BMI productivity– therefore HU-1 is ranked as FAIR at 8cfs. Using this ranking system, each study site was then assessed as a sequence of hydraulic units with varying thresholds. This process was termed the continuity assessment (Continuity Assessment 6.3).

The continuity assessment makes it easier to see instream flow thresholds for a study site. However some degree of professional judgment is still required. For example, is it necessary for every HU in a study site to provide FAIR or better habitat conditions for the site to be rated as FAIR? A single hydraulic unit with abnormally high thresholds shouldn't necessarily dictate the instream flow thresholds for the entire study site. To address this issue we used the sequences of ranked hydraulic units and our knowledge of the stream to create narrow 'bands' of streamflow where thresholds are met at each study site. For a discrete threshold the middle value of each band can be used.

4 STUDY SITES

The study area corresponded to the CDFG Mattole Watershed Assessment "Southern Sub-Basin" (Downie et al. 2002, Figure 1) with a drainage area of 29.5 mi^2 (including McKee Creek, entering the mainstem just upstream of Bridge Creek). Four reaches were assessed along 6.5 miles of the Mattole River mainstem upstream of Thorn Junction (Figure 1).The reach selections (3 mainstem and 1 tributary) established upper and lower boundaries to the Mattole Headwaters Southern Sub-Basin with known gaining and losing mainstem reaches. Each study site included 5 to 7 hydraulic units (Section 5.1).

The study reaches were:

Junction Study Site
The mainstem Junction Study Site starts approximately 1200 ft upstream from the confluence of Mckee Creek and the Mattole River, just south of Thorn Junction (Figure 1). There is a box car bridge and access to Rd A, at the downstream end of Junction Study Site. This mainstem study site continues 1560 ft upstream and has a sequence of seven hydraulic units.

Schaefer Study Site
The mainstem Schaefer Study Site starts approximately 300 ft downstream from the confluence of Gibson Creek and the Mattole River (Figure 1). Schaefer Bridge, at the downstream end of the site, can be accessed approximately ¼ mile north of Whitethorn Elementary School. The Schaefer Study Site continues 1830 upstream and has a sequence of eight hydraulic units. During summer this reach often experiences losing streamflow.

Abbey Study Site
The mainstem Abbey Study Site starts approximately 950 ft upstream of the entrance to Our Lady of the Redwoods Abbey and 1700 ft downstream from Thompson Creek. The Abbey Study Site continues upstream 700 ft and ends below the Abbey's storage buildings.

Thompson Creek Study Site

The Thompson Creek Study Site begins at its confluence with the mainstem Mattole River and extends 600ft upstream to the Abbey's water diversion. Thompson Creek watershed is 3.7 mi^2. and the Mattole River Sub-Basin upstream of Thompson Creek has a drainage area of 5.8 mi^2.This confluence changes the mainstem's downstream stream order from 3 to 4. Our Lady of the Redwoods Abbey is located between the Thompson Creek Study Site and the Abbey Study Site.

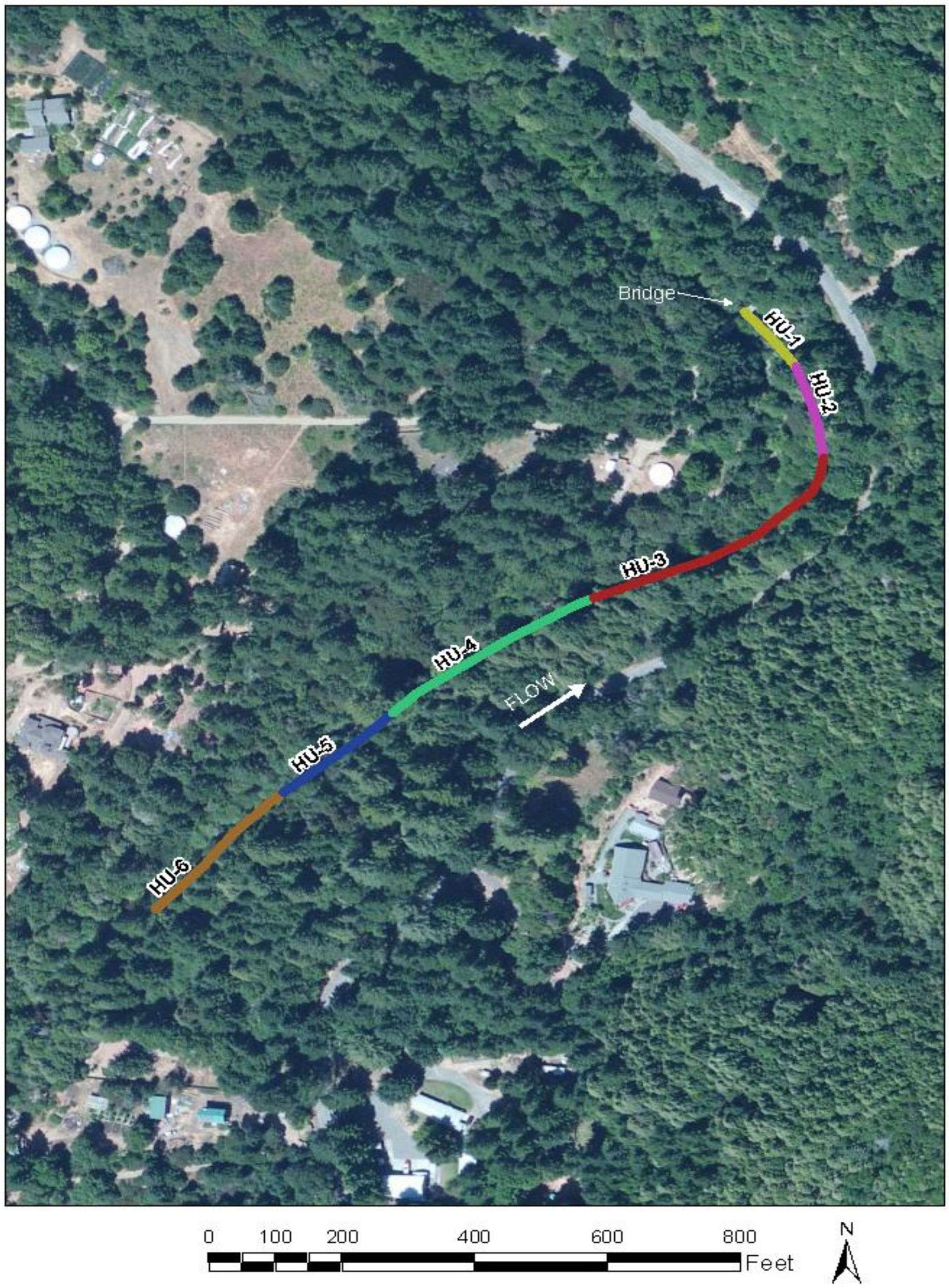

Figure 3. Junction Study Site and designated hydraulic units (HU).

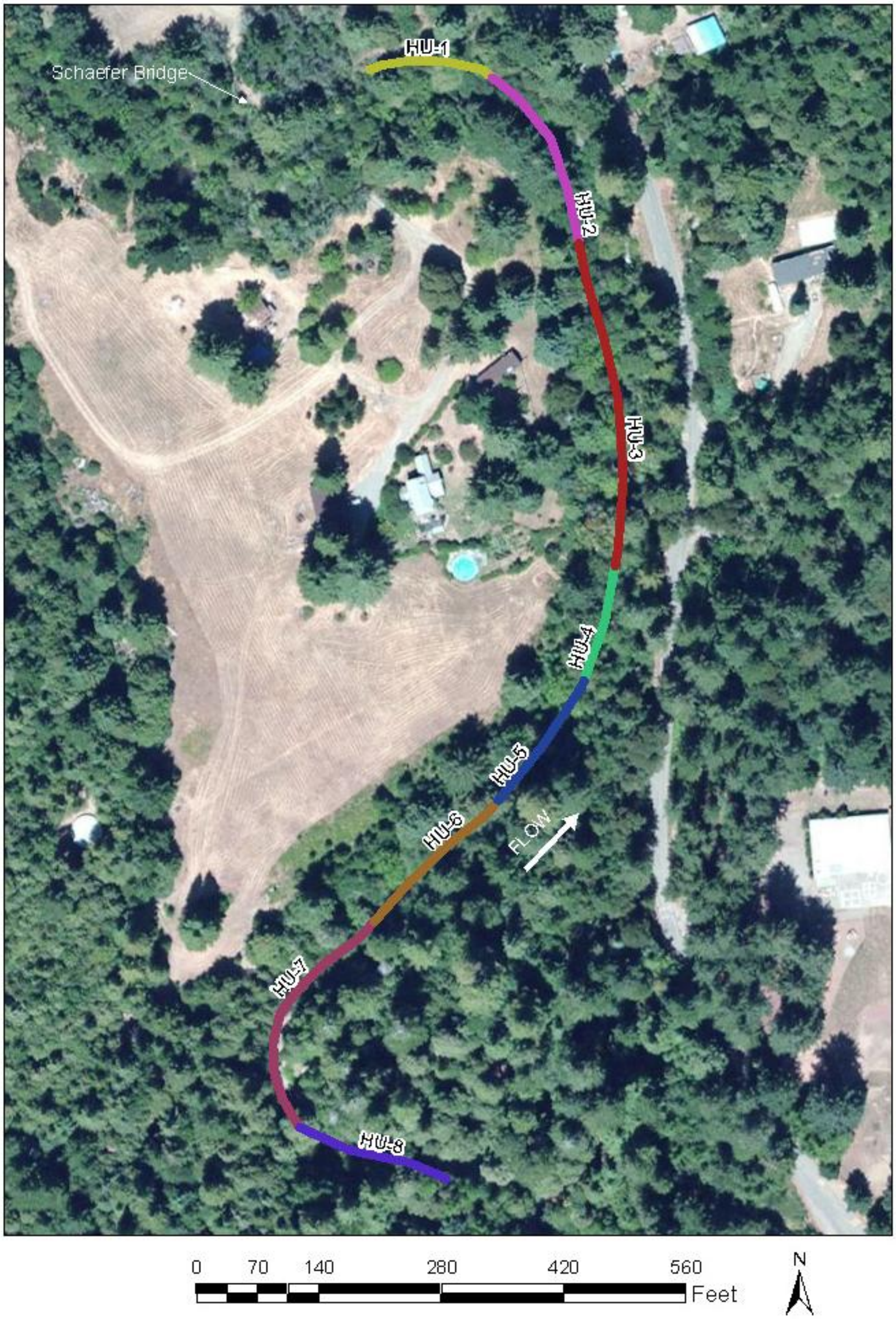

Figure 4. Schaefer Study Site and designated hydraulic units.

Figure 5. Abbey Study Site and Thompson Creek Study Site with designated hydraulic units.

5 METHODS

5.1 Streamflow Data

One of TU's principal goals for the Water Diversion and Streamflow Protection Plan is to identify how often the flow thresholds associated with particular ecological processes or functions are exceeded at each study site over a long-term period. Quantifying the number of days the specific instream flow thresholds were met in a given water year is beyond the scope of this ISF study, however, a series of annual hydrographs were used to provide a visual representation showing the periodicity of flow thresholds in different water years. CEMAR provided the flow data for this effort. Because no long-term streamflow records exist for the upper Mattole watershed, flow data for this analysis were scaled from a USGS the Mattole River at Ettersburg USGS streamflow gauge (11468900) for the period of Ettersburg gauge operation (June 2002 – October 2011) based on a series of empirical relationships between Ettersburg streamflow data and streamflow measurements at each site in 2010 and 2011. The upper Mattole watershed comprises approximately one-third of the total catchment area upstream of the Ettersburg streamflow gauge.

Data measured at Thorn Junction and Ettersburg indicate that streamflow is approximately proportional according to a ratio of catchment area through winter, but not in spring and summer. National Park Service hydrologist Randy Klein (author of Sanctuary Forest's 2004, 2007, and 2011 Hydrologic Assessments of Low Flows in the Mattole River Basin) derived statistical linear relationships between measurements made by Sanctuary Forest in 2010 at their Thorn Junction site (named Mainstem-6, or MS6) and USGS-recorded streamflow at the same time at the Ettersburg gauge (Klein, Unpublished). Klein's results were applicable for streamflow at Ettersburg below 50 ft^3/s (corresponding to approximately 14 ft^3/s at MS6). These relationships were used to estimate streamflow at MS6 when streamflow was less than 50 ft^3/s at Ettersburg during the period 2002 – 2009.

To estimate data at MS6 when streamflow at Ettersburg was greater than 50 ft^3/s, CEMAR derived a statistical linear relationship between streamflow data collected by CEMAR at MS6 and USGS streamflow at Ettersburg, in water years 2010 and 2011 (CEMAR operated a streamflow gauge at MS6 in 2010 and 2011). This linear relationship was used to estimate streamflow above 50 ft^3/s at MS6 during the period 2002 – 2009. CEMAR's streamflow data from 2010 and 2011 were used for all 2010 and 2011 analyses.

This MS6 data set from 2002 – 2011 was used to estimate streamflow at upstream habitat study sites using similar methods. Streamflow was measured at MS6 and habitat sites (Mattole River at Shaefer Bridge, Mattole River below Thompson Creek, and Thompson Creek) periodically during summer and fall 2011; these empirical measurements were used to derive statistical relationships between streamflow at MS6 and other upstream sites. Once these relationships were derived, they were used to estimate streamflow at each site during the entire period WY 2002 to WY 2011.

5.2 Applying Hydraulic Habitat Thresholds

As described in section 3.3, Hydraulic Habitat Thresholds (HHTs) were used to rate juvenile habitat conditions as EXCELLENT, GOOD, or FAIR in each hydraulic unit. Five primary monitoring locations and a minimum of one cross section were used to identify flow thresholds for HHTs, Figure 6. In addition 0-5 monumented pins were placed in each hydraulic unit at selected juvenile rearing locations to supplement observations from the primary HHTs. Physical suitability criteria were established for each HHT monitoring location to identify flow thresholds (Table **2**), although, often multiple HHTs were used collectively to identify a specific threshold (Table 3). Our analytical method for this study was to use physical criteria at each HHT to develop instream flow thresholds for each hydraulic unit, and through a continuity assessment (Section 3.3) use the individual HU thresholds to identify reach based thresholds for each study site. In order to meet stated goals, three parameters of habitat were considered: abundance, quality and BMI productivity. These parameters were assessed at every hydraulic unit within each of the four study sites. Habitat parameters were assessed based on HHTs at one or more locations within a Hydraulic unit (Table 3). To meet Study Goal No. 3 spawning preference criteria were applied to HHTs in the pool ramp (tail) and RCT (See Section 5.4).

The thresholds identified in Table 2 (and Table 3) were compiled from a combination of literature values and our professional judgment based on observations of juvenile rearing over 20+ years of study. Section 5.2.1 through 5.2.3 provide a brief description of our basis for using specific HHTs to identify thresholds in juvenile salmonid habitat abundance, quality, and BMI productivity.

5.2.1 Abundance

HHTs do not directly quantify habitat abundance (ft^2 of habitat), but they can identify a flow threshold were habitat is available across the majority of a hydraulic unit. In this ISF study we identify this threshold using the Pool Maximum Depth (PM) location (Table 1, Table 3). During low flow conditions, water velocity is high over riffles and low through pools. In the absence of eddies created by large wood or boulders, the deepest point of the channel thalweg (PM) generally is associated with the slowest velocity through the pool or run. When minimum velocity criteria for juvenile rearing are met at the PM location, we observe that velocities throughout the pool or run generally exceed these minimum criteria. For this study, streamflows where PM velocity was less than 0.2 fps were considered to produce minimal habitat conditions for rearing juvenile salmonids in a given hydraulic unit. The threshold of 0.2 fps was used because it represents minimum preference criteria for small juvenile steelhead (Everest and Chapman, 1972).

5.1.2.1 <u>Hydraulic Unit Connectivity</u>

Connectivity is also a critical parameter of juvenile habitat abundance. Streamflows where juveniles cannot easily migrate between hydraulic units indicate a change in feeding behavior and an increase in risk of predation. Streamflows were RCT depth was less than 0.15 ft, were considered the minimum acceptable flow that could still support juvenile connectivity. This connectivity threshold targeted ecological processes being lost, rather than the absence of surface flow through a riffle. At a 0.15 ft RCT depth, juveniles are not free to migrate between pools, and could not if they needed to in many locations. In addition BMI riffle habitat is too de-watered to provide drift to the run or pool downstream. Rather than being physically isolated at an RCT depth of 0.15 ft, the pools become functionally isolated.

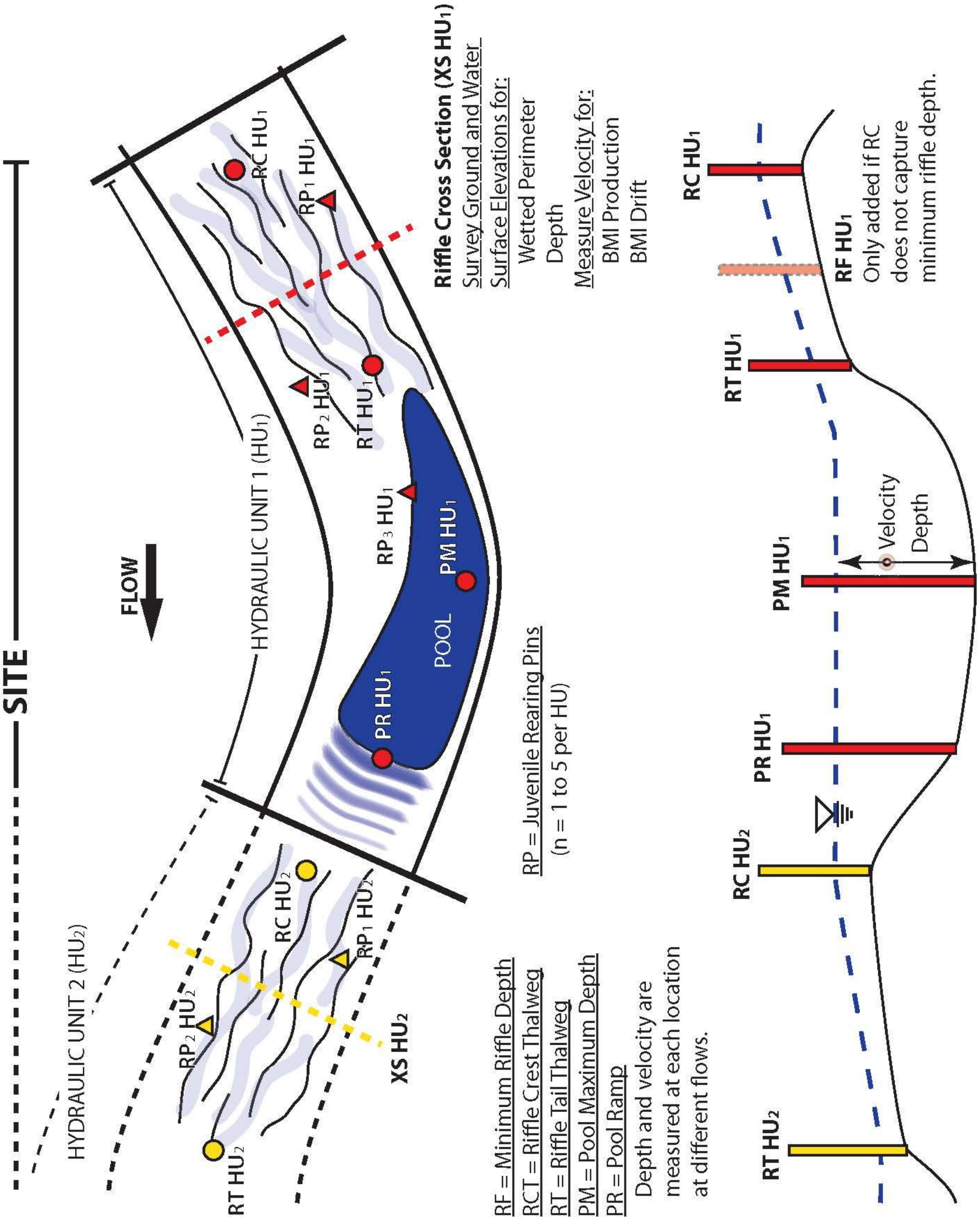

Figure 6 Schematic of a hydraulic unit showing the core and supplementary Hydraulic Habitat Thresholds (HHTs)

Table 1. Physical habitats and HHT monitoring locations.

Physical Habitat	Habitat Monitoring Locations	Abbreviation	Monitoring Method
Juvenile Riffle Rearing	Riffle Crest Thalweg	RCT	Single Point
	Riffle Tail	RT	Single Point
	Riffle Minimum Depth	RF min	Multiple Points
Juvenile Pool Rearing	Pool	PM	Single Point
	Pool Ramp	PR	Single Point
Adult Steelhead Spawning	Riffle Crest Thalweg	RCT	Single Point
	Pool Ramp	PR	Single Point
Benthic Macroinvertebrate	BMI Riffle Cross-Section	BMI XS	% of Active Channel Width at XS

Table 2. HHT criteria for juvenile steelhead rearing habitat and BMI productivity. These thresholds are used to meet Study Goals No.1 and No. 2.

Rating	**Riffle Crest Thalweg**	**Riffle Connectivity**	**Riffle Tail**	**Pool Maximum Depth**	**Pool/Run Ramp**	**BMI Cross-Section**
EXCELLENT	Velocity > 1.5 fps	Depth > 0.15 ft	Velocity > 1.5 fps	Velocity > 0.5 fps	Velocity > 1.0 fps	80% > 0.5 fps & 50 % > 1.5 fps
GOOD	Velocity > 1.0 fps	Depth > 0.15 ft	Velocity > 1.0 fps	Velocity > 0.3 fps	Velocity > 0.5 fps	50% > 0.5 fps & 30 % > 1.5 fps
FAIR	Velocity > 0.5 fps & Depth > 0.15 ft	Depth > 0.15 ft	Velocity > 0.5 fps	Velocity > 0.2 fps	Velocity > 0.3 fps	10% > 0.5 fps
POOR	Velocity < 0.5 fps & Depth < 0.15 ft	Depth < 0.15 ft	Velocity < 0.5 fps	Velocity < 0.2 fps	Velocity < 0.3 fps	Less than 10% > 0.5 fps

Table 3. This table contains the same data as Table 2, but it is reorganized to show which monitoring locations are associated with each habitat parameter assessed for juvenile salmonids.

Rating	**Habitat Abundance**		**Habitat Quality**		**Productive BMI Riffle Habitat**
	Pool Max Depth	**Connectivity**	**RCT**	**Riffle Tail**	**BMI**
Excellent Juvenile Rearing Habitat	V > 0.5 fps	D > 0.15 ft	V > 1.5 fps	V > 1.5 fps	80% > 0.5 fps 50 % > 1.5 fps
Good Juvenile Rearing Habitat	V > 0.3 fps	D > 0.15 ft	V > 1.0 fps	V > 1.0 fps	50% > 0.5 fps 30 % > 1.5 fps
Fair Juvenile Rearing Habitat	V> 0.2 fps	D > 0.15 ft	V > 0.5 fps	V > 0.5 fps	10% > 0.5 fps
Poor Habitat And Productivity	V < 0.2 fps	D < 0.15 ft	V < 0.5 fps	V < 0.5 fps	Less than 10% > 0.5 fps

5.2.2 Quality

A juvenile salmonid requires shelter and access to food. Shelter is primarily a function of substrate, channel morphology, and cover, but the ability to access food is primarily a function of water velocity (Chapman, 1966). When streamflow is high enough, juvenile salmonids generally orient themselves facing upstream in the direction of flow and maintain a focal position to take advantage of drifting food (Giger, 1973). Thus velocity can trigger successful behavior for rearing juvenile salmonids. Velocity for good juvenile rearing habitat should be sufficiently high to promote upstream orientation, but not too high for a fish to maintain a focal position (Baldes, 1968). Since our Study Goals were focused on low flow of juvenile rearing thresholds we did not define a maximum velocity criteria for habitat quality (although this could easily be done).

Minimum velocities of 0.5 fps at the Riffle Crest Thalweg (RCT) and the Riffle Tail (RT), and 0.3 fps at the pool ramp, were established as supportive of successful juvenile rearing behavior. These velocities were based on preference criteria from Thompson (1972), and Everest and Chapman (1972), as referred to in Giger, (1973).

5.2.3 BMI Productivity

Benthic Macroinvertebrates (BMI) are the primary prey for rearing juvenile salmonids. Velocity and substrate are the important drivers of BMI habitat (Gore 2001). The highest density of BMI, and specifically the highest density of species that are important food sources for juvenile salmonids, occur in riffles (Logan and Brooker 1983). The majority of BMI species are found in riffle environments when velocity is between 1 fps and 2.5 fps (Giger 1973). Gore et al. (2001) found the highest BMI diversity at velocities between 1.5 fps and 2.5 fps, while significantly fewer BMI species were found when velocities were less than 0.5 fps (Kennedy 1967).

The production and drift of BMI is considered a necessary component to juvenile rearing habitat in the Mattole Headwaters. To identify streamflow thresholds that support BMI production and drift, HHTs were applied to a cross section analysis. In riffles with appropriate substrate for potentially productive BMI riffle habitat, a cross section was installed perpendicular to the direction of streamflow. Velocity was measured along each BMI cross-section and classified according to the BMI HHTs (Figure 7).

Three velocity thresholds were identified: BMI biomass (standing crop) maintenance (<0.5 fps), BMI drift (0.5 to 1.5 fps), and high BMI production (>1.5 fps). Each BMI cross section was rated based on the percent of the active channel that met each HHT.

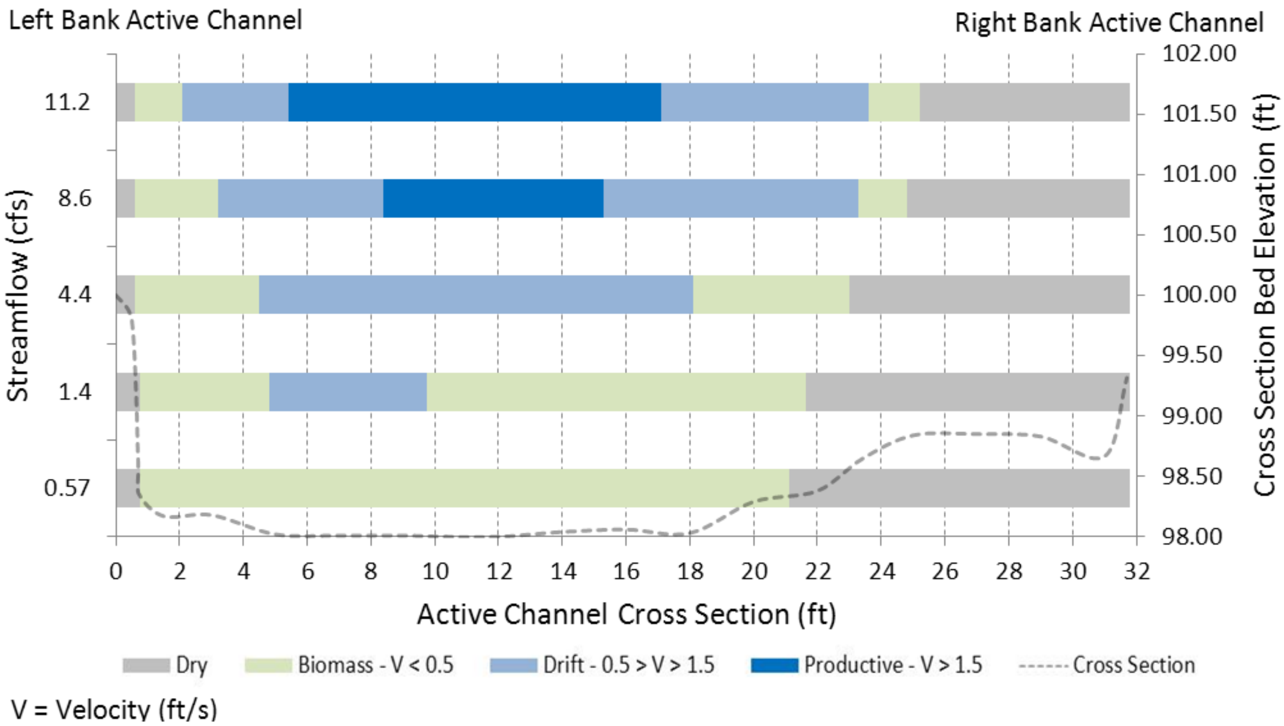

Figure 7. An example of the percent change in productive, drift, and biomass BMI riffle habitat within the active channel for measured streamflows at Schaefer Site, HU-2 BMI XS.

5.3 Wetted Perimeter Methods

Wetted perimeter is the width of wetted channel bed between left and right bank edges of the water surface. The 'wetted perimeter method' assumes a direct relationship between the wetted perimeter in riffles and juvenile rearing habitat abundance (Annear and Conder 1984), or favorable benthic macroinvertebrate food production (Bell 1973, Swift 1976). The method plots wetted perimeter (WP) versus streamflow to identify the maximum curvature (or 'breakpoint') in the wetted perimeter curve Figure 8), (CDFG 2011). However, Dunbar et al. (1998), found that the minimum streamflow, determined by the break point had significantly reduced invertebrate production. To "maintain habitat conditions that support typical densities of juvenile steelhead" CDFG identifies the streamflow at which the wetted perimeter just reaches an 'incipient' asymptote (CDFG 2011). Once the breakpoint and incipient asymptote have been identified, the associated streamflows can be determined from the WP curves.

Riffle cross-sections for the productive BMI habitat analysis were surveyed for the wetted perimeter at each streamflow to compute the breakpoint and incipient asymptote streamflows. Both wetted perimeter streamflow thresholds were compared with the EXCELLENT, GOOD, and FAIR juvenile habitat streamflow thresholds estimated from the HHTs and from the continuity assessment at the four study sites. The purpose of including wetted perimeter thresholds in this analysis was provide a cross-walk between HHTs and more traditional IFN assessment methods.

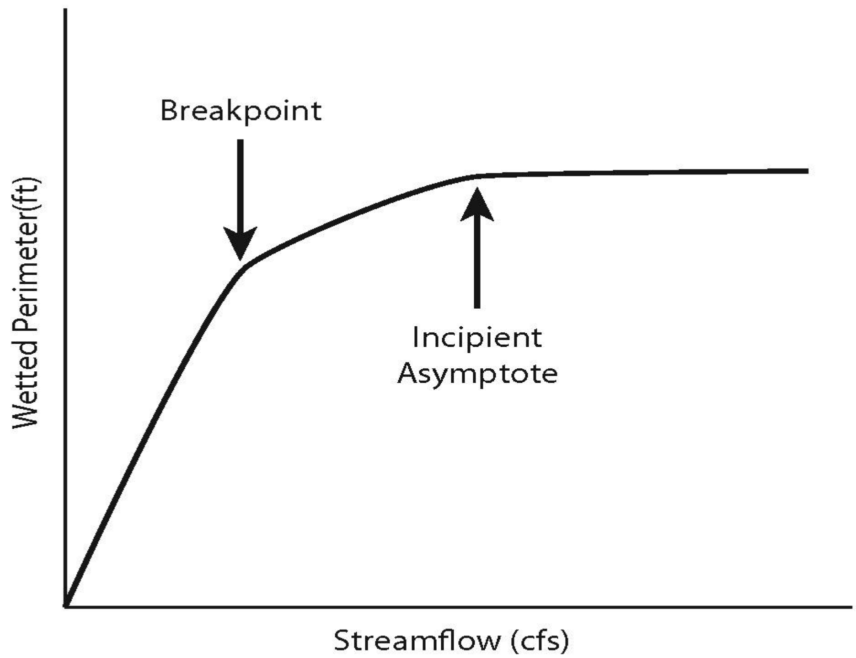

Figure 8. Wetted perimeter 'breakpoint' and 'incipient asymptote' streamflow thresholds (CDFG 2011).

5.4 HHTs to Estimate Streamflow Thresholds for Spawning Habitat

The hydraulic setting of pool ramps (tails) is highly attractive to spawning female steelhead. To meet Study Goal No. 3, two HHT pins, one at the Riffle Crest Thalweg (RCT) and another at the Pool or Run Ramp (Figure 11), were needed to estimate the range of streamflows at a pool or run tail providing spawning habitat. Steelhead prefer spawning in velocities between 0.5 fps and 2.5 fps (M&T 2012), in depths between 0.5 ft and 3 ft, and in substrate between 6 mm and 102 mm (Bjornn and Reiser 1991). The minimum streamflow threshold creating spawning habitat was determined at the RCT Pin. The streamflow at which D_{RCT} was greater than or equal to 0.5 ft, and V_{RCT} was greater than or equal to 1.0 fps was the minimum spawning streamflow ($Q_{S\ min}$) We used 1.0 fps, rather than the minimum preferred velocity of 0.5 fps, (as the HHT threshold) because (1) of the sharp increase in roughness when shallow streamflows approach the riffle crest and (2) theoretically, just equaling the 0.5 fpsec threshold at the RCT Pin would identify a very small patch of spawnable channel bed (right at the RCT) that would not be sufficiently large to attract spawning. Provided D_{RCT} exceeded 0.5 ft, the maximum streamflow providing spawning habitat ($Q_{S\ max}$) was determined at the Ramp Pin when V_{RAMP} = 2.5 fps (although this threshold was not observed at our monitored streamflows). A third threshold, where most of a run or pool tail becomes spawnable, (Q_{Sramp}) was identified when V_{RAMP} > 0.5 fpsec AND D_{RCT} > 0.5 ft. This threshold can define the minimum flow for GOOD spawning conditions.

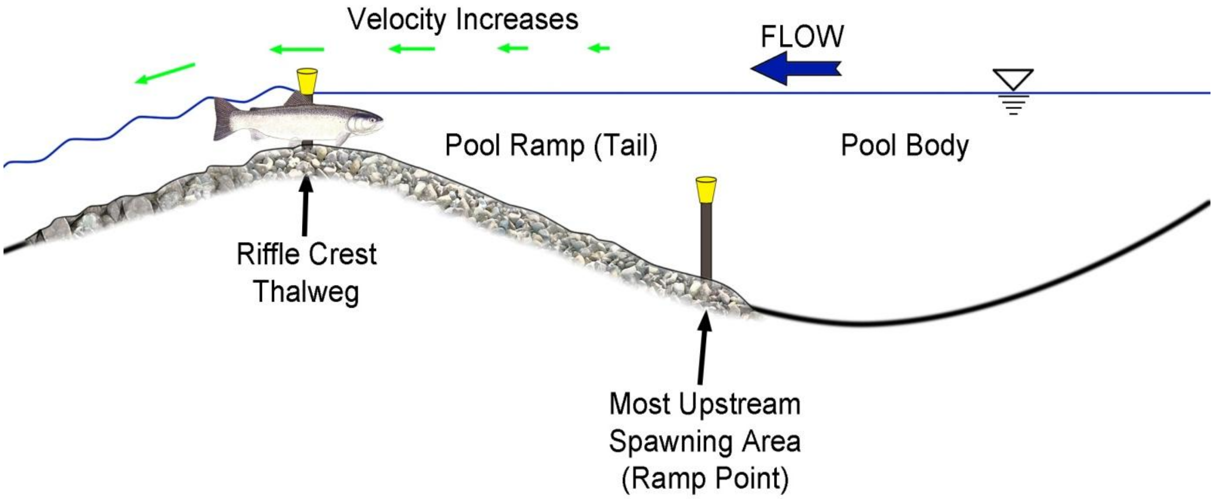

Figure 9. HHT pin locations within a pool or run ramp to estimate streamflow thresholds for spawning habitat.

6 RESULTS

This study produced instream flow thresholds for EXCELLENT, GOOD, and FAIR juvenile rearing habitat and adult steelhead spawning habitat at each study site. Hydraulic habitat threshold data and BMI productivity data were used to develop these thresholds. In addition a wetted perimeter threshold analysis was performed as a cross-walk between HHTs and traditional IFN assessment methods. A continuity assessment was developed to help us achieve our goal of identifying the instream flow threshold that marks the transitions to the Doldrums at each study (Figure 15 to Figure 17. Spawning thresholds were estimated for each hydraulic unit with spawning habitat according to the methods described in Section 5.4 and presented in Figure 18 to Figure 20.

6.1 HHT Field Measurements in Each Study Site

Data was collected at seven streamflows in the Mattole Headwaters during this ISF study (Table 4). Depth and velocity data collected at each HHT monitoring location (Appendix 8.1 and 8.2) were plotted against streamflow to identify the HHTs for juvenile salmonid habitat abundance and quality, BMI productivity, and adult steelhead spawning. Figure 10 shows an example of how HHTs were identified from using the habitat criteria in Table 3.

Table 4. Observed streamflows at each Study Site.

Site	5/23/2011	6/22/2011	7/20/2011	8/17/2011	9/14/2011	2/3/2012	2/23/2012
Junction	*20.0*	*15.3*	*7.2*	*2.8*	*0.96*	*62*	*44*
Schaefer	*11.2*	*8.6*	*4.4*	*1.4*	*0.57*	*37*	*26*
Abbey		*5.3*	*2.5*	*1.4*	*0.56*	*26*	*16*
Thompson		*2.6*	*1*	*0.45*	*0.46*	*10*	*7.6*

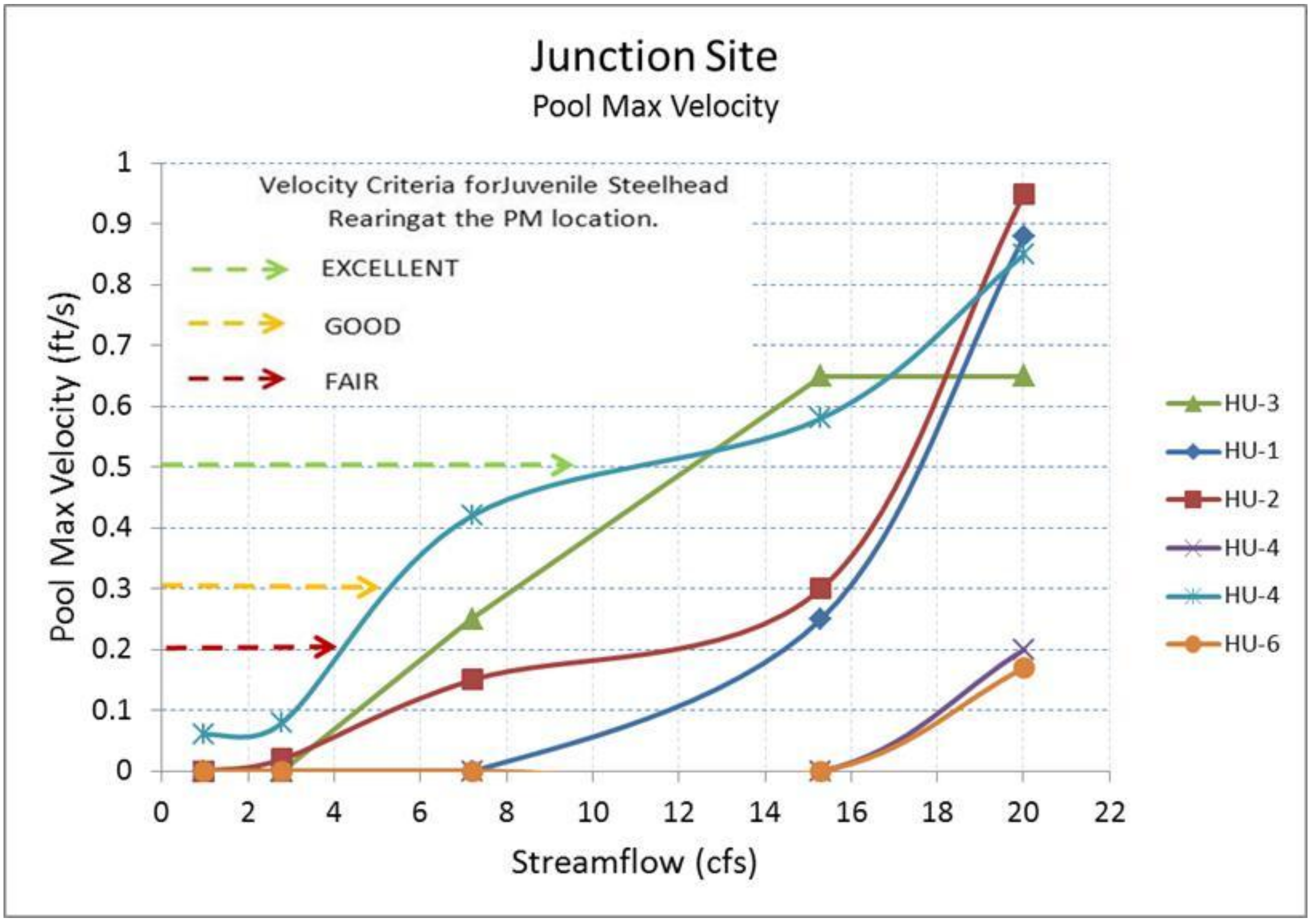

Figure 10. Identification of HHTs using threshold criteria – example showing velocities at Pool Maximum Depth Locations (PM) for the Junction Study Site.

6.2 **Wetted Perimeter Results.**

Wetted perimeter was plotted against streamflow at each BMI cross-section to identify the CDFG breakpoint and incipient asymptote thresholds (Figure 11 to Figure 14). Data points are connected by linear interpolation to help identify thresholds that lie between two points.

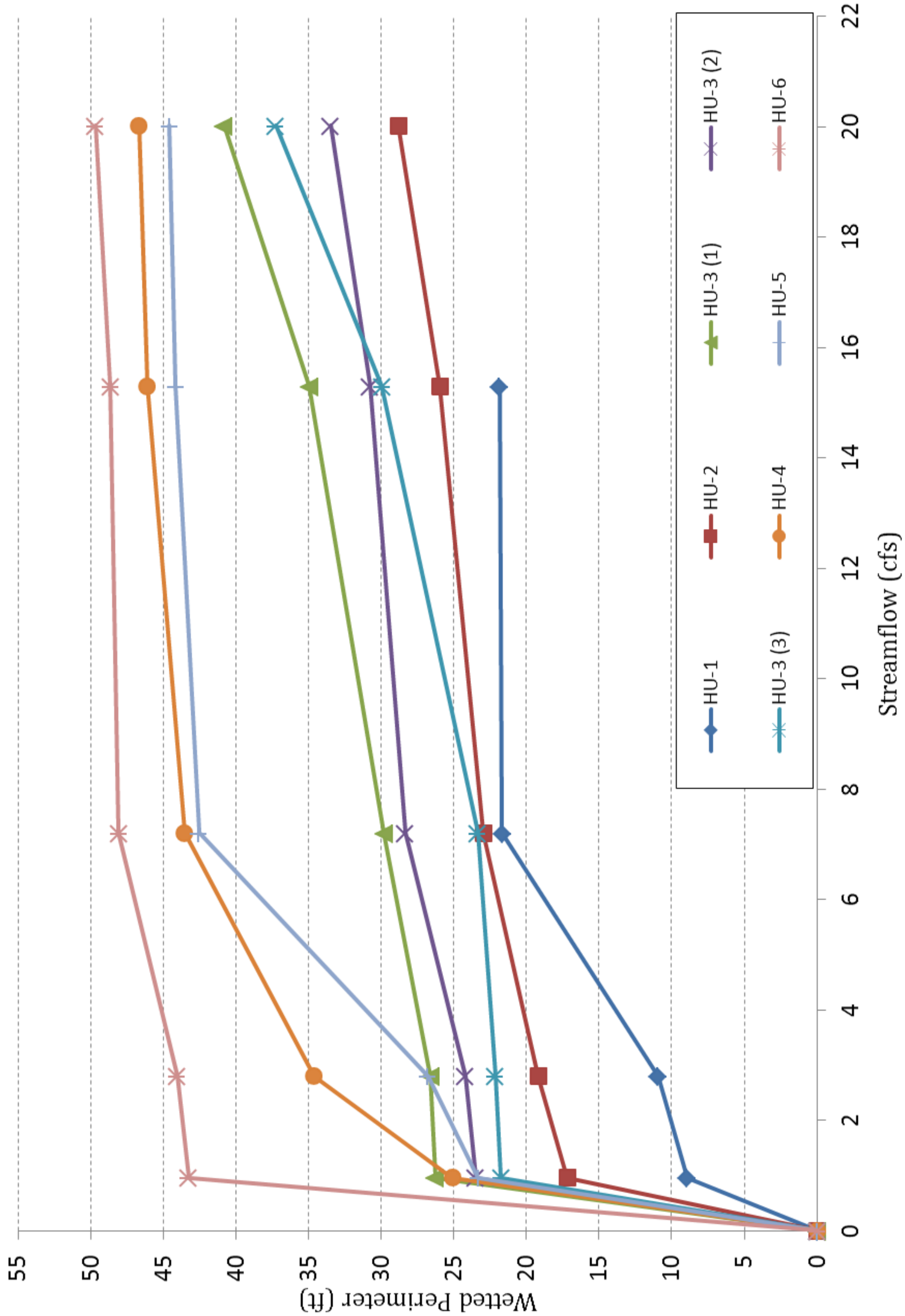

Figure 11. Junction Study Site: Wetted Perimeter vs. Streamflow at BMI Cross Sections

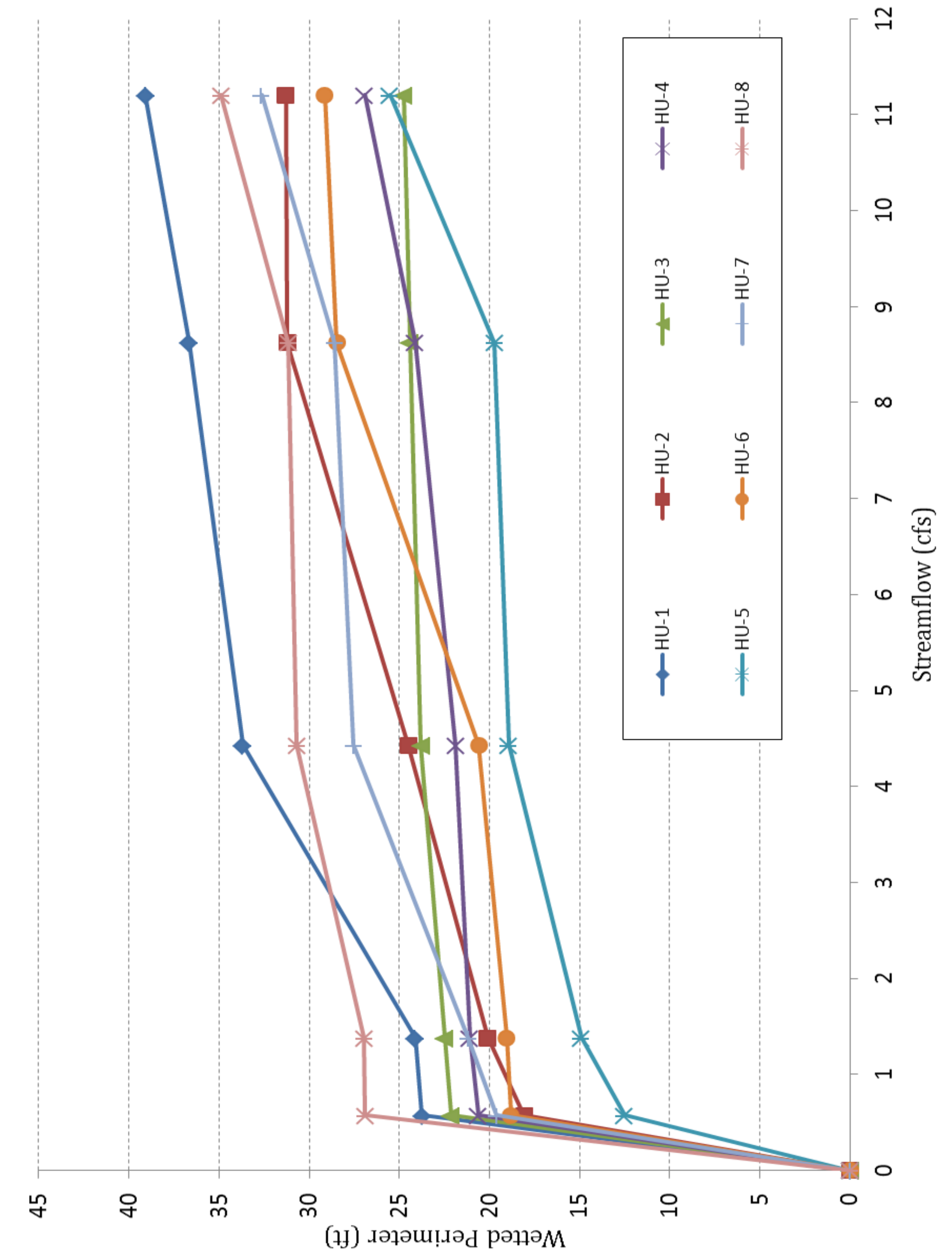

Figure 12. Schaefer Study Site: Wetted Perimeter vs Streamflow Curves at BMI Cross Sections.

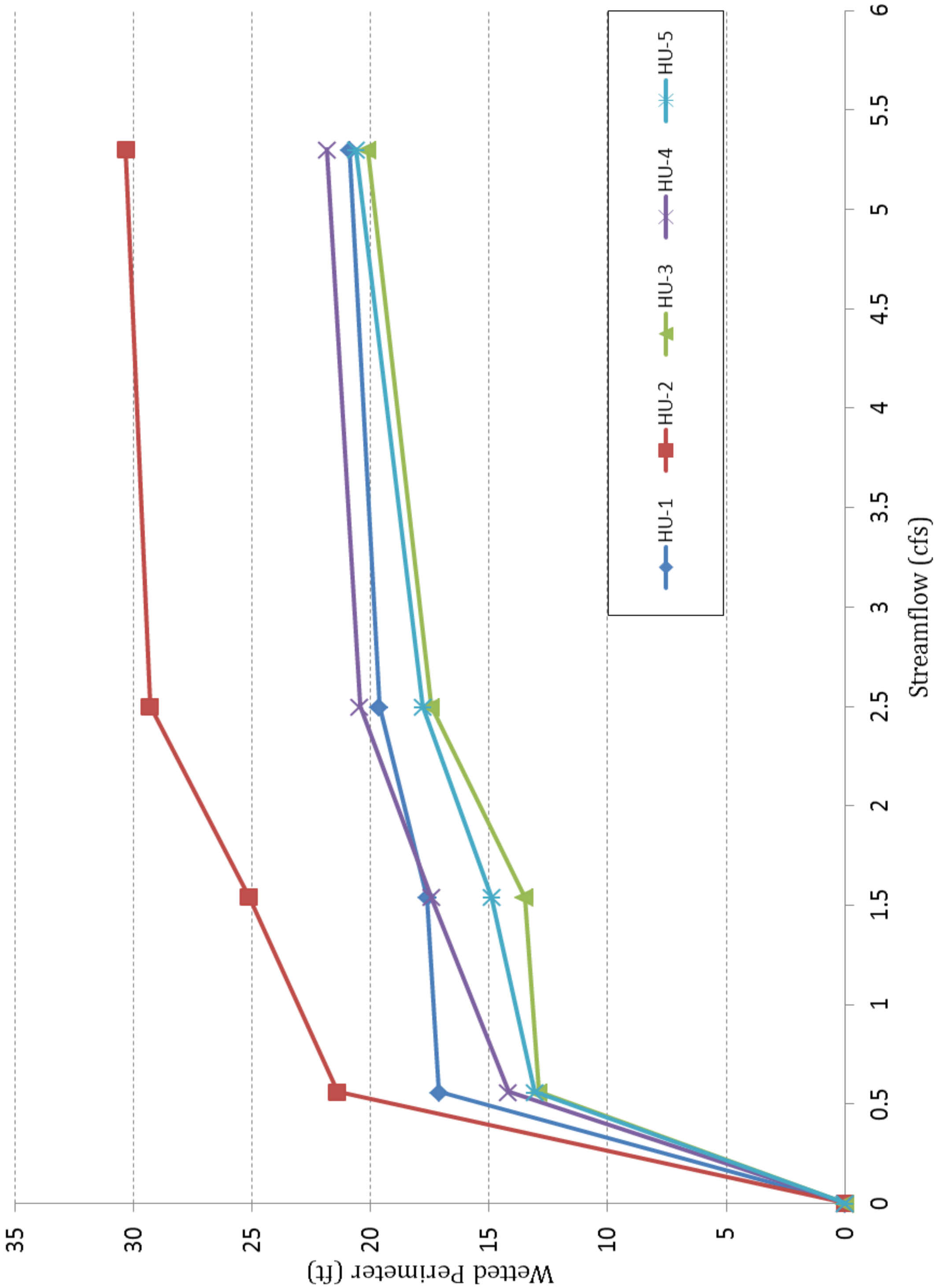

Figure 13. Abbey Site Wetted Perimeter vs. Streamflow at BMI Cross Sections.

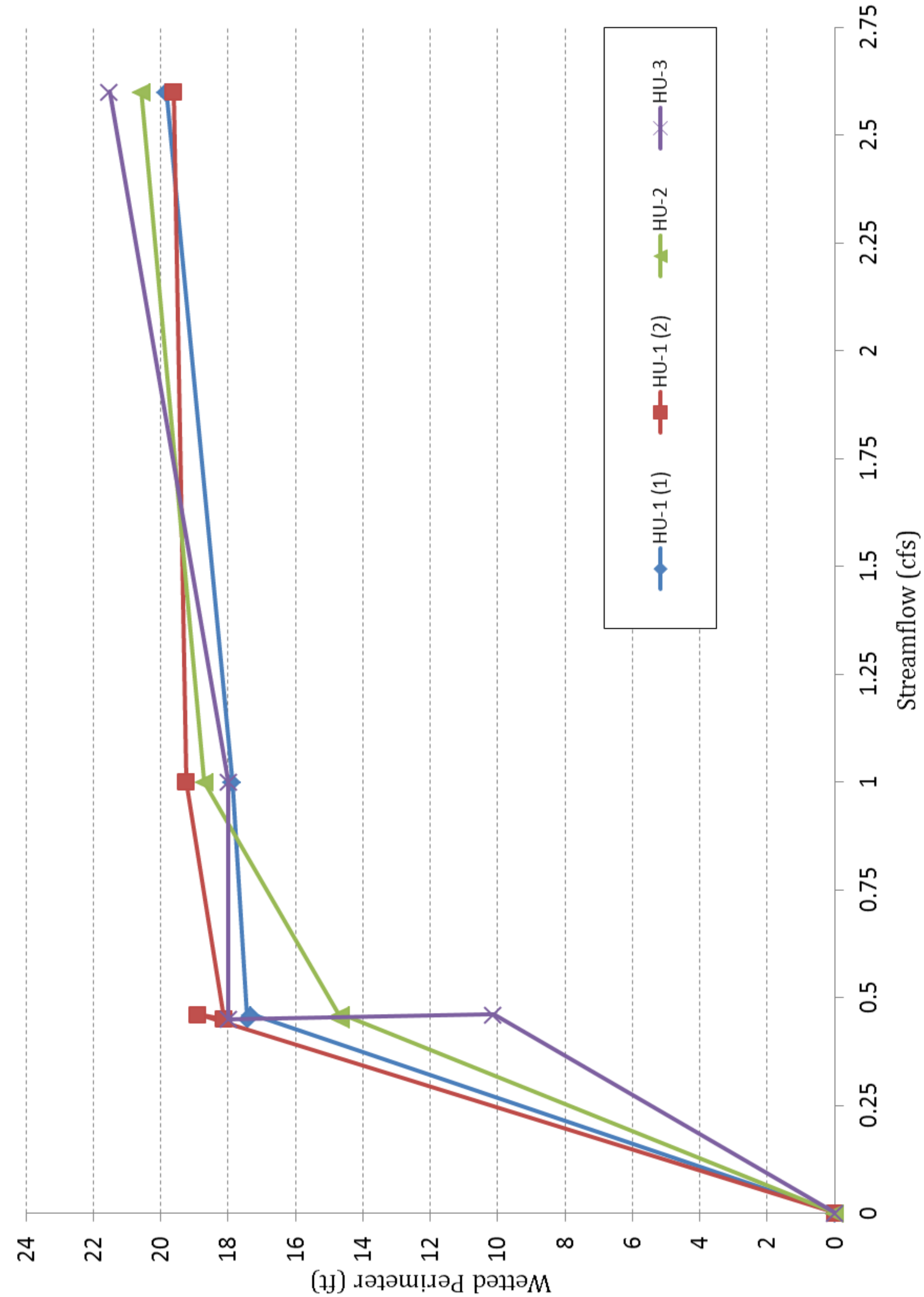

Figure 14. Thompson Creek Study Site: Wetted Perimeter vs. Streamflow at BMI Cross Sections

Thresholds for the breakpoint and incipient asymptote in the wetted perimeter data were determined from the data sets in Figure 11 to Figure 14 and compiled in Table 5. The definition of these thresholds is subject to how well they are 'trapped' between observed streamflows. Based on the number and density of observed streamflows the 'real' incipient asymptote or breakpoint may be different than one identified from a line or a curve fit by eye between two data points.

Table 5. Summary of Breakpoint and Incipient Asymptote Streamflow Thresholds for All Study Sites.

Site	HU	Q Break Point	Q Incipient Asymptote
Junction	1	3.5	7.2
	2	1.0	7.2
	3 (1)	1.0	3.0
	3 (2)	1.0	7.2
	3 (3)	1.0	1.0
	4	2.5	7.2
	5	4.0	7.2
	6	1.0	4.0

Site	HU	Q Break Point	Q Incipient Asymptote
Schaefer	1	1.0	4.4
	2	1.0	8.2
	3	0.6	0.6
	4	0.6	0.6
	5	1.0	4.4
	6	0.6	8.2
	7	0.6	4.4
	8	0.6	2.0

Site	HU	Q Break Point	Q Incipient Asymptote
Abbey	1	0.5	2.5
	2	1	2.5
	3	0.5	2.5
	4	0.5	2.5
	5	0.5	2.5

Site	HU	Q Break Point	Q Incipient Asymptote
Thompson Creek	1 (1)	0.45	1
	1 (2)	0.45	1
	2	0.65	1
	3	0.4	1

6.3 Continuity Analysis for Juvenile Rearing Habitat

As discussed in Section 3.3, a continuity assessment of multiple hydraulic units is necessary to describe reach based thresholds at each study site. Figure 15 to Figure 17 show the continuous progression of habitat conditions (aka sequence) along each reach as streamflow increases. Each hydraulic unit was given a marker to represent the habitat rating it provided at a given flow. Habitat abundance and quality are assessed together as “habitat” and BMI productivity is assessed as “Productivity.” If an hydraulic unit provided FAIR habitat, but less than FAIR BMI riffle habitat the marker was represented as a hash, with the FAIR color as the background.

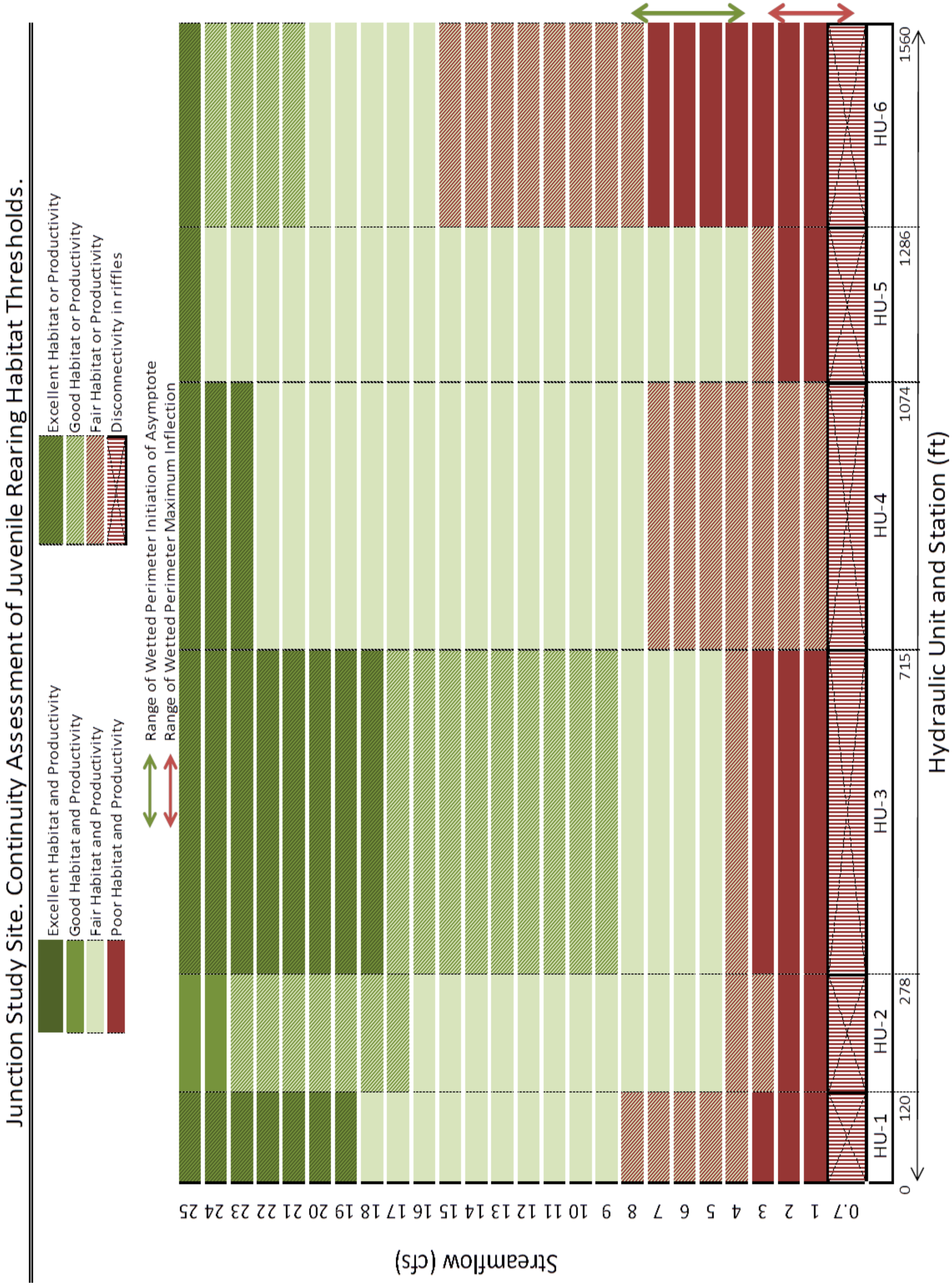

Figure 15. Junction Study Site: Continuity assessment for juvenile salmonid rearing habitat conditions.

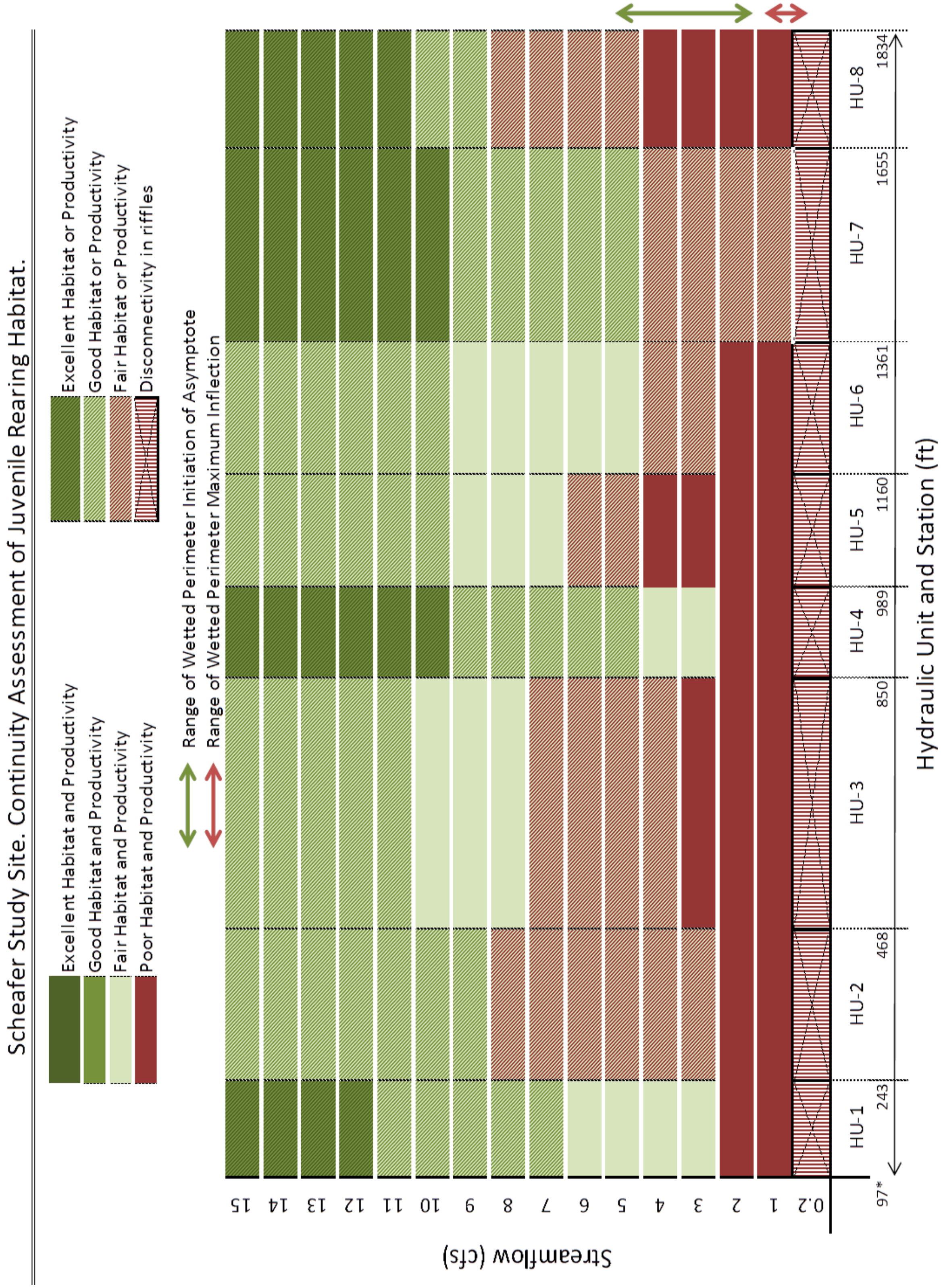

Figure 16. Schaefer Study Site. Continuity assessment of hydraulic units for juvenile rearing habitat.

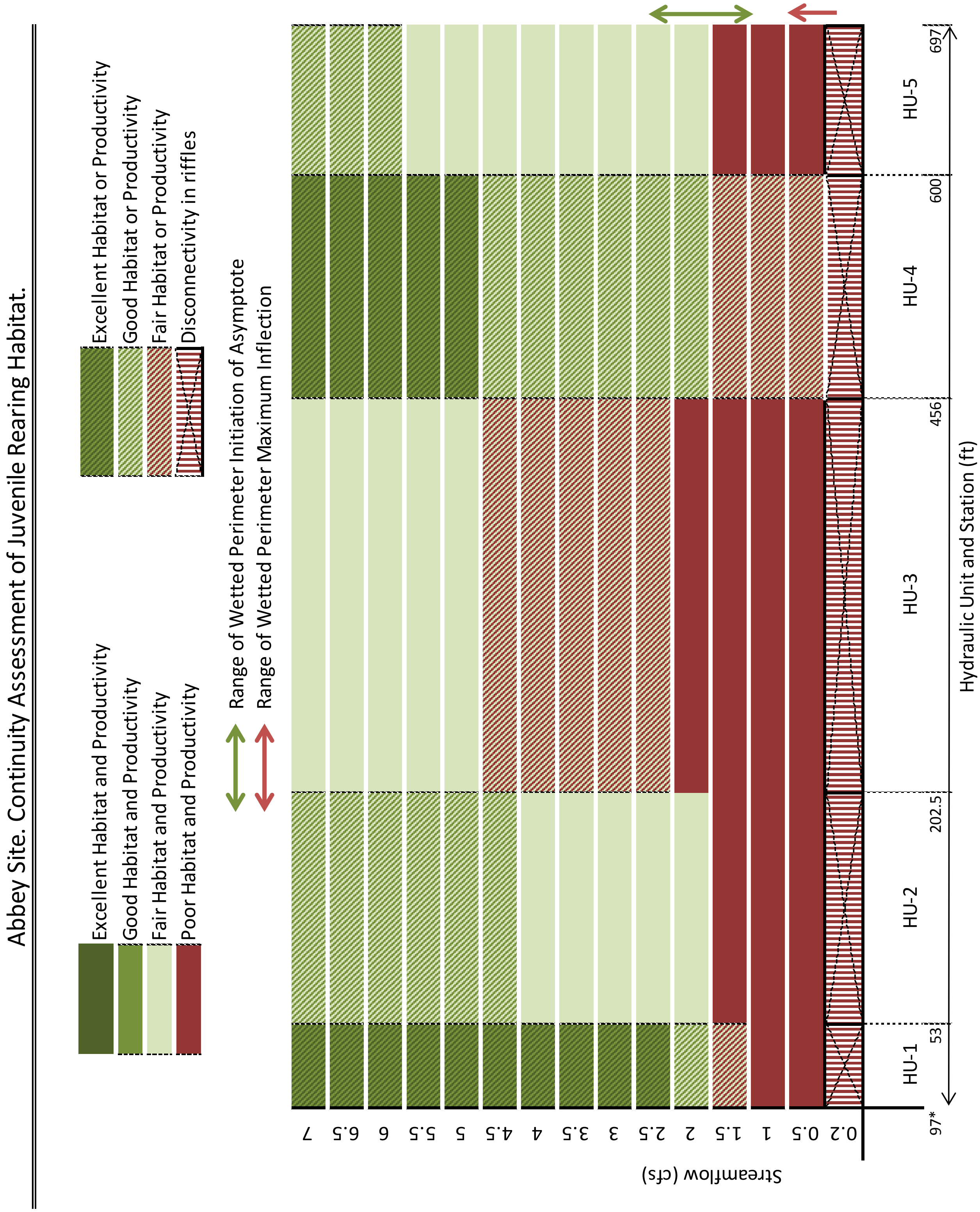

Figure 17. Abbey Study Site. Continuity assessment of hydraulic units for juvenile rearing habitat.

6.4 Streamflow Thresholds for Spawning

Spawning thresholds were only established on hydraulic units with spawning habitat. Figures 18 through 20 show the minimum instream flow threshold that produces spawning habitat, and the minimum instream flow threshold for GOOD spawning habitat (Q_{Sramp}) for each spawnable hydraulic unit. Thresholds for Qs_{min} and Qs_{ramp} are also established in each figure, and compiled in Table 6.

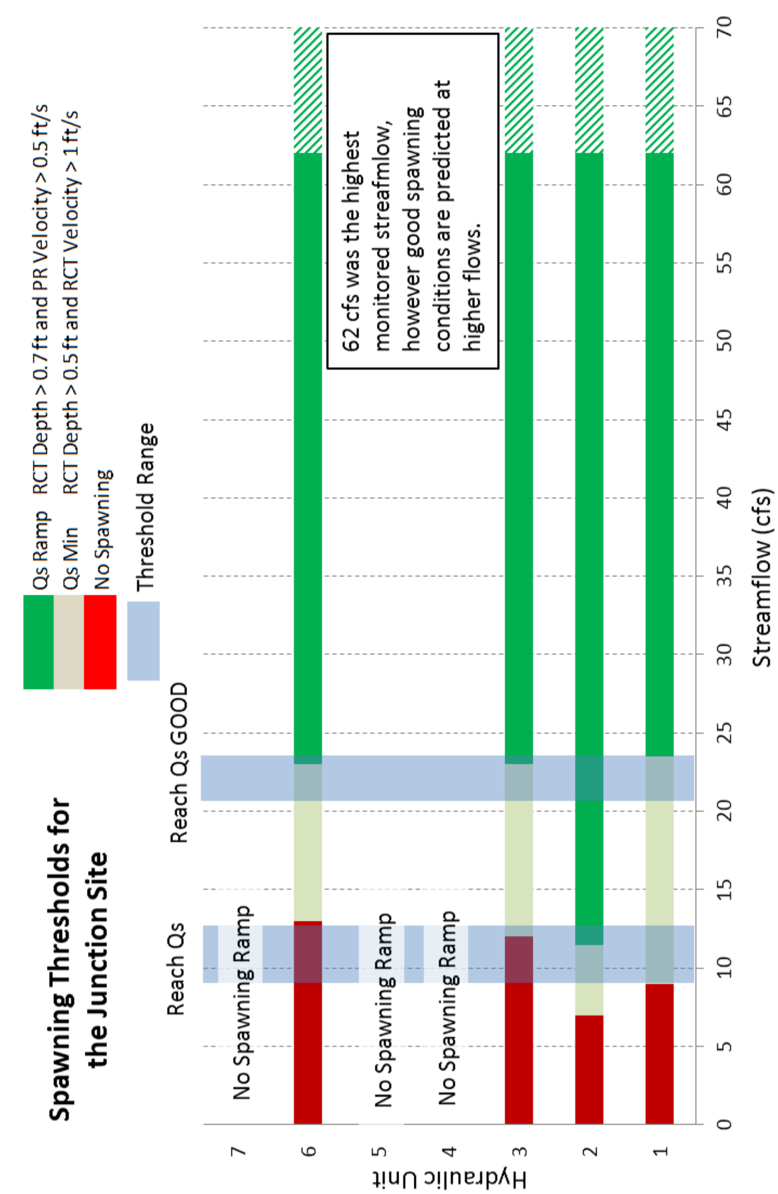

Figure 18 Streamflow thresholds for minimum (Q_S min) and good spawning habitat (Q_S ramp) in the Junction Study Site. Maximum (Q_S max limit) spawning habitat was not observed however, good spawning conditions are predicted to occur beyond 62 cfs.

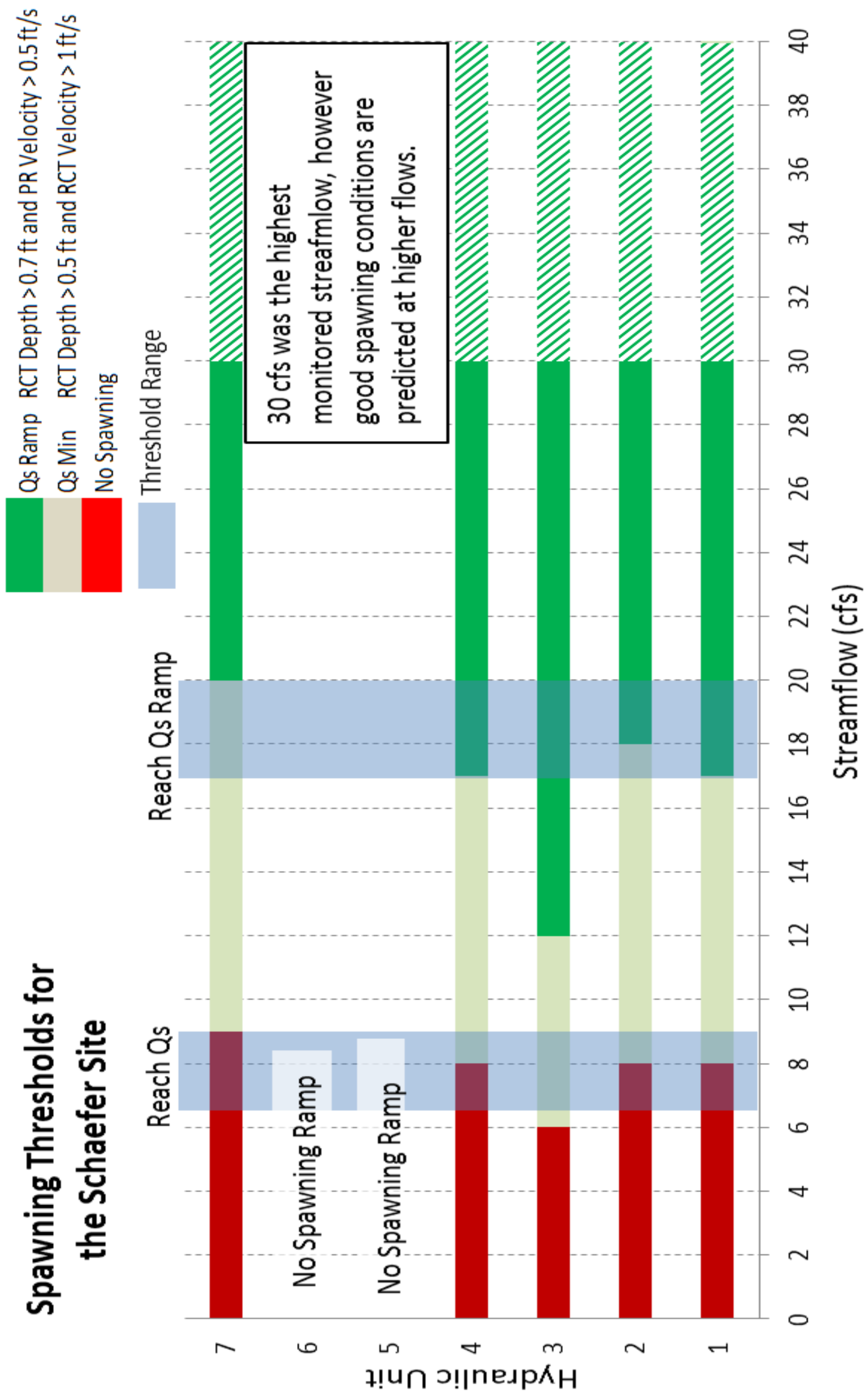

Figure 19 . Streamflow thresholds for minimum (Q_S min) and good spawning habitat (Q_S ramp) in the Schaefer Study Site. Maximum (Q_S max limit) spawning habitat was not observed however, good spawning conditions are predicted to occur beyond 30 cfs.

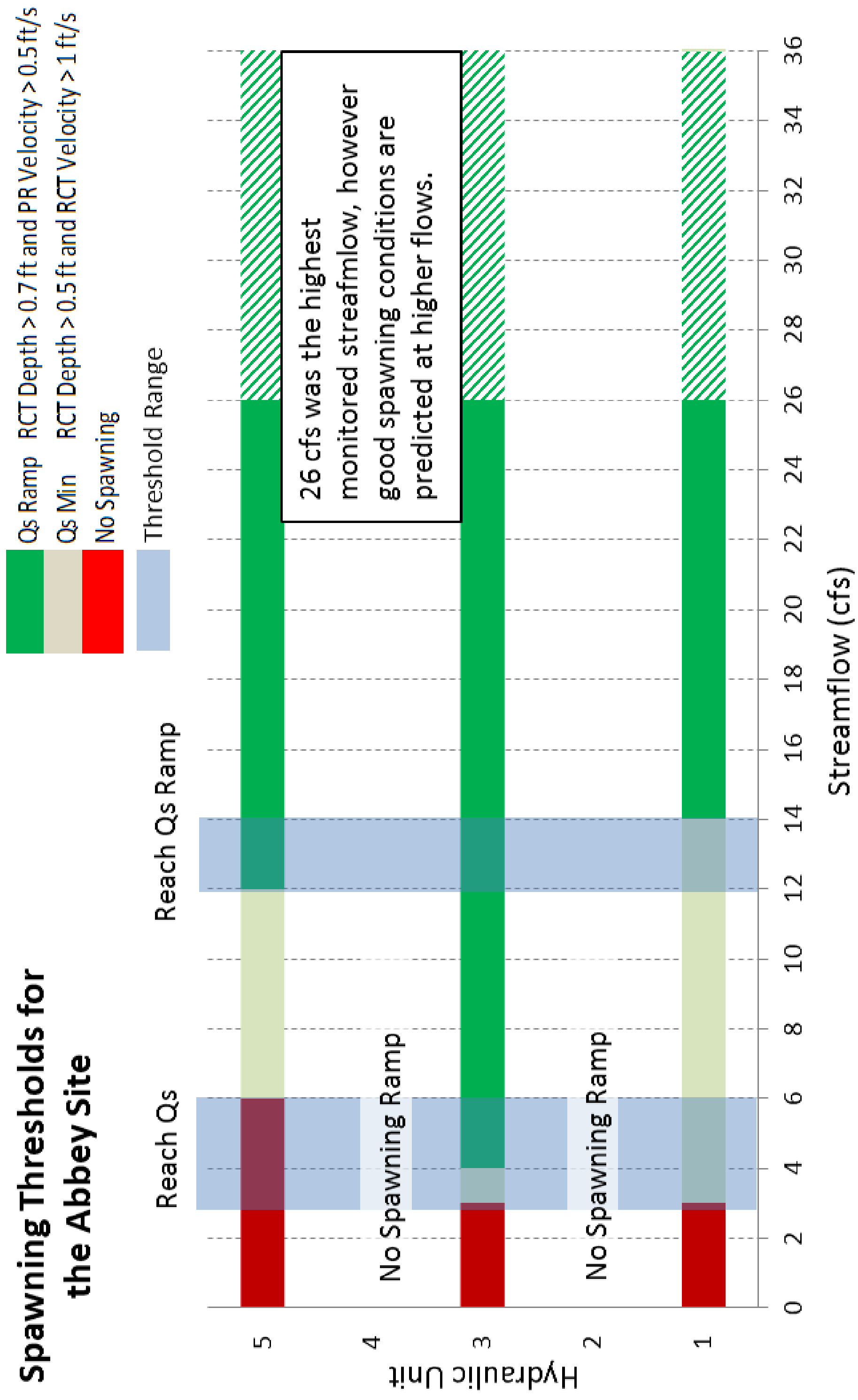

Figure 20 Streamflow thresholds for minimum (Q_S min) and good spawning habitat (Q_S ramp) in the Abbey Study Site. Maximum (Q_S max limit) spawning habitat was not observed however, good spawning conditions are predicted to occur beyond 26 cfs.

6.5 **Streamflow Thresholds**

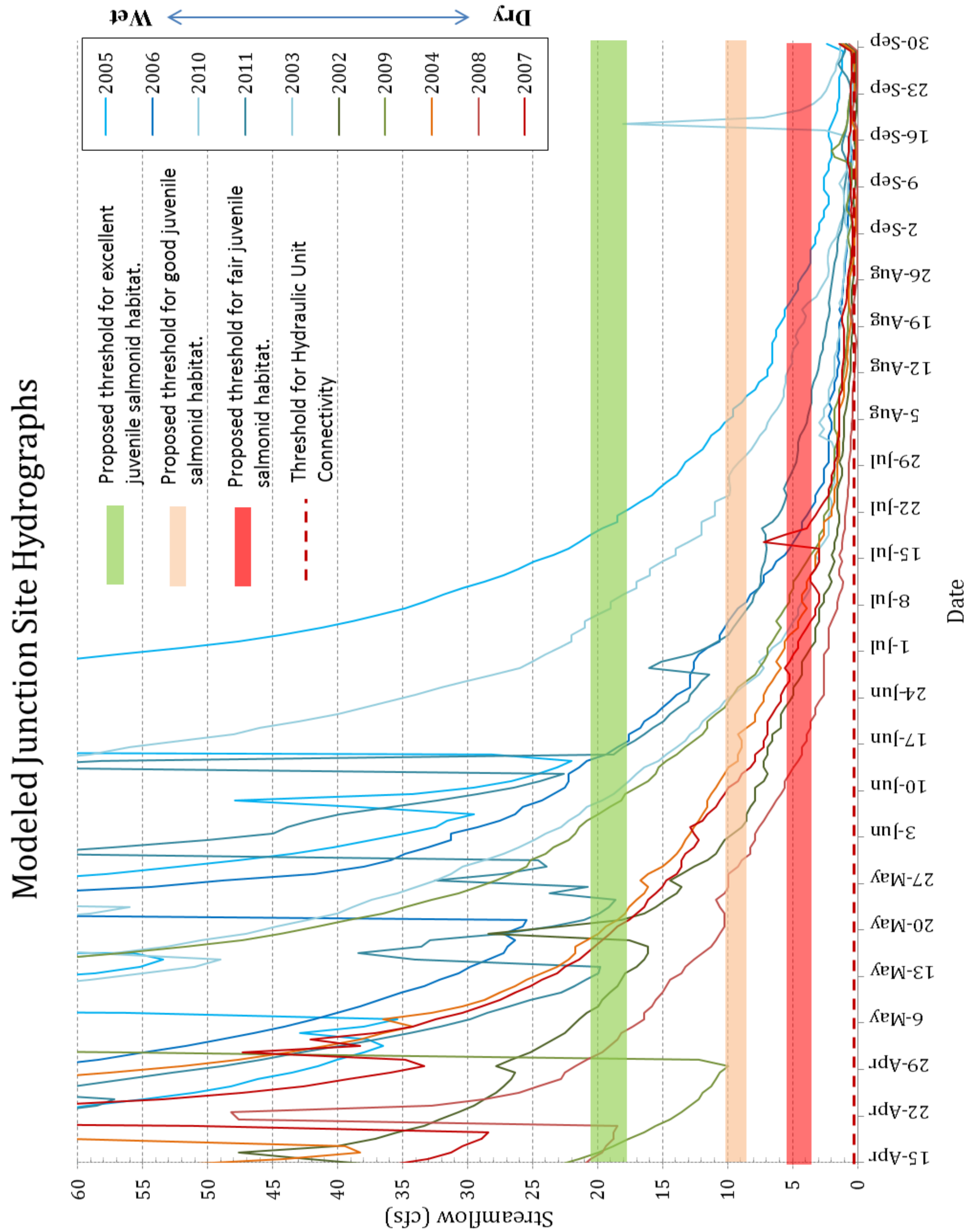

Figure 21. Spring through early fall recession daily average hydrographs for WY2002 through WY2011 at the Junction Study Site with streamflow thresholds for EXCELLENT, GOOD, and FAIR juvenile rearing habitat conditions. Streamflows modeled by CEMAR (See Section 5.1)

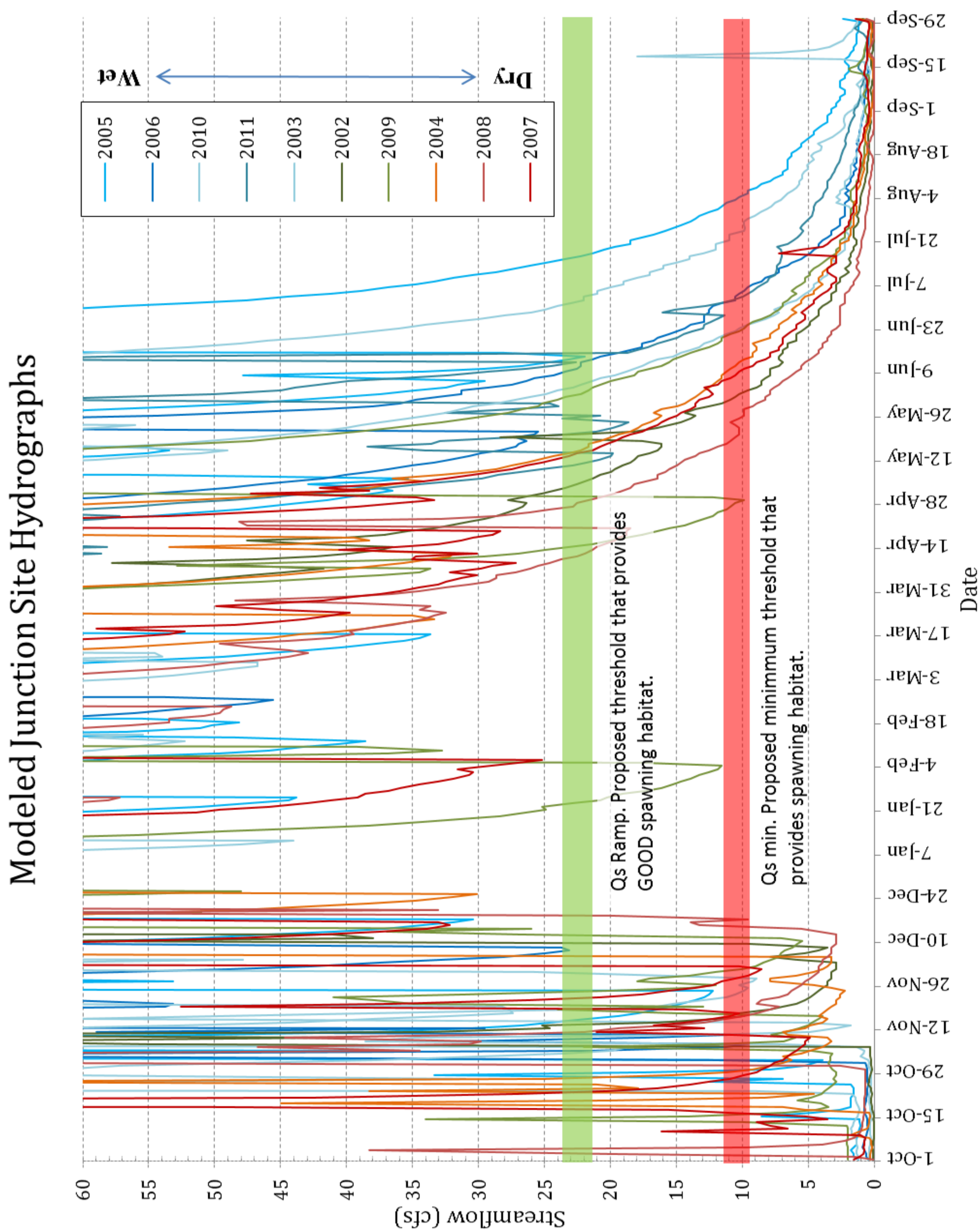

Figure 22. Annual hydrographs for WY 2002 to WY 2011showing streamflows during the spawning season with thresholds for spawning habitat. Streamflows modeled by CEMAR (See Section 5.1).

The thresholds in Figures 20 and 21 were identified from the continuity analysis (Figures 15 to 17) and spawning analysis (Figures 18 to 20). As discussed in Section 3.3 these thresholds are bands, or ranges of flow that meet the HHT criteria in the majority of hydraulic untis for each study site. The middle flow from each band was used to estimate a discrete threshold for each study site.

7 RECOMMENDATIONS

Our primary study goal (Study Goal No. 1) was to estimate a threshold streamflow for the Summer Doldrums in the Mattole River at our four study sites from the confluence of Thompson Creek downstream to Thorn Junction. The threshold streamflow for the Summer Doldrums for each study site is shown in the top row of Table 6. During a summer recession hydrograph, the streamflow threshold for FAIR rearing habitat for juveniles signals the start of the Summer Doldrums (Figure 21).

Table 6 Streamflow Thresholds for Juvenile and Smolt Rearing and Adult Spawning for Mattole

Streamflow Thresholds	Study Goals	Junction Study Site	Schaefer Study Site	Abbey Study Site	Thompson Creek Study Site
FAIR Juvenile Rearing Habitat	No. 1	5 cfs	4 cfs	2 cfs	1.5 cfs
Good Juvenile and Smolt Rearing Habitat	No. 2	9 cfs	8 cfs	5 cfs	3 cfs
Excellent Large-Juvenile/Smolt Rearing Habitat	No. 2	23 cfs	15 cfs	10 cfs	7 cfs
Wetted Perimeter: Median Incipient Asymptote		7.2 cfs	4.4 cfs	2.5 cfs	1 cfs
Juvenile HU Connectivity		0.7 cfs	0.5 cfs	0.5 cfs	0.25 cfs
Minimum Spawning Habitat $Q_{S\ min}$	No. 3	10 cfs	8 cfs	5 cfs	n/a
Abundant Spawning Habitat Qs_{ramp}	No. 3	24 cfs	18 cfs	13 cfs	n/a

Study Goal No. 2 was to identify thresholds above the Summer Doldrums that could make juvenile rearing habitat conditions vulnerable to cumulative diversions. The thresholds for GOOD and EXCELLENT rearing habitat were used accomplish Study Goal No. 2. The streamflow thresholds for GOOD rearing habitat for juveniles establishes a window of receding baseflows (between GOOD and FAIR) that could make juvenile rearing habitat conditions vulnerable to cumulative diversions. This window must figure prominently into any cumulative diversion plan proposed. Similarly, the streamflow threshold for EXCELLENT to GOOD rearing habitat establishes a window of receding baseflows (between GOOD and FAIR) occurring earlier in recession hydrograph that could make smolt rearing habitat conditions vulnerable to cumulative diversions. This window also must figure prominently into any cumulative diversion plan proposed. This window might be considered the window-of-opportunity to complete water storage, and therefore could have a significantly higher cumulative diversion rate. Diversions at streamflows above the threshold for EXCELLENT are not expected to have significant detrimental effects on juvenile rearing habitat.

Study Goal No. 3 was to estimate streamflow thresholds for spawning habitat availability in each study site. We identified two spawning thresholds "Minimum Spawning Habitat" Q_{Smin} and GOOD Spawning Habitat $Qs_{ramp.}$ These findings are represented for each study site in the bottom two rows of Table 6.

In crafting future diversion guidelines, the metric of evaluation for smolt habitat should be the reduced number of days that a sequence's hydraulic units offer EXCELLENT and/or GOOD habitat conditions. For juveniles, metrics of evaluation should be: (1) the reduced number of days that rearing habitat conditions remain GOOD and/or FAIR and (2) the increased number of Summer Doldrums days (i.e., days with daily average streamflows below the FAIR threshold). If summer diversions occur throughout the baseflow recession, a third metric should be assessed: the reduced number of days that the hydraulic units stay functionally connected. Note that none of these metrics are telling us how many days lost or gained is desirable or acceptable. Each, therefore, will require an acceptable loss/gain in duration for each streamflow threshold. For example, how many more days of reduced GOOD/FAIR days for juvenile rearing will be acceptable? Only this goal, of how many days lost or gained, can determine a recommended cumulative diversion rate. The first step in this analysis will be to do a sensitivity analysis, computing changes in streamflow threshold duration with incremental increases in cumulative diversion or incremental improvements (essentially negative incremental diversion rates) in returning surface streamflows through the proposed actions. Although this "number of days" analysis is beyond the scope of this ISF study, Table 6 provides the framework to complete this task

8 <u>APPENDIX</u>

8.1 HHT Data

Table 7. HHT field measurements in the seven hydraulic units at the Junction Study Site for seven streamflows ranging between 1.0 cfs and 62 cfs.

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	HU-6	HU-7	Streamflow (cfs)
Riffle Crest Thalweg	Depth (ft)	1.45	1.25	1.35	1.7	1.2	1.15	1.6	62
		1.25	0.72	1.15	1.05	0.91	0.75	1.3	44
		0.9	0.58	0.9	0.9	0.67	0.65	1.05	20
		0.8	0.4	0.85	0.8	0.45	0.62	0.85	15.3
		0.55	0.375	0.75	0.7	0.4	0.5	0.75	7.2
		0.25	0.18	0.55	0.48	0.2	0.445	0.4	2.8
		0.18	0.15	0.5	0.4	0.2		0.38	1.0

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	HU-6	HU-7	Streamflow (cfs)
Riffle Crest Thalweg	Velocity (fps)	3	2.5	2.55	2.75	2.49	3.1	3.45	62
		2.23	3.16	2.71	3.5	2.05	3.36	3.12	44
		1.73	2.38	1.75	3.5			2.6	20
		1.71	1.85	1.55	2.5	1.75	2.4	1.65	15.3
		0.6	1.3	1.65	2.35	1.5	2.2	1.6	7.2
		1.25	0.76	0.65	1.8	0.62	0.28	1.85	2.8
		0	0.1	0.68	1.38	0.4		1.8	1.0

Point	Units	HU-1	HU-2	HU-3	HU-5	Streamflow (cfs)
Riffle Tail	Velocity (fps)	3.26	2.41	3.37	2.45	62
		2.5	2.11		2.29	44
		2.05	2.2	1.72	2.5	20
		1.71	1.75	1.35	2.3	15.3
		0.3	1.3	1.37	1.75	7.2
		0.35	0.85	0.82	1.35	2.8
		0.05	0.38	0.71	1.5	1.0

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-4	HU-5	HU-6	Streamflow (cfs)
Pool Max Depth	Velocity (fps)	1.65	0.89	1.95	0.75	1.32	0.8	0.38	62
		1.48	1.81	1.4	1.13	1.15	0.51	0.09	44
		0.88	0.95	0.65	0.2	0.85	0.15	0.17	20
		0.25	0.3	0.65	0	0.58	0	0	15.3
		0	0.15	0.25	0	0.42	0	0	7.2
		0	0.02	0	0	0.08	0.02	0	2.8
		0	0	0	0	0.06	0	0	1.0

Point	Units	HU-1	HU-2	HU-3	HU-6	Streamflow (cfs)
Pool Ramp	Velocity (fps)	2.63	2.72	1.87	1.52	62
		2.05	2.35	1.4	1.35	44
		1.15	1.7	1.06	0.58	20
		0.75	1.25	0.95	0.3	15.3
		0.4	0.87	0.42	0.2	7.2
		0	0.32	0.13	0.05	2.8
		0	0.2	0	0.05	1.0

Table 8. HHT field measurements in the eight hydraulic units at the Schaefer Study Site for seven streamflows ranging between 0.6 cfs and 37 cfs.

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	HU-6	HU-7	HU-8	Streamflow (cfs)
Riffle Crest Thalweg	Depth (ft)	0.82	1	1.25	0.55	0.8		0.65	0.68	37
		0.65	0.78	1.1	0.55	0.75		0.55	0.65	25
		0.58	0.58	0.65		0.6	0.5	0.53	0.54	11.2
		0.45	0.5	0.6	0.5	0.4	0.45	0.4	0.45	8.6
		0.37	0.4	0.47	0.4	0.3	0.35	0.35	0.37	4.4
		0.27	0.3	0.3	0.3	0.11	0.263	0.25	0.25	1.4
		0.25	0.29	0.29	0.28	0.1	0.25	0.2	0.23	0.6
Riffle Crest Thalweg	Velocity (fps)	2.9	1.87	1.88	2.67	2.5		2	2.7	37
		3.15	1.3	1.61	1.31	2.9		1.54	1.89	25
		1.8	1.4	1.95		1.2	1.4		1.1	11.2
		1.52	1.25	1.4	1.76	2.1	1.54	1.87	1.11	8.6
		1	0.8	1.3	1.1	0.5	1.45	2	1.16	4.4
		0.64	0.45	0.61	0.72	0.01	0.68		0.75	1.4
		0.21	0.36	0.24	0.55	0.01	0.29	0.63	0.38	0.6
Riffle Tail	Velocity (fps)				1.75	3		3.19	1.9	37
		3.69				2.32			1.35	25
		4.7			2.55	2.9		2.5	1	11.2
		4.06			3.27	2.22		1.55	1	8.6
		2			1.7	1.65		0.39	1.05	4.4
		1.84			0.03	0.83		0	0	1.4
		0.86			0	0.72		0	0	0.6
Pool Max Depth	Velocity (fps)	1.49	0.71	0.84	1.91	0.85	0.6	2.47	1.29	37
		1.1	0.52	0.49	1.84	1.46	0.2	1.9	1.19	25
		0.1	0.2	0.23	0.6	0.1	0	0.3	0.7	11.2
		0.6	0.27	0.2	0.66	0.1	0.34	0.67	0.46	8.6
		0.1	0.1	0.05	0.3	0.1	0.05	0.44	0.3	4.4
		0.02	0.03	0.01	0.03	0.04	0.01	0	0.03	1.4
		0	0	0	0	0	0	0	0	0.6
Pool Ramp	Velocity (fps)		1.1	1.13	1.43	0.145			1.27	37
			0.81	1.03	1.24	0.84			1.23	25
			0.3	0.67	1.03	0.5			0.7	11.2
			0.31	0.62	0.71	0.4			0.62	8.6
			0.08	0.35	0.4	0.2			0.3	4.4
			0.01	0.15	0.23	0.01			0.1	1.4
			0	0.03	0.15	0			0.02	0.6

Table 9. HHT field measurements in the 5 hydraulic units at the Abbey Study Site for 6 streamflows ranging between 0.56 cfs and 26 cfs.

Point	Units	HU-1	HU-1 (ds)	HU-2	HU-3	HU-4	HU-5	Streamflow (cfs)
Riffle Crest Thalweg	Depth (ft)	0.67	0.95	1.4	0.9	0.85	0.7	26
		0.7	0.82	1.05	0.75	0.77	0.7	16
		0.5	0.5	0.8	1.05	0.51	0.49	5.3
		0.38	0.45	0.5	0.5	0.45	0.3	2.5
		0.2	0.35	0.27	0.35	0.3	0.25	1.54
		0.1	0.29	0.27	0.3	0.3	0.25	0.56

Point	Units	HU-1	HU-1 (ds)	HU-2	HU-3	HU-4	HU-5	Streamflow (cfs)
Riffle Crest Thalweg	Velocity (fps)	3.25	1.82	2.74	4	1.97	2.49	26
		3.5	1.53	2.7	4.02	1.6	2.41	16
		2.05	1.2	1.25	1	1.35	1.82	5.3
		1.4	1.3	1.36	2.4	1.23	1.2	2.5
		1.8	0.7	1	1.5	0.95	0.97	1.54
		0.4	0.86	1	1.75	0.48	1.15	0.56

Point	Units	HU-2	HU-3	HU-3	HU-4	HU-5	Streamflow (cfs)
Riffle Tail	Velocity (fps)	2.65	2.4	2.52	1.9	2.45	26
		1.6	2	2.6	1.78	2.67	16
		0.9	1.35	1	1.5	2.2	5.3
		0.86	1.31	0.1	1	2.8	2.5
		0.24	0.51	0.3	0.52	1.97	1.54
		0.08	0.23	0.03	0.5	1.84	0.56

Point	Units	HU-2	HU-3	HU-3	HU-4	HU-5	Streamflow (cfs)
Pool Max Depth	Velocity (fps)	1.19	0.69	0.18	1.56	1.56	26
		0.83	0.37	0	1.02	1.61	16
		0.3	0.4	0.35	0.15	1	5.3
		0.1	0.02	0.04	0	0.45	2.5
		0	0.21	0.02	0	0.25	1.54
		0	0.06	0	0	0.1	0.56

Point	Units	HU-1	HU-1	HU-3	HU-3	Streamflow (cfs)
Pool Ramp	Velocity (fps)	0.69	1.4	gone	1.6	26
		0.47	1.09		1.67	16
		0	1.1	0.2	1.2	5.3
		0	0.5	0.23	0.92	2.5
		0	0.35	0	0.5	1.54
		0	0.23	0	0.52	0.56

Table 10. HHT field measurements in six hydraulic units at the Thompson Creek Study Site for six streamflows ranging between 0.46 cfs and 10 cfs.

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	HU-6	Streamflow (cfs)
Riffle Crest Thalweg	Depth (ft)	1.05	0.55	0.65	0.5	0.6	0.68	10
		0.9	0.6	0.55	0.5	0.5	0.6	7.6
		0.72	0.4	0.4	0.4	0.45	0.42	2.65
		0.55	0.4	0.32	0.22	0.31	0.27	1
		0.45	0.2	0.26	0.27	0.25	0.15	0.45
		0.5	0.3	0.26	0.13	0.25	0.14	0.46

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	HU-6	Streamflow (cfs)
Riffle Crest Thalweg	Velocity (fps)	2.3	1.28	2.1	2.65	2.81	2	10
		1.82	1.7	2.2	2.4	2.54	2	7.6
		1.4	0.96	2.05	1.65	2.05	1.45	2.65
		0.7	0.51	1.7	0.83	1.75	0.93	1
		0.5	0.35	1.3	1.25	1.46	0.65	0.45
		0.28	0.15	0.75	0.18	1.26	0.25	0.46

Point	Units	HU-2	HU-2	HU-2	HU-2	HU-2	HU-3	HU-4	HU-4	Streamflow (cfs)
Juvinal Rearing	Velocity (fps)			0.85			1.45	1.3	0.87	10
		1.07	1.25	1.2	1	2	1.1	0.87	0.38	7.6
		0.7	0.5	0.9	0.5	1.85	0.65	0.7	0.2	2.65
		0.35	0.12	0.61	0.26	0.75	0.37	0.41	0.08	1
		0.11	0.07	0.36	0.11	0.56	0.2	0.2	0	0.45
		0.02	0	0	0.19	0.22	0.1	0.14	0	0.46

Point	Units	HU-1	HU-4	HU-5	HU-5	HU-5	HU-5	HU-6	HU-6	HU-6	Streamflow (cfs)
Pool Max Depth	Velocity (fps)	0.38	2	0.86	0.68	0.85	1.2	0.37	0.91	0	10
		0.23	1.08				1.17	0.15	0.75	0	7.6
		0.05	0.6	0.4	0.3	0.1	0.85	0.4	0.45	0.3	2.65
		0.05	0.15	0.14	0.14	0.13	0.35	0.27	0.1	0	1
		0	0	0.14	0.04	0	0.15	0.05	0.23	0.01	0.45
		0	0	0.03	0	0	0	0.02	0.05	0	0.46

Point	Units	HU-1	HU-4	HU-5	Streamflow (cfs)
Pool Ramp	Velocity (fps)	0.89	0.87	0.35	10
		0.61	0.2	0.28	7.6
		0.4	0.01	0.25	2.65
		0.16	0.01	0.12	1
		0.05	0	0.05	0.45
		0	0	0.03	0.46

8.2 Productive BMI Riffle Habitat Data

Table 11. Junction Study Site BMI Productivity Data.

Point	Units	HU-1	HU-2	HU-3(1)	HU-3(2)	HU-3(3)	HU-4	HU-5	HU-6	Streamflow (cfs)
BMI XS Drift	% Active Channel Width V > 0.5 fps	79%	62%	69%	69%	43%	70%	64%	88%	62
		59%	61%	62%	69%	37%		67%	52%	44
		44%	56%	51%	57%	34%	48%	62%	52%	20
		36%	45%	41%	60%	21%	29%	23%	37%	15.3
		21%	33%	34%	55%	16%	9%	25%	8%	7.2
		8%	12%	0%	31%	5%	0%	12%	0%	2.8
		5%	2%	0%	24%	1%	0%	1%	0%	1.0

Point	Units	HU-1	HU-2	HU-3(1)	HU-3(2)	HU-3(3)	HU-4	HU-5	HU-6	Streamflow (cfs)
BMI XS Productive	% Active Channel Width V > 1.5 fps	42%	51%	56%	54%	37%	12%	58%	11%	62
		40%	38%	43%	47%	29%		45%	0%	44
		30%	27%	16%	33%	28%	0%	23%	0%	20
		15%	5%	0%	21%	10%	0%	9%	0%	15.3
		12%	4%	0%	13%	8%	0%	4%	0%	7.2
		5%	0%	0%	0%	0%	0%	0%	0%	2.8
		2%	3%	0%	3%	0%	0%	0%	0%	1.0

Table 12. Schaefer Site BMI Productivity Data.

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	HU-6*	HU-7	HU-8	Streamflow (cfs)
BMI XS Drift	% Active Channel Width V > 0.5 fps	60%	70%	50%	79%	71%	21%	69%	55%	37
		50%	65%	46%	67%	62%	15%	70%	55%	25
		36%	60%	43%	64%	55%	64%	50%	53%	11.2
		34%	52%	36%	33%	47%	62%	51%	44%	8.6
		27%	37%	27%	30%	37%	53%	28%	30%	4.4
		10%	12%	12%	21%	24%	26%	14%	13%	1.4
		6%	0%	2%	7%	10%	9%	4%	5%	0.6

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	HU-6*	HU-7	HU-8	Streamflow (cfs)
BMI XS Productive	% Active Channel Width V > 1.5 fps	38%	61%	41%	75%	61%	17%	59%	48%	37
		31%	54%	34%	62%	43%	10%	52%	48%	25
		30%	29%	13%	54%	35%	37%	28%	25%	11.2
		27%	12%	12%	29%	29%	20%	27%	7%	8.6
		16%	0%	2%	22%	8%	11%	19%	0%	4.4
		3%	0%	0%	1%	0%	0%	4%	0%	1.4
		3%	0%	0%	0%	0%	0%	0%	0%	0.6

*HU-6 experienced significant geomorphic change during high flow events which affected the cross-section shape at the BMI monitoring location.

Table 13. Abbey Study Site: Productive BMI Riffle Habitat Data.

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	Streamflow (cfs)
BMI XS Drift	% Active Channel Width V > 0.5 fps	66%	58%	34%	73%	66%	26
		57%	57%	30%	61%	58%	16
		37%	27%	35%	63%	48%	5.3
		33%	24%	17%	42%	35%	2.5
		0%	0%	0%	13%	19%	1.54
		0%	0%	0%	7%	8%	0.56

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	Streamflow (cfs)
BMI XS Productive	% Active Channel Width V > 1.5 fps	37%	0%	24%	38%	56%	26
		13%	0%	17%	25%	50%	16
		0%	0%	11%	0%	30%	5.3
		0%	0%	0%	0%	10%	2.5
		0%	0%	0%	0%	0%	1.54
		0%	0%	0%	0%	0%	0.56

Table 14. Thompson Creek Study Site: Productive BMI Riffle Habitat Field Measurements.

Point	Units	HU-1	HU-1	HU-2	HU-3	Streamflow (cfs)
BMI XS Drift	% Active Channel Width V > 0.5 fps	75%	80%	28%	66%	10
		72%	85%	42%	63%	7.6
		34%	21%	17%	56%	2.65
		21%	4%	4%	32%	1
		0.15	0.00	0.00	0.10	0.45
		0.15	0.00	0.00	0.10	0.46

Point	Units	HU-1	HU-1	HU-2	HU-3	Streamflow (cfs)
BMI XS Productive	% Active Channel Width V > 1.5 fps	33%	0%	0%	55%	10
		26%	0%	0%	49%	7.6
		16%	0%	0%	12%	2.65
		0%	0%	0%	7%	1
		0%	0%	0%	0%	0.45
		0.00	0.00	0.00	0.00	0.46

9 REFERENCES

Annear, T.C. and A.L. Condor. 1984. *Relative bias of several fisheries instream flow methods*. North American Journal of Fisheries Management 4:531-539.

Bell, M.C. 1986. *Fisheries Handbook of Engineering Requirements and Biological Criteria*. Fish Passage Development and Evaluation Program. U.S. Army Corps of Engineers. Portland, OR. 290 pp.

Bjornn, T.C. and D.W. Reiser. 1991. *Habitat requirements of salmonids in streams*. In Influence of forest and range management on salmonid fishes and their habitats, Pages 83-138. American Fisheries Society Special Publication 19, Bethesda, MD.

CDFG (California Department of Fish and Game). 2011. Interim Minimum Flow Recommendation for Maintenance of Juvenile Steelhead Rearing Habitat on the Big Sur River, Monterey County, California.

Dietrich, W. E. (1987). "Mechanics of flow and sediment transport in river bends." River Channel Environment and Process, K. Richards, editor, Basil Blackwell, 179-227.

Downie, S. T., C.W. Davenport, E. Dudik, F. Yee, and J. Clements. 2003. *Mattole River Watershed Assessment Report.* North Coast Watershed Assessment Program, 441 p. plus Appendices. California Resources Agency and California Environmental Protection Agency, Sacramento, California.

Dunbar, M.J., A. Gustard, M.C. Acreman, and C.R.N. Elliott. 1998. *Overseas approaches to setting river flow objectives*. Environment Agency, Bristol, U.K. R&D Technical Report W6B (96)4.

Everes t , F . H . , and D . W . Chapman . 19 72. *Habitat selection and spatial interaction by* juvenile chinook s almon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada , 2 9 : 9 1- 10 0 .

Flosi, G. Downie, S. Hopelain, J. Bird, M. Coey, R and Collins, B . *California Salmonid Stream Habitat Restoration Manual.* California Department of Fish and Game. 1998, revised 2003.

Giger, R.D. *Streamflow Requirements of Salmonids.* 1973. Federal Aid and Progress Reports, Fisheries. Oregon Wildlife Commission, Research Division.

Gore JA, Layzer JB, Mead J. 2001. *Macroinvertebrate instream flow studies after 20 years: a role in stream management and restoration*. Regulated Rivers: Research & Management 17: 527–542.

Harrelson, C.C. C. L. Rawlins, and J. P. Potyondy. 1994. *Stream Channel Reference Sites: An Illustrated Guide to Field Technique*. General Technical Report RM-245. U.S.

Department of Agriculture, U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Logan, P. & Brooker, M. P. 1983. T*he macroinvertebrate faunas of riffles and pools*. Water Research, 17(3): 263-270.

Mattole River and Range Partnership (MRRP). 2009. *Mattole Integrated Coastal Watershed Management Plan, Foresight 2020.* MRRP – strategic alliance of the Mattole Restoration Council, Mattole Salmon Group, and Sanctuary Forest. Petrolia, CA. August 31.

McBain & Trush, Inc. and the Department of Environmental Resources Engineering, Humboldt State University, 2012. Shasta River Big Springs Complex Interim Instream Flow Needs Assessment, Final Draft. Prepared for Ocean Protection Council and California Department of Fish and Game, Currently under peer review.

M&T and TU (McBain and Trush and Trout Unlimited). 2009. *Joint Recommendations for the Northcoast Instream Flow Policy*. Joint letter to the State Water Resources Control Board. Draft April 30, 2009.

National Marine Fisheries Service (NMFS). 2012. *SONCC Coho Recovery Plan*. Volume 2, Chapter 29, Mattole River Population. Page 29-11.
Lisle, T. E. *Using Residual Depths to Monitor Pool Depths Independantly of Discharge.* 1987. Berkely Ca: United States Department of Agriculture.

Swift, C.H. III. 1976. *Estimation of stream discharges preferred by steelhead trout for spawning and rearing in western Washington*. US Geological Survey Open File Report 75-155. Prepared in cooperation with the State of Washington Department of Game.

Thompson, K . E . 1972 . *Determining Streamflows for Fish Life* , In Proceedings , Instream Flow Requirement Workshop , Pacific NW River Basins Commitee., Portlan d, Oregon. p . 31- 50.