State of California
Department of Fish and Wildlife

PGC
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M e m o r a n d u m

Date: February 15, 2013

To: Phil Crader, Program Manager
State Water Resources Control Board
Division of Water Rights
PO Box 2000
Sacramento, CA 95812-2000

From: Curt Babcock, Habitat Conservation Program Manager
California Department of Fish and Wildlife
Region 1 – Northern

Subject: Upper Mattole River Site-Specific Study

The California Department of Fish and Wildlife (Department) received the technical memorandum "Streamflow Thresholds for Juvenile Salmonid Rearing and Adult Spawning Habitat in the Mattole Headwaters Southern Sub-Basin" (Report) prepared by McBain and Trush for Trout Unlimited. The upper Mattole River has coho salmon (*Oncorhynchus kisutch*), steelhead trout (*O. mykiss*), and other native aquatic organisms.

The purpose of the Report is to provide elements of a site-specific study outlined in the State Water Resources Control Board's 2010 "Policy for Maintaining Instream Flows in Northern California Coastal Streams" (Policy). The Report provides site-specific spawning and rearing flows for salmonids in the upper Mattole River as described in the Policy's Appendix C, Guidelines for Site-Specific Studies. The Report also describes the habitat available by type and assesses habitat quality.

McBain and Trush and Trout Unlimited consulted with the Department on the study design and drafts of the Report. The Department's comments on the study plan and the Report were as trustee agency for the aquatic resources in the upper Mattole River.

The Department believes the Report provides site-specific flow recommendations consistent with the Policy's Appendix C for juvenile rearing and spawning in the upper Mattole River that will, if applied, benefit salmonids. The Department is supportive of Trout Unlimited submitting it to the Division of Water Rights as part of the information needed for future water right applications or change petitions in the upper Mattole River.

If you have any questions or comments regarding this matter, please contact Staff Environmental Scientist Jane Arnold at 619 Second Street, Eureka, California 95501 or (707) 441-5671 or jane.arnold@wildlife.ca.gov.

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TECHNICAL MEMORANDUM

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

August 7, 2012

PREPARED FOR:

TROUT UNLIMITED

PREPARED BY:

MCBAIN & TRUSH, INC.

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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 streamflow by mid-summer in drier years. A one to two-and-a-half month period of very low seasonal baseflow occurs in almost all summers in the Mattole Headwaters. During this summer low flow period, juvenile steelhead and coho struggle to survive. If a juvenile salmonid does survive, it can rear through the winter and migrate to the Pacific Ocean the following spring.

For a juvenile steelhead or coho, the chance of returning as a spawning adult is very much a function of its smolt size upon entering the Pacific Ocean (Kabel and German 1967, Hume and Parkinson 1988, Ward and Slaney 1988, Ward et al. 1989, and Hayes et al. 2008). But the Mattole's lower mainstem and estuarine rearing habitats have been significantly degraded (MRRP 2009). As a result, juvenile salmonids can no longer 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 low flow period 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 early-summer transition from productive to stressful rearing conditions was a common and natural occurrence when the Mattole watershed was pristine, 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 by mid-summer through early-fall. To improve streamflow during receding summer baseflow, but particularly during the highly stressful summer low flow period, Trout Unlimited and the Center for Ecosystem Management and Restoration (TU/CEMAR) have partnered with the Mattole River's Sanctuary Forest and local water users to increase winter water storage as an alternative to direct summertime diversions. Sanctuary Forest has a well-established program to help local residences install water tanks as an alternative to summertime diversions. TU and CEMAR are working with Sanctuary Forest expand that program to non-residential water users and develop a long-term Streamflow Improvement Plan for Mattole Headwaters local water users, which includes this instream flow needs (IFN) study.

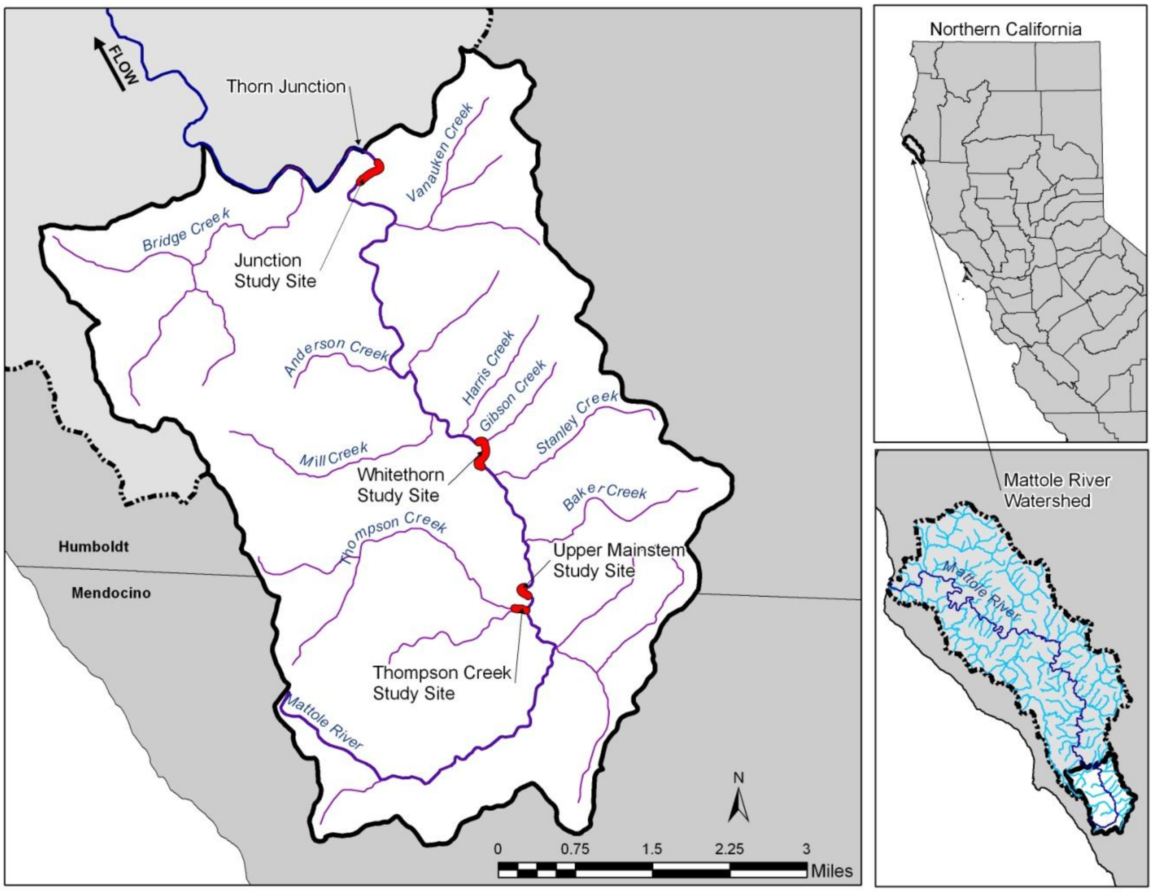

Figure 1. The Mattole Headwaters Southern Sub-Basin (Downie et al. 2003).

2 STUDY GOALS

Our primary study goal was to identify an instream flow threshold for the summer low flow period in the Mattole Headwaters. In an instream flow needs (IFN) study, the term “threshold” denotes an abrupt change in habitat or ecological function as a direct response to a small change in streamflow. We identify the summer low flow period by its effect on juvenile salmonid growth. Streamflow less than the summer 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 streamflow below the summer low flow threshold will substantially decrease chances of a juvenile salmonid surviving the summer. But survival through the low flow period will also depend on a juvenile’s condition and health upon entering the summer low flow period. Cumulative diversions during receding baseflow leading up to the summer low flow period could still degrade juvenile salmonid rearing habitat and lower overall stream productivity. From a management perspective, cumulative diversions during summer low flow could be curtailed, but the success of juvenile steelhead and coho would still be compromised if cumulative diversions preceding the summer low flow were significant. A secondary study goal, therefore, was to identify streamflow thresholds occurring before the onset of the summer low flow period that might jeopardize a juvenile salmonid’s chances of surviving. Also, the recession from spring high flows to summer low flows may begin when adult steelhead are still spawning, particularly in drier water years. A third study goal, therefore, was to estimate minimum streamflow thresholds for spawning habitat availability. Collectively, these streamflow thresholds will be necessary in devise a cumulative diversion strategy for the Mattole Southern Sub-Basin and permit terms acceptable to the State Water Resources Control Board, Department of Fish and Game, and other state/federal resource agencies.

Study Goal No. 1 – Estimate the upper instream flow threshold for the summer low flow period in the Mattole Headwaters.

Study Goal No. 2 – Estimate instream flow thresholds during receding spring and early-summer streamflows below which diversions would likely affect the ability of juvenile salmonids to survive the summer low flow period in the Mattole Headwaters.

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

3 STUDY SITES

The study area is the CDFG Mattole Watershed Assessment "Southern Sub-Basin" (Downie et al. 2003, Figure 1) with a drainage area of 29.5 mi^2 (including McKee Creek, entering the mainstem just upstream of Bridge Creek). Within this study area, four study sites were assessed along 6.5 miles of the Mattole River mainstem upstream of Thorn Junction (Figure 1). The sites included three mainstem sites and one tributary site, incorporating gaining and losing reaches of the watershed.

Each study site included five to seven hydraulic units. 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, the depositional bar-pool sequence (hydraulic unit) occurred 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 contained 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 used these naturally delineated hydraulic units to quantify the transition from good to poor habitat conditions in a reach.

Junction study site

The mainstem Junction study site (Figure 2) 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, continuing 1560 ft upstream, has seven hydraulic units (HU-7 was not mapped).

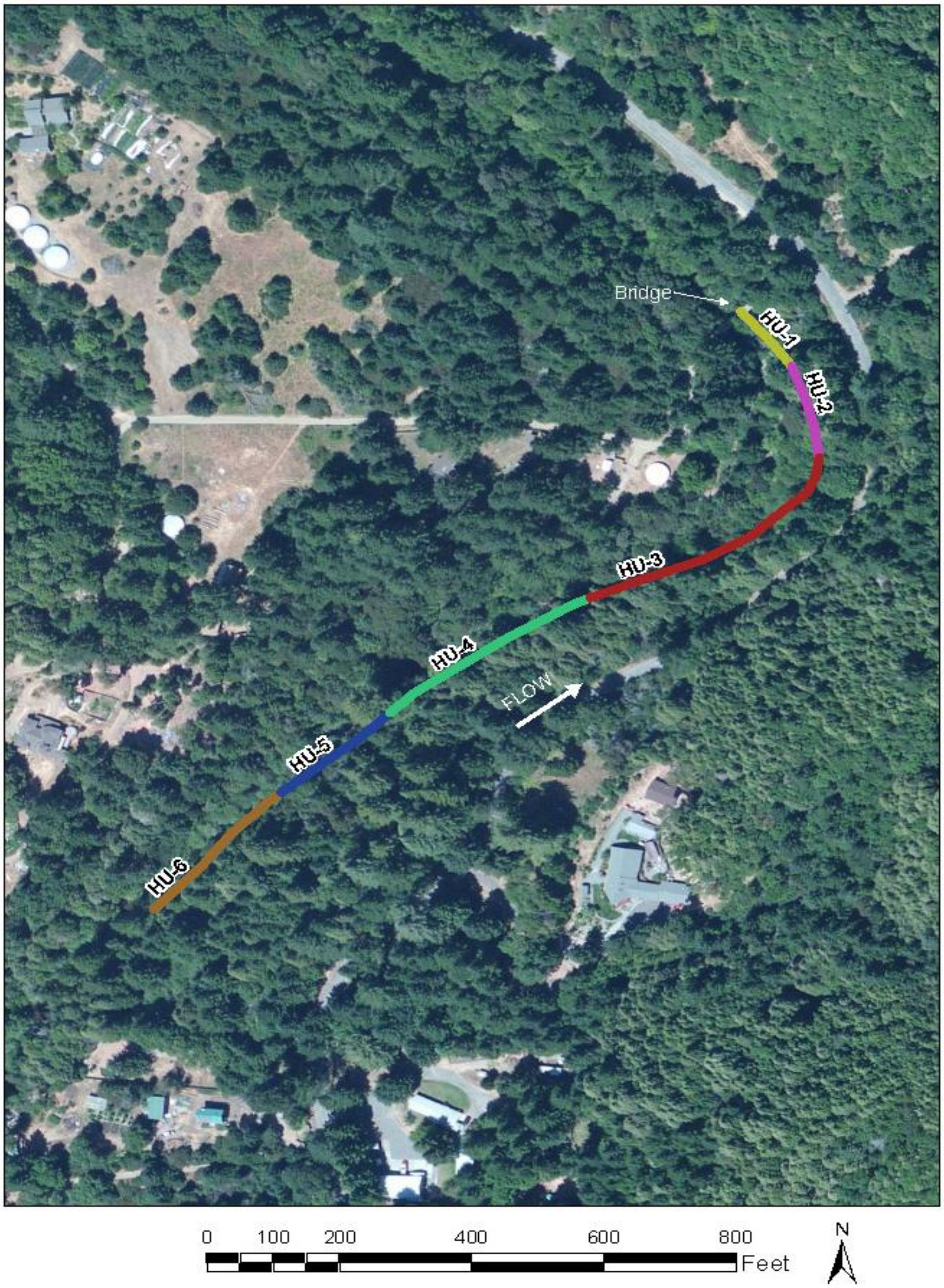

Figure 2. Junction study site and designated hydraulic units (HU).

Whitethorn study site

The mainstem Whitethorn study site (Figure 3) starts approximately 300 ft downstream from the confluence of Gibson Creek and the Mattole River (Figure 1). Shafer Bridge, at the downstream end, can be accessed approximately 0.25 mile north of Whitethorn Elementary School. The Whitethorn study site continues 1830 ft upstream and has a sequence of eight hydraulic units. During summer, this reach often experiences losing streamflow.

Figure 3. Whitethorn study site and designated hydraulic units.

Upper Mainstem study site

The Upper Mainstem study site (Figure 4) starts approximately 950 ft upstream of the entrance to the redwood retreat property and 1700 ft downstream from Thompson Creek. The Upper Mainstem study site continues upstream 700 ft and has a sequence of five hydraulic units. The site ends below the redwood retreat's storage buildings.

Figure 4. Upper Mainstem study site and Thompson Creek study site with designated hydraulic units.

Thompson Creek study site

The Thompson Creek study site (Figure 4) begins at the confluence with the mainstem Mattole River and extends 600 ft upstream to the redwood retreats' water diversion. The Thompson Creek study site includes a sequence of six hydraulic units. 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. The redwood retreat center is located between the Thompson Creek study site and the Upper Mainstem study site.

4 METHODS

4.1 Streamflow Data

One of TU's principal goals for the Streamflow Improvement 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 IFN study, however, a series of annual hydrographs provided a shows the periodicity of flow thresholds in different water years.

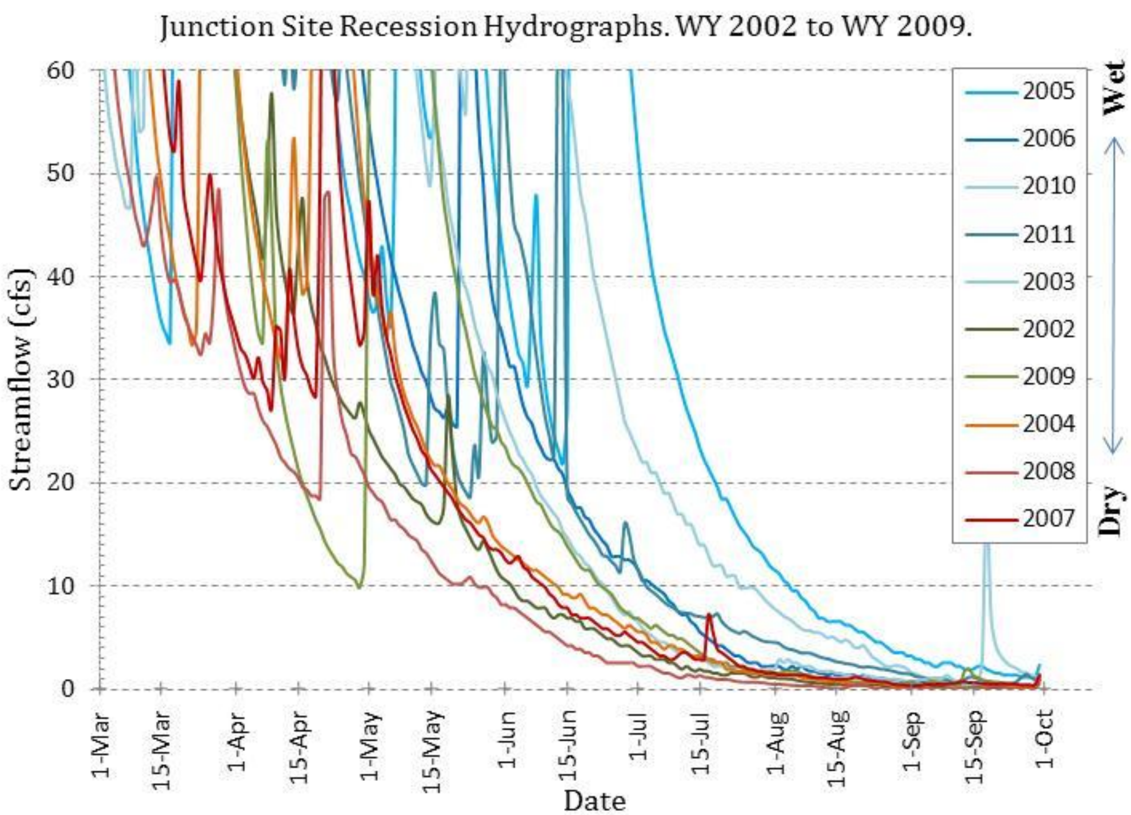

Figure 5. Modeled annual hydrographs showing spring/summer recession at Junction study site in Mattole Headwaters.

Because no long-term streamflow records exist for the upper Mattole watershed, flow data for this analysis were scaled from the USGS Mattole River at Ettersburg streamflow gauge (11468900) for the period of operation (June 2002 – October 2011). Streamflow data were based on empirical relationships between Ettersburg streamflow data and streamflow measurements at each site in WY2010 and WY2011.

Data measured at Thorn Junction and Ettersburg suggested that streamflow was approximately proportional between the two sites according to a ratio of catchment area through winter, but not in spring and summer. The upper Mattole watershed comprises approximately one-third of the total catchment area upstream of the Ettersburg streamflow gauge. 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 linear relationships between measurements made by Sanctuary Forest staff in WY2010 at their Thorn Junction site (named Mainstem-6, or MS6) and concurrent USGS streamflow data from Ettersburg gauge (Klein, unpublished report). Klein's results were applicable for streamflow at Ettersburg below 50 cfs (corresponding to approximately 14 cfs at MS6). These relationships were used to estimate streamflow at MS6 when streamflow was less than 50 cfs at Ettersburg during WY2002 to WY2009.

To estimate daily average streamflow at MS6 when streamflow at Ettersburg was greater than 50 cfs, CEMAR derived a statistical linear relationship between daily average streamflows at MS6 and USGS streamflows at Ettersburg, in water years 2010 and 2011. CEMAR operated a streamflow gauge at MS6 in 2010 and 2011. The linear relationship between streamflows at MS6 and USGS streamflows at Ettersburg was used to estimate streamflow above 50 cfs at MS6 during the period 2002 to 2009. CEMAR's streamflow data from 2010 and 2011 were used for all 2010 and 2011 analyses rather than estimates derived from linear relationships.

The MS6 data set from 2002 to 2011 was used to estimate streamflow at upstream study sites. Streamflow was measured at MS6 (just downstream from Junction Study Site) and at the Whitethorn study site, Upper Mainstem study site and Thompson Creek study site periodically during summer and fall 2011; these measured streamflows were used to derive statistical relationships between streamflow at MS6 and other upstream sites. These relationships were used to estimate daily average streamflows at each site from WY 2002 to WY 2011.

4.2 Streamflow Thresholds for Smolt and Juvenile Steelhead and Coho Rearing Habitat

To meet Study Goals No.1 and No. 2, three temporal phases of juvenile salmonid rearing and growth were defined 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 grow rapidly when riffle habitat with high benthic macroinvertebrate productivity (BMI) is abundant, low water temperatures favor the growth of fish and macroinvertebrates, and physical rearing habitat is abundant and diverse. From early-June through mid-July (depending on the WY type), juvenile salmonids struggle to maintain their weight and health as riffles shift from being productive to simply maintaining BMI biomass.

Water temperatures are higher than desired for rapid growth and rearing habitat becomes confined to pools/runs because riffles are 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 low flow period, when streamflow through the riffles can become extremely shallow or even go sub-surface, effectively isolating pools with no chance of juveniles escaping, 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.

Three streamflow thresholds corresponding to these three juvenile rearing phases were defined for juvenile salmonid and smolt rearing conditions: EXCELLENT, GOOD, and FAIR. Daily average streamflows dropping below the FAIR threshold defined the summer low flow period. A fourth streamflow threshold, CONNECTIVITY, identified when very low baseflow within the summer low flow period became intermittent.

Three scales of analyses were used in this study: specific monitoring locations, hydraulic units, and study sites (Figure 6). Streamflow thresholds were first identified at specific monitoring locations within each hydraulic unit. Multiple thresholds were assessed within each hydraulic unit to compute a single streamflow threshold for the hydraulic unit. Finally thresholds from each hydraulic unit in a study site were assessed cumulatively to assign a single streamflow threshold for a study site.

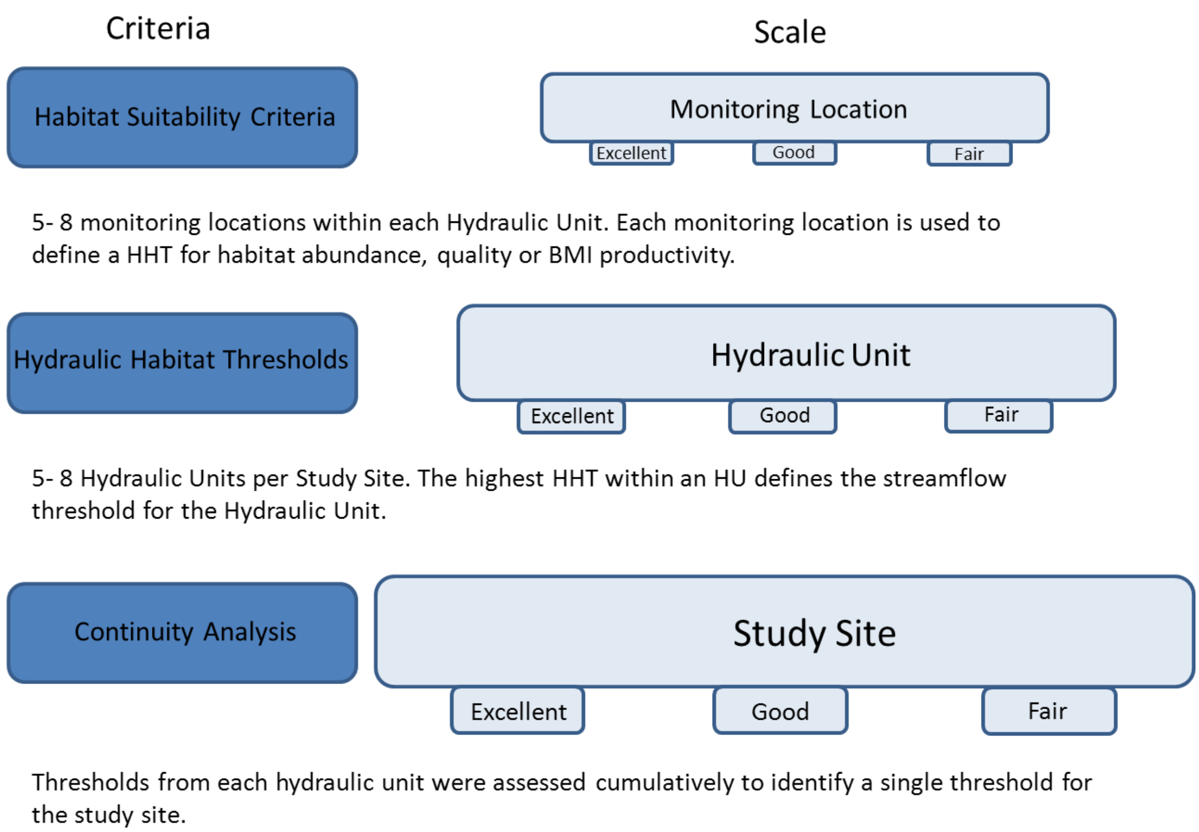

Figure 6. *Three scales of analysis used in this instream flow study.*

4.3 Applying Hydraulic Habitat Thresholds to Estimate Site Based Streamflow Thresholds

Hydraulic Habitat Thresholds (HHTs) were used to identify streamflows that provided EXCELLENT, GOOD, or FAIR juvenile salmonid rearing conditions within each hydraulic unit. In addition HHTs were used to identify GOOD habitat conditions for 1+ coho rearing in a subset of HUs. As in a PHABSIM analysis, HHTs employ suitability criteria to quantify habitat availability. In this HHT study, relationships between streamflow and suitability criteria are quantified at specific monitoring locations and/or cross-sections within each hydraulic unit (Figure 7 and Table 1) as indicators of habitat availability and quality, but habitat area (ft^2) is not quantified.

The monitoring locations used to quantify HHTs generally represent physical thresholds (e.g. hydraulic controls such as the riffle crest, areas of transition such as the base of the pool ramp, and/or locations of maximum depth). An HHT, therefore, identifies a threshold streamflow using physical criteria at a location that indicates a physical threshold or control in habitat or process being addressed. Our analytical method to identify streamflow thresholds at each study site had three parts:

1. Use physical suitability criteria at specific monitoring locations within each hydraulic unit to identify EXCELLENT, GOOD, or FAIR thresholds (HHTs) for salmonid habitat abundance, quality, and BMI productivity;
2. Use the minimum streamflow that met all HHTs for salmonid habitat abundance, quality, and BMI productivity to identify instream flow thresholds for EXCELLENT, GOOD, or FAIR juvenile rearing conditions in each hydraulic unit; and
3. Evaluate the juvenile rearing thresholds from each hydraulic unit collectively using a continuity assessment (described below) to identify reach-based HHT streamflow thresholds for each study site.

Three parameters of habitat were evaluated using monitoring locations within each hydraulic unit: salmonid habitat abundance, salmonid habitat quality, and BMI productivity (methods are described in Sections 4.4.1, 4.4.2, and 4.4.3). These parameters were assessed at every hydraulic unit within the four study sites. Five primary monitoring locations, and a minimum of one cross section, installed in each hydraulic unit, were used to evaluate habitat abundance, quality, and BMI productivity (Figure 7). Each parameter was ranked as EXCELLENT, GOOD, or FAIR based on physical suitability criteria at one or more monitoring locations or cross-sections (Table 3). The minimum streamflow (HHT) where all three habitat parameters were FAIR was used to rate the hydraulic unit as FAIR; the minimum streamflow where all three habitat parameters were GOOD was used to rate the hydraulic unit as GOOD, etc. Streamflow thresholds for each hydraulic unit were evaluated collectively using a continuity assessment to identify a streamflow threshold for the study site. In addition, to meet Study Goal No. 3 spawning preference criteria were applied to HHTs in the pool ramp (tail) and riffle crest thalweg (RCT).

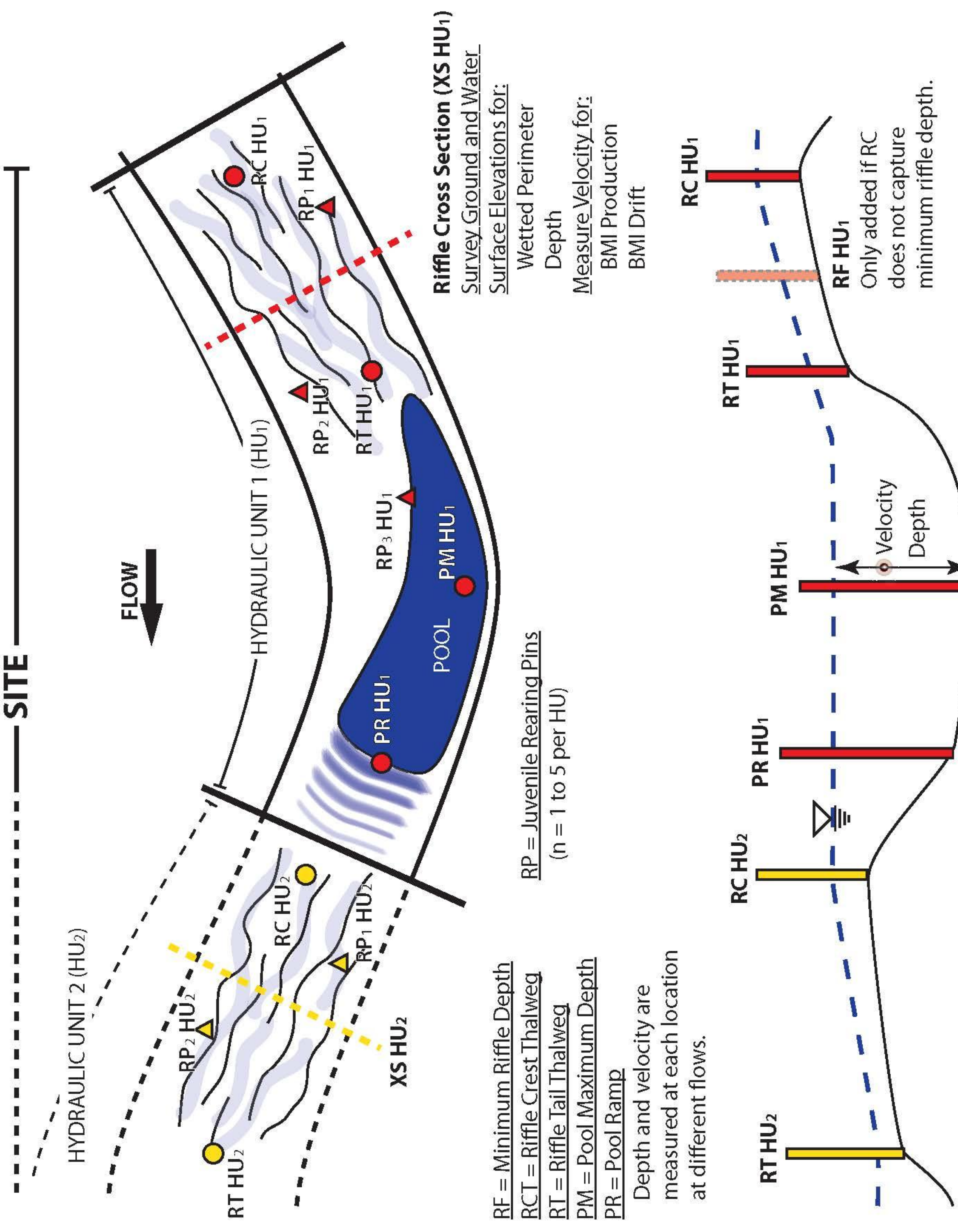

Figure 7. Schematic of an hydraulic unit illustrating the core and supplementary monitoring locations used to identify HHTs.

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 salmonids rearing habitat and BMI productivity. These thresholds were 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
Summer Low Flow Period	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 were associated with each habitat parameter assessed for juvenile salmonids.

Rating	**Habitat Abundance**		**Habitat Quality**		**Productive BMI Riffle Habitat**
Monitoring Location	***Pool Max Depth***	***Connectivity***	***RCT***	***Riffle Tail***	***BMI***
EXCELLENT Juv 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
Summer Low Flow 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

4.3.1 Habitat Continuity Assessment

No two hydraulic units provide the same area or quality of salmonid habitat for the same streamflow and, therefore, each has unique habitat streamflow thresholds. Using HHTs for the juvenile rearing parameters of habitat abundance, quality, and BMI productivity, hydraulic units were ranked as EXCELLENT, GOOD, or FAIR at every observed streamflow. This process produces a longitudinal mosaic of ranked hydraulic units throughout a study site. A chart showing the rank for each hydraulic unit as streamflow increases was created to estimate streamflow thresholds for the entire study site. This chart makes it easier to visually identify the minimum streamflows where all or most hydraulic units rank as FAIR, GOOD or EXCELLENT.

There is considerable natural variability between HUs in all the study sites. It was not considered necessary for every HU in a study site to provide FAIR or better habitat conditions for the site to be rated as FAIR. As a result, a single hydraulic unit with abnormally high thresholds does not dictate the instream flow thresholds for the entire study site. Instead, we used the sequences of ranked hydraulic units to create narrow ‘bands’ of streamflow where thresholds were met at each study site. This process is termed a habitat continuity assessment. In cases when an outlier HU was not identified the median value of each band was used as a discrete threshold.

4.4 Applying Hydraulic Habitat Thresholds to Estimate Streamflow Thresholds for Juvenile Steelhead and Coho Rearing

The physical suitability criteria used to evaluate salmonid habitat abundance, quality, and BMI productivity were compiled from literature values. Where necessary, we used our professional judgment based on observations of juvenile rearing over 20+ years of study to select suitability criteria from the available data. Sections 4.4.1 through 4.4.3 briefly describe how we used specific HHTs to identify streamflow thresholds in juvenile salmonid habitat abundance, quality, and BMI productivity.

4.4.1 Juvenile Salmonid Habitat Abundance

HHTs do not directly quantify habitat abundance (ft^2 of habitat), but instead identify a streamflow threshold where habitat is available across the majority of an hydraulic unit. In this IFN study we identified this threshold using the Pool Maximum Depth (PM) location (Table 1 and 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 were met at the PM location, we observed velocities throughout the pool or run generally exceeding these minimum criteria. For this study the streamflow which produced 0.2 fps of velocity at the PM location was used as the habitat abundance threshold representing minimum preference criteria for small juvenile steelhead (Everest and Chapman 1972).

4.4.1.1 Hydraulic Unit Connectivity

Connectivity is also a critical parameter of juvenile habitat abundance. Streamflows where juveniles cannot migrate between hydraulic units necessitate a change in feeding behavior and an increase in risk of predation. The streamflow where RCT depth was less than 0.15 ft was considered the minimum acceptable flow that could still support juvenile connectivity. At a 0.15 ft RCT depth, or less, juveniles are not free to migrate between pools. In addition BMI riffle habitat is too de-watered to provide drift to the run or pool downstream. Therefore, at an RCT depth of 0.15 ft, the pools also become functionally isolated without a supply of drifting BMI prey.

4.4.2 Juvenile Salmonid Habitat 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 good velocities will trigger successful behavior for rearing juvenile salmonids. Velocity for good juvenile rearing habitat should be sufficiently high, but not too high, to for a fish to maintain a focal position (Baldes 1968). 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). Because our study goals were focused on low flow of juvenile rearing thresholds, we did not define maximum velocity criteria for habitat quality (although this could be done).

4.4.3 BMI Productivity

Benthic Macroinvertebrates (BMI) are the primary prey for rearing juvenile salmonids. Velocity and substrate are the important drivers of BMI habitat (Gore et al. 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). The highest diversity and abundance in BMI assemblages have been found at velocities between 1.5 fps and 2.5 fps (Gore et al. 2001), while significantly fewer BMI species have been found when velocities were less than 0.5 fps (Kennedy 1967).

The production and drift of BMI were 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 within cross section analysis. In a riffle with appropriate substrate for productive BMI 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 (Table 3 and Figure 8). 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 percentage of the active channel meeting each HHT.

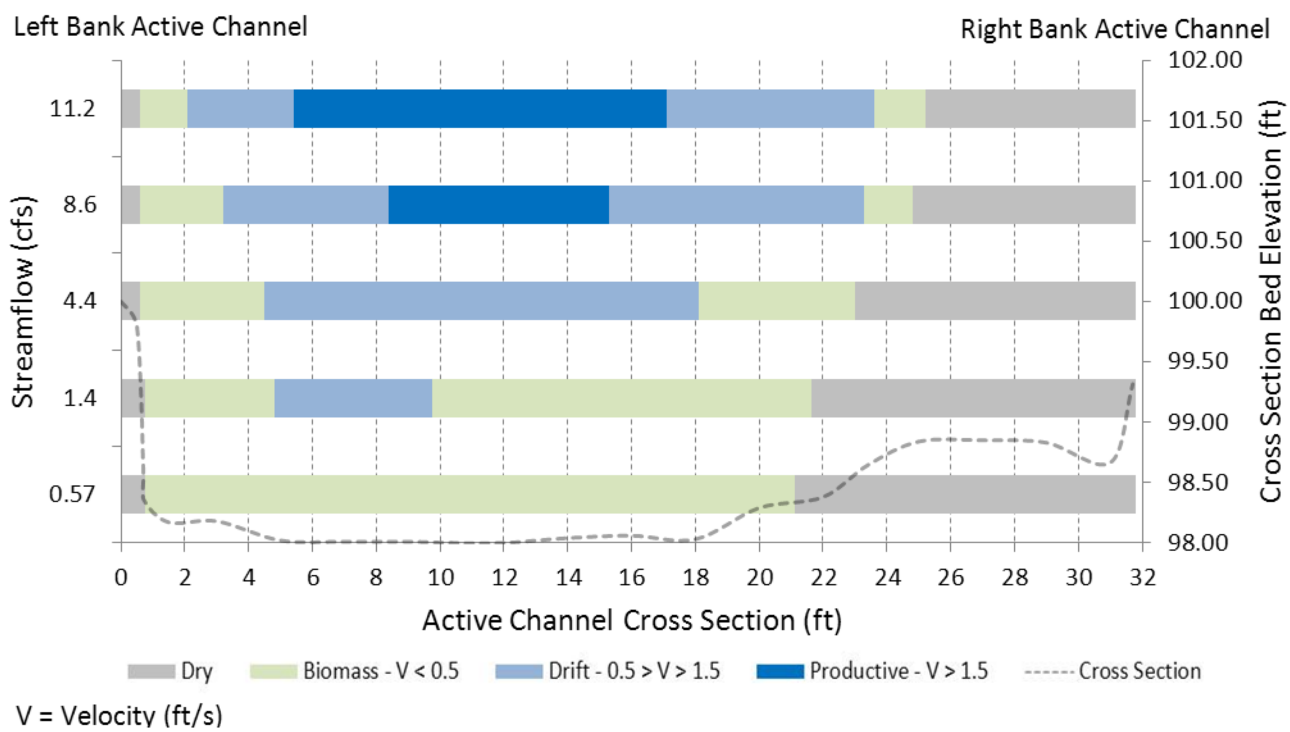

Figure 8. An example of the percent change in productive, drift, and biomass BMI riffle habitat within the active channel for measured streamflows at Whitethorn Study Site, HU-2 BMI XS.

4.5 HHTs to Estimate Streamflow Thresholds for Spawning Habitat

4.5.1 The Geomorphic Setting for Pool Ramp Spawning Habitat

During low flow conditions, the riffle-crest acts as a natural weir controlling the water surface elevation in the upstream pool. The riffle crest and the Pool Ramp (PR) are different faces of the same depositional feature (Figure 9). The PR is the bottom and side slope of a transverse bar and the riffle crest is the ‘crest’ of the bar. During low flow conditions the PR is creates a convergence and acceleration of flow as water moves towards the riffle crest. The physical properties of the PR and the riffle crest make them well suited to indicate hydraulic habitat thresholds for salmonid spawning.

The hydraulic setting of PRs is highly attractive to spawning female steelhead and coho. At spawning streamflows, the depth of flow increases upstream from the riffle crest as it approaches the PR and the velocity of flow increases downstream from the PR as it approaches the riffle crest. If minimum habitat suitability criteria of minimum depth at the riffle crest and minimum velocity at the PR are met at these thresholds locations than the reach between them generally exceeds these thresholds.

4.5.2 HHTs for Spawning Habitat Availability

We monitored thirteen pool ramp spawning locations to estimate minimum streamflow thresholds for adult steelhead/coho spawning habitat availability (Study Goal No. 3). The selected pool ramps were identified during an initial site visit based on substrate and hydraulic conditions for steelhead/coho spawning. At each spawning location two Hydraulic Habitat Thresholds (HHTs) were used to estimate Q_{Smin} and $Q_{Sminpreferred}$. Q_{Smin} is the minimum streamflow, based on habitat suitability criteria that provides any spawnable habitat in a given pool ramp; $Q_{Sminpreferred}$ is the minimum streamflow that provides preferred spawnable habitat along the extent of the pool ramp.

Q_{Smin} and $Q_{Sminpreferred}$ were estimated using depth and velocity criteria applied at the RCT, and the PR. At each selected spawning location two pins where placed in the channel thalweg – one pin at the upstream extent of the spawnable habitat (PR Pin) and another pin at the downstream riffle crest (RCT Pin), Figure 9. The distance between each pin was measured during installation; depth and velocity were recorded at both pins during each subsequent data collection effort.

The two pin method described above is suitable for the study sites in the current project but would probably be inadequate to evaluate spawning in complex hydraulic units, especially on riffles with multiple entrances. The RCT and PR pins evaluate thalweg hydraulic conditions. The PRs sampled in this study tended to have low channel side slopes and relative uniform hydraulics in the mid channel. Therefore we considered depth and velocity measured along the thalweg adequate to identify incipient spawning conditions in these relatively uniform hydraulic units. However good spawning conditions may become available at higher flow towards the channel boundaries; pool ramps with complex topography could require more than two pins or a cross-sectional approach for evaluating spawning criteria.

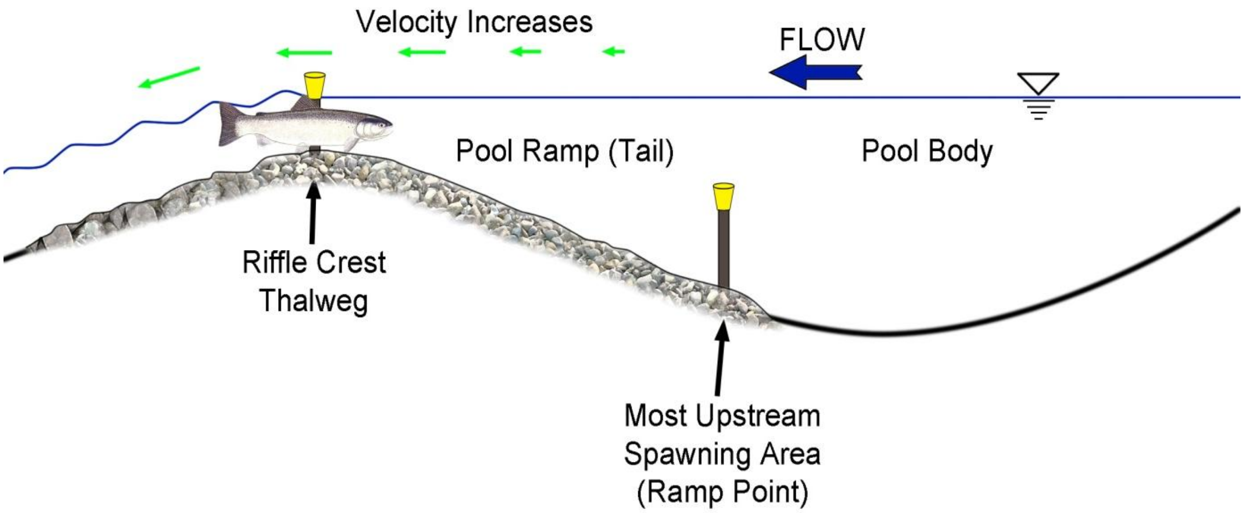

Figure 9. Pin locations within a pool ramp to estimate Hydraulic Habitat Thresholds for spawning habitat.

This IFN quantifies flows for both "minimum" and what we call "minimum preferred" spawning. Many studies indicate that although steelhead and coho generally prefer spawning at 0.8 ft depth or greater, spawning occurs at depths down to and even below 0.5 ft (Moyle et al. 1995, Bratovich and Kelly 1988, Barnhart 1986, Bovee 1978). (Note that when RCT depth is equal to 0.5, then depths exceeding 0.5 ft and often exceeding 0.8 ft occur at some location between the RCT and the PR.) Therefor minimum depth criteria at the RCT of 0.5 ft $Q_{S\ min}$ and 0.8 ft for $Q_{Sminpreferred}$ were used to indicate the initiation of spawning depth. Similarly, minimum velocity criteria at the PR Pin of 0.5 fps for $Q_{S\ min}$ and 1.0 fps for $Q_{Sminpreferred}$ were used to estimate initiation of velocities promoting spawning in the downstream PR.

Table 4. Suitability criteria for spawning HHTs.

Thresholds	Suitability Criteria	
	Depth [ft]	**Velocity [fps]**
Q_{Smin}	0.5	0.5
$Q_{Sminpreferred}$	0.8	1.0

The Q_{Smin} and $Q_{Sminpreferred}$ are the HHTs that met the habitat suitability criteria (RCT depth or PR Velocity) from Table 4. Good spawning conditions can and do occur at streamflows above $Q_{Spreferred}$, similarly streamflows between Q_{Smin} and $Q_{Sminpreferred}$ are expected to provide increasingly favorable spawning possibilities for steelhead.

4.6 Large (1+) Juvenile Coho Rearing

The presence of instream wood was not a required parameter in the HHT evaluation of instream flow thresholds for rearing juvenile salmonids. However the density of summer rearing juvenile coho is positively correlated with instream wood (Roni and Quinn, 2001) and the affinity of juvenile coho for cover is believed to increase with fish size (Reinhardt and Healey, 1997). To estimate instream flow thresholds for large (1+) rearing juvenile coho habitat, we identified five hydraulic units (Table 5) which contained instream wood and log jams typical of desirable coho rearing habitat (e.g., Figure 10 and

Figure 11). In these hydraulic units we monitored thalweg water velocity in the deepest part of the pool at or directly adjacent to the instream wood or cover (the Pool Maximum Depth monitoring location). A minimum velocity of 0.2 fps at the monitoring location identified a streamflow threshold providing benthic invertebrate drift and hydraulic habitat for 1+ juvenile coho rearing under woody cover and log jam structures. This was considered the streamflow threshold for GOOD rearing habitat for 1+ coho. While 0.2 fps represented the upper end of coho preference velocities (Beecher et al. 2002) an HHT of 0.2 fps on the thalweg general created lower velocities and small eddies as flow moves through instream wood structures which can provide GOOD coho habitat.

Table 5. Hydraulic units used to evaluated for coho rearing habitat.

Study Site	Hydraulic Unit	Estimated Residual Pool Depth (ft)*	Presence of Wood
Junction	3	1.95	Yes
Junction	7	6	Yes
Junction	8	4	Yes
Whitethorn	6	2.95	Yes
Upper Mainstem	3	2.6	Yes

***Average RCT depth – average Pool Maximum Depth = Estimated Residual Pool Depth**

Figure 10. Hydraulic unit #6 in the Whitethorn study site.

Figure 11. Hydraulic unit #3 in the Upper Mainstem study site.

4.7 Wetted Perimeter Methods

Wetted perimeter (WP) 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 Condor 1984), or favorable BMI food production (Bell 1973 and Swift 1976). Wetted perimeter was plotted versus streamflow to identify the maximum curvature (or 'breakpoint') in the wetted perimeter curve, Figure 12 (CDFG 2011). However, Dunbar et al. (1998), find that the minimum streamflow, determined by the break point significantly reduces 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 asymptotes have been identified, associated streamflows can be determined from the WP curves.

Riffle cross-sections in the productive BMI habitat analysis were surveyed for the wetted perimeter at each streamflow to compute 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. Wetted perimeter thresholds were included in this analysis to cross-walk HHTs with more traditional IFN assessment methods.

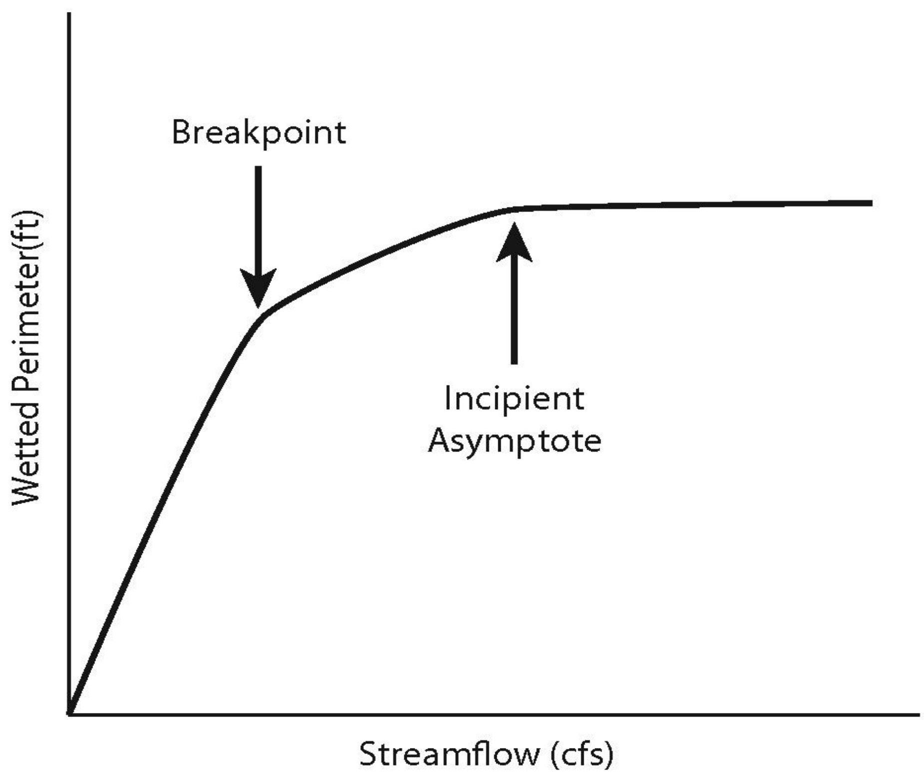

Figure 12. CDFG (2011) wetted perimeter 'breakpoint' and 'incipient asymptote' streamflow thresholds.

5 RESULTS

This IFN study estimated instream flow thresholds for EXCELLENT, GOOD, and FAIR juvenile salmonid rearing habitat and adult steelhead and coho spawning habitat at each study site. 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 identify the instream flow threshold marking transitions to the summer low flow period at each study (Figure 18 to Figure 20). Two minimum spawning thresholds were estimated and are presented in Table 9.

5.1 HHT Field Measurements in Each Study Site

Data were collected at seven streamflows in the Mattole Headwaters during this IFN study (Table 6). Depth and velocity data 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/coho spawning. Figure 13 is an example of how HHTs were identified using habitat criteria in Table 3.

Table 6. Observed streamflows (cfs) at each study site.

Study 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*
Whitethorn	*11.2*	*8.6*	*4.4*	*1.4*	*0.57*	*37*	*26*
Upper Mainstem		*5.3*	*2.5*	*1.4*	*0.56*	*26*	*16*
Thompson		*2.6*	*1*	*0.45*	*0.46*	*10*	*7.6*

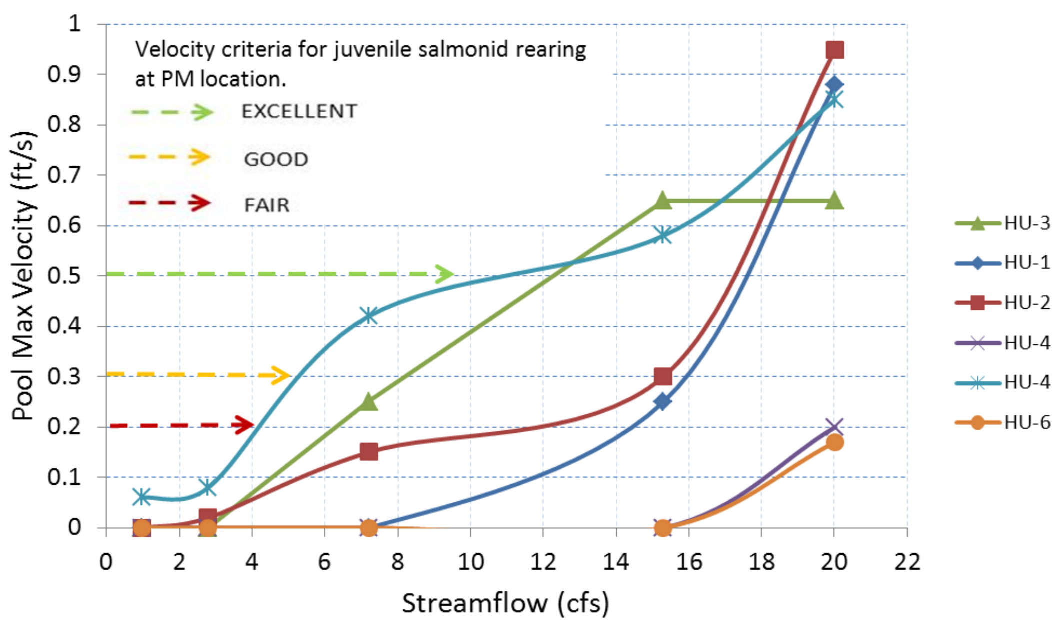

Figure 13. Identification of HHTs using threshold criteria – example showing velocities at Pool Maximum Depth locations (PM) for the Junction study site.

5.2 Wetted Perimeter Results.

Wetted perimeter was plotted against streamflow at each BMI cross-section to identify the CDFG breakpoint and incipient asymptote thresholds (Figure 14 to Figure 17). Data points were connected by linear interpolation to help identify thresholds between two points. Some HU had multiple wetted perimter cross sections; in these cases the HU's were labeled HU #(1), (2), (3) etc.

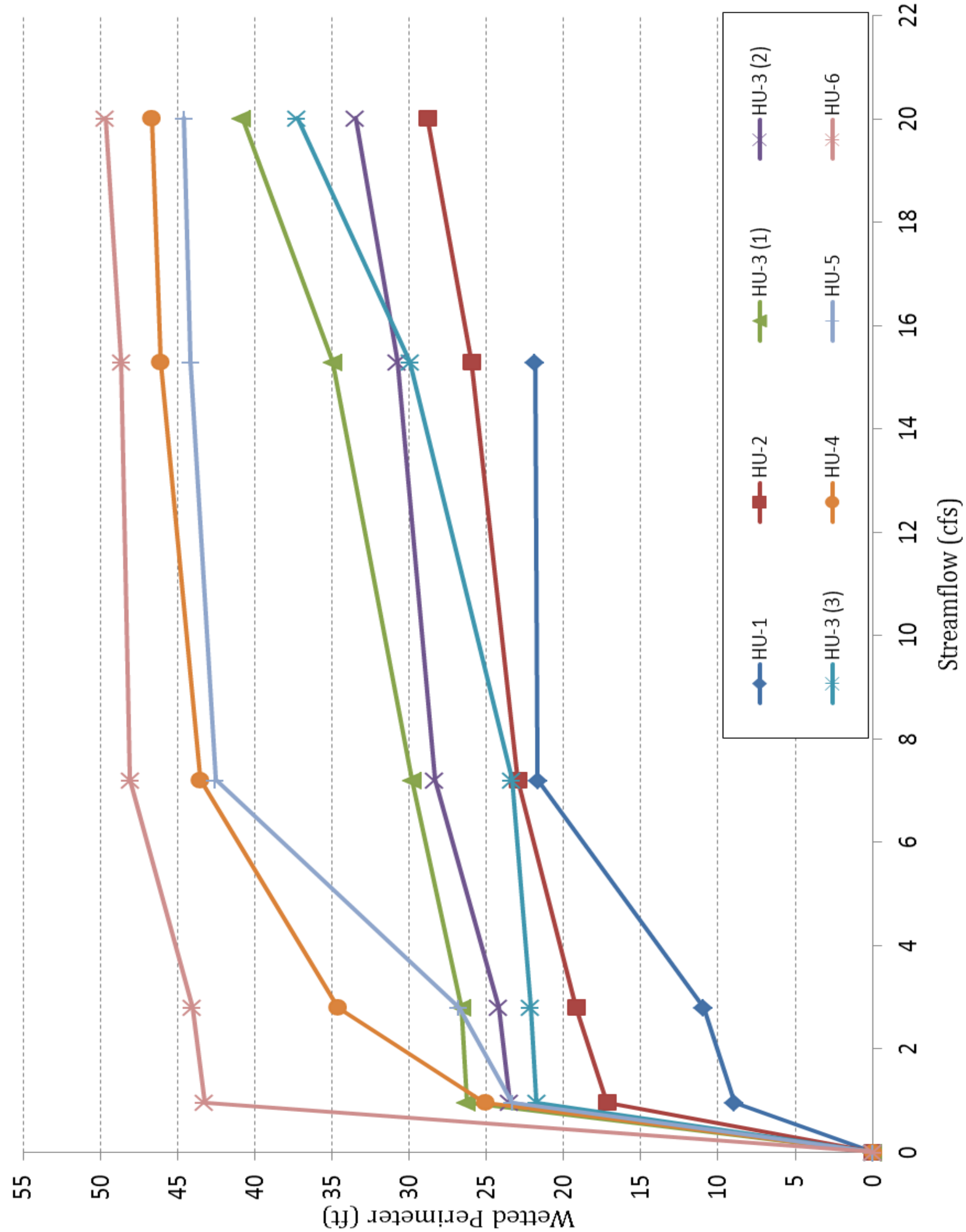

Figure 14. Junction study site: wetted perimeter vs. streamflow at BMI cross sections.

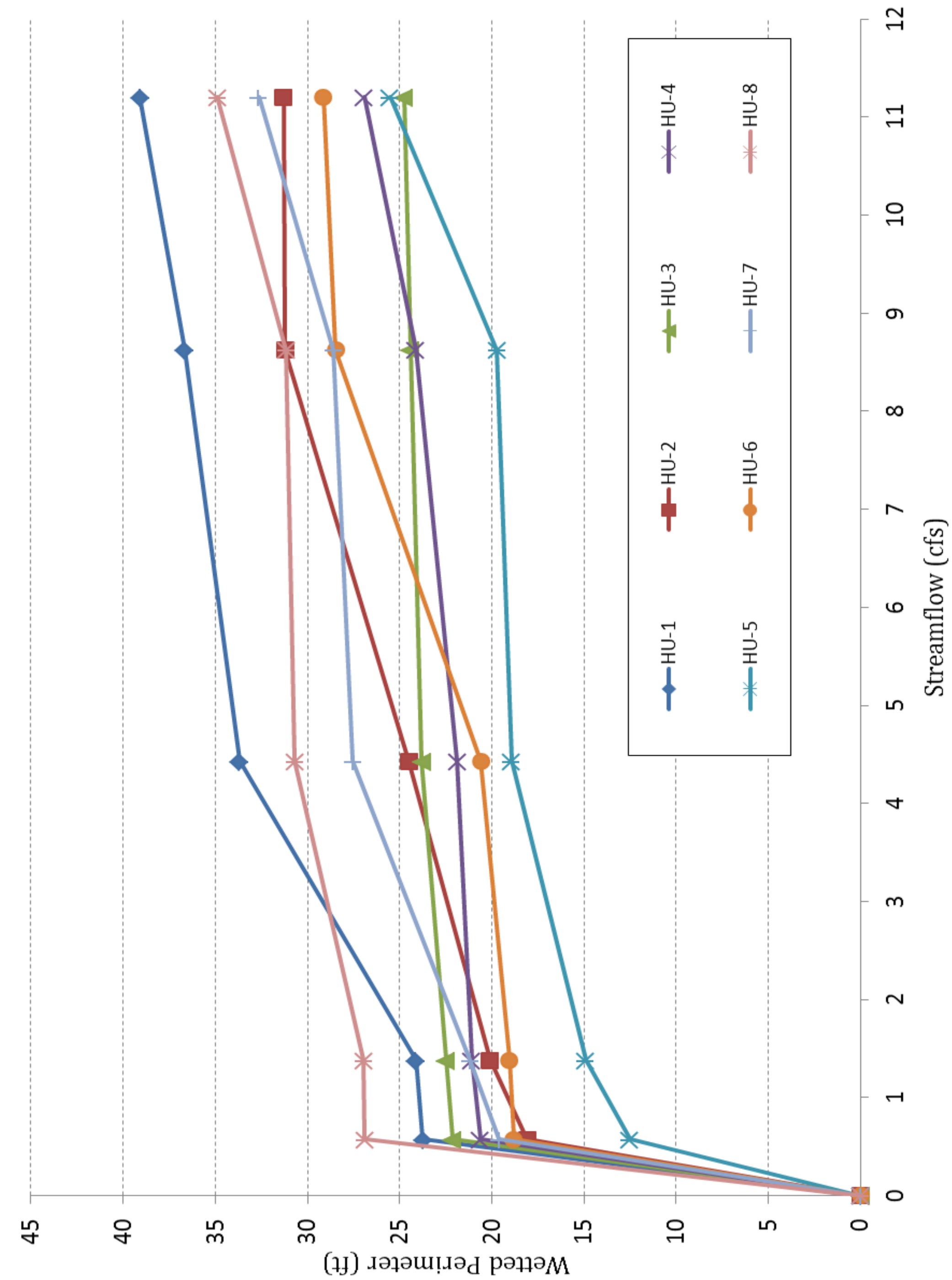

Figure 15. Whitethorn study site: wetted perimeter vs. streamflow at BMI cross sections.

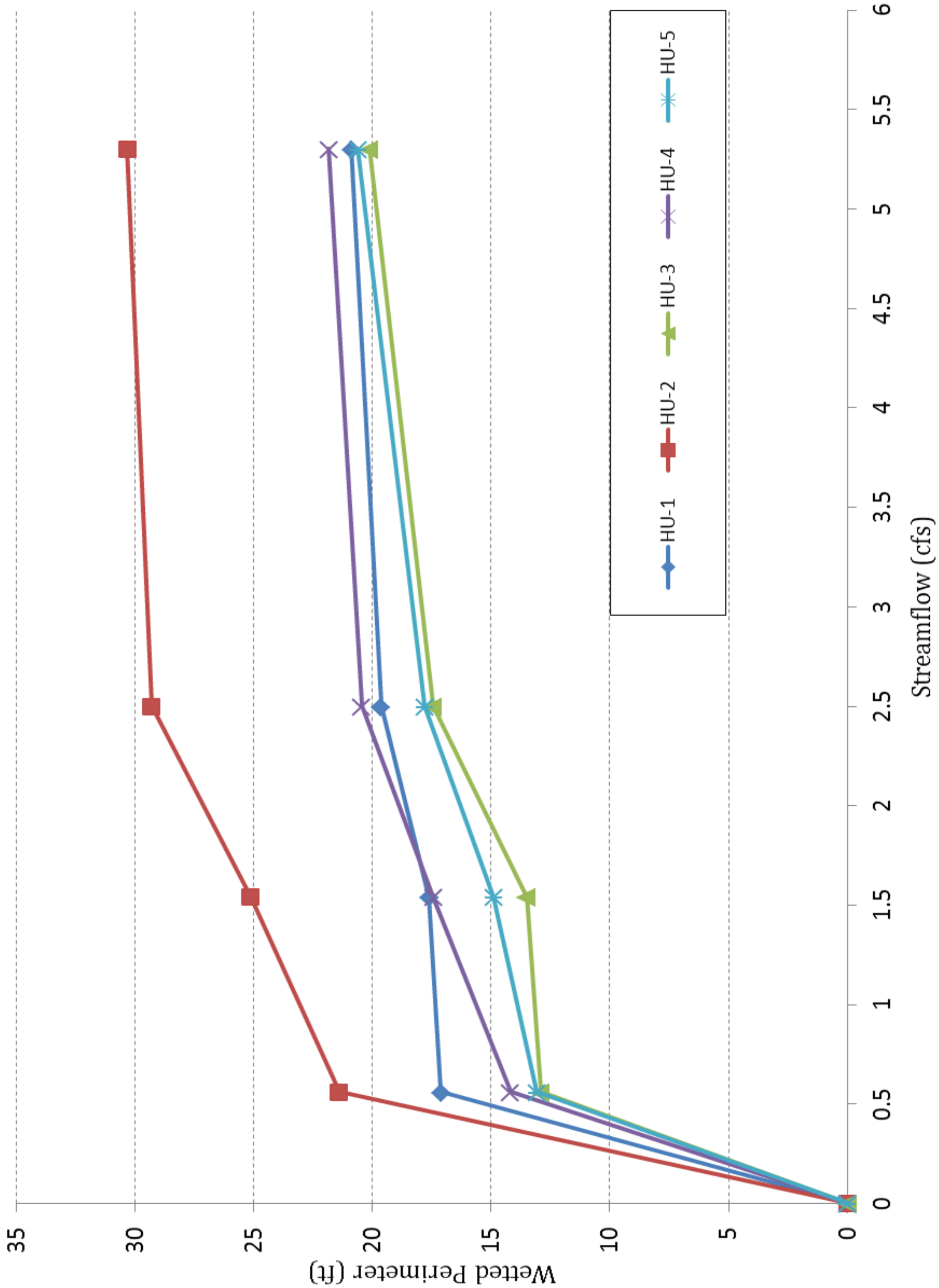

Figure 16. Upper Mainstem study site: wetted perimeter vs. streamflow at BMI cross sections

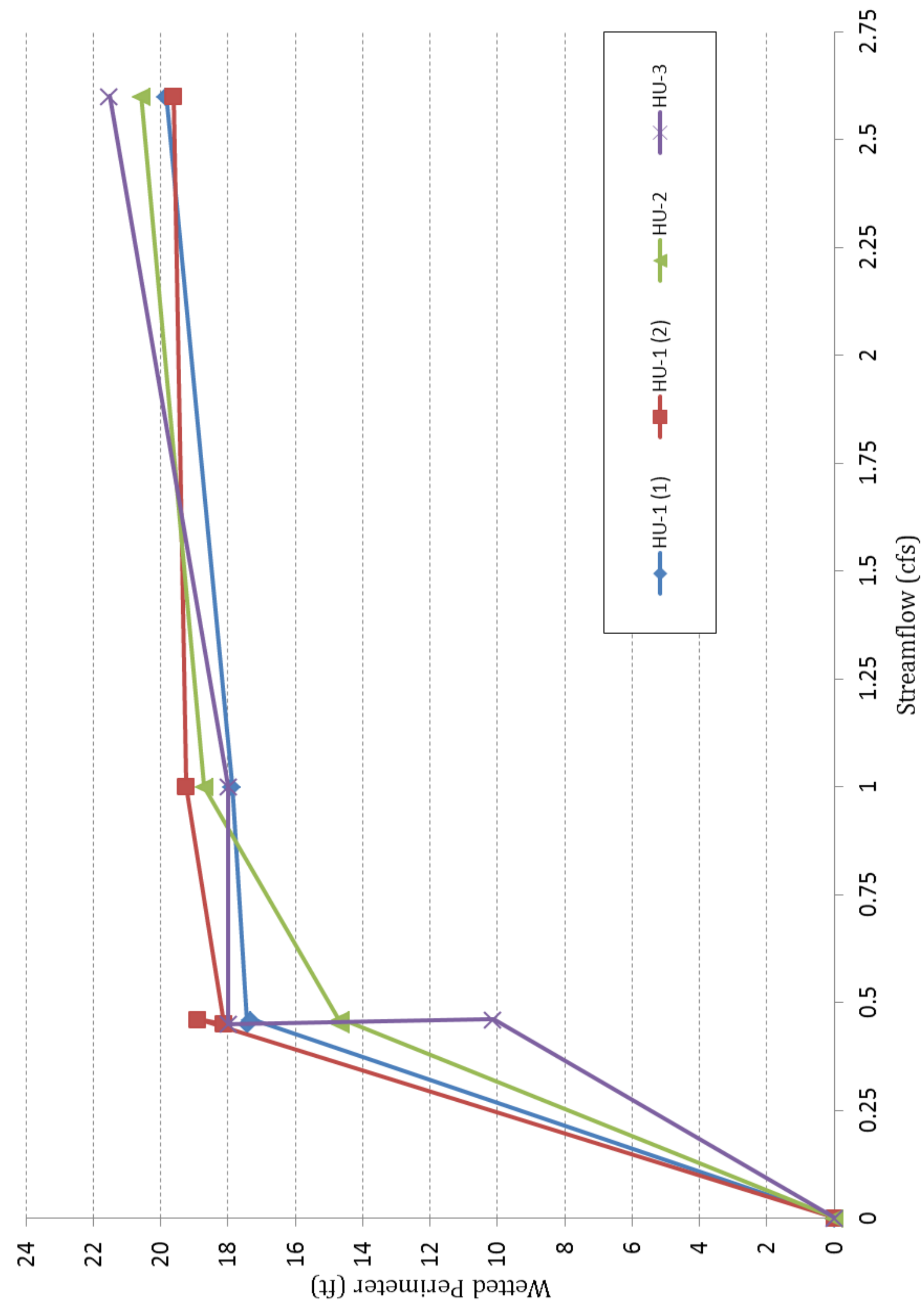

Figure 17. Thompson Creek study site: wetted perimeter vs. streamflow at BMI cross sections.

Thresholds for the breakpoint and incipient asymptote in the wetted perimeter data were identified in Figure 14 to Figure 17 and compiled in Table 7. The value of these thresholds is subject to the number and density of observed streamflows. The more streamflows that are monitored close to the threshold value, the more refined the breakpoint and incipient asymptote thresholds become. Therefore the breakpoint and incipient asymptote thresholds presented here could change slightly if more data were collected.

Table 7. Summary of breakpoint and incipient asymptote streamflow thresholds for all study sites

Study Site	**HU**	**Q Breakpoint (cfs)**	**Q Incipient Asymptote (cfs)**
Junction	1	3.5	7.2
	2	1	7.2
	3 (1)	1	3
	3 (2)	1	7.2
	3 (3)	1	1
	4	2.5	7.2
	5	4	7.2
	6	1	4
Whitethorn	1	1	4.4
	2	1	8.2
	3	0.6	0.6
	4	0.6	0.6
	5	1	4.4
	6	0.6	8.2
	7	0.6	4.4
	8	0.6	2
Upper Mainstem	1	0.5	2.5
	2	1	2.5
	3	0.5	2.5
	4	0.5	2.5
	5	0.5	2.5
Thompson Creek	1 (1)	0.45	1
	1 (2)	0.45	1
	2	0.65	1
	3	0.4	1

5.3 Instream Flow Thresholds for 1+ Coho Rearing Habitat

As discussed in Section 4.6, we identified a streamflow threshold for GOOD 1+ coho rearing habitat in five hydraulic units (Table 8). Streamflow thresholds for coho rearing habitat were estimated from rating curves following the same methodology as all HHTs (Section 5.1). These thresholds supplement thresholds identified from the continuity assessment (Section 5.4) for Study Goals 1 and 2. Streamflow thresholds for GOOD 1+ coho rearing habitat do not incorporate productive BMI habitat and thus are not included in the continuity assessment, however we compared GOOD 1+ coho thresholds to the general streamflow thresholds for rearing juvenile salmonids (Table 10) in the recommendations (Section 6).

Table 8. Instream flow thresholds for 1+ coho rearing habitat.

Study Site	Hydraulic Unit	Estimated Streamflow Threshold for GOOD 1+ Coho Rearing (cfs).*
Junction	3	6.5
	7	20
	8	6
Whitethorn	6	6.5
Upper Mainstem	3	4.5

* Estimated streamflow based on 0.2 fps velocity threshold at Pool Maximum Depth location adjacent to instream wood.

5.4 Continuity Assessment for Juvenile Rearing Habitat

A continuity assessment of multiple hydraulic units was used to identify reach based thresholds at each study site. The continuity assessment incorporated juvenile salmonid habitat and productivity thresholds as well as wetted perimeter data to present a longitudinal picture of instream flow conditions. Overlying multiple thresholds for each hydraulic unit provided a tool from which to interpret reach based thresholds. Habitat abundance and quality were assessed together as “habitat” and BMI productivity was assessed as “Productivity.” A chart showing the rank of habitat and productivity (EXCELLENT, GOOD, FAIR or less than FAIR) for each hydraulic unit as streamflow increases was created. A marker color was created for each ranking. If an hydraulic unit provided FAIR habitat, but less than FAIR productivity, the marker was represented as a hash, with the FAIR color as the background. Figure 18 to Figure 20 show the continuity assessments for the Junction, Whitethorn, and Upper Mainstem study sites.

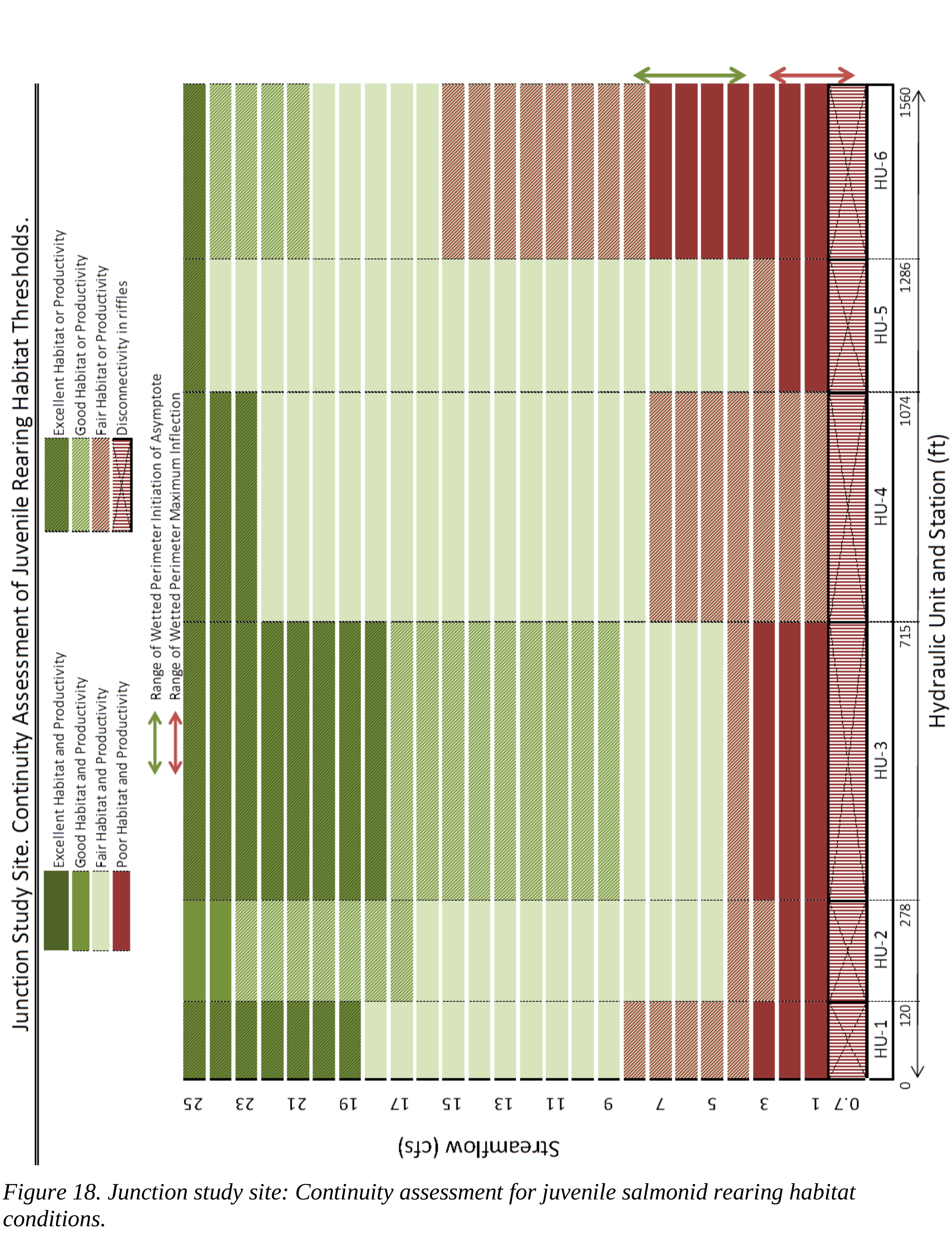

Figure 18. Junction study site: Continuity assessment for juvenile salmonid rearing habitat conditions.

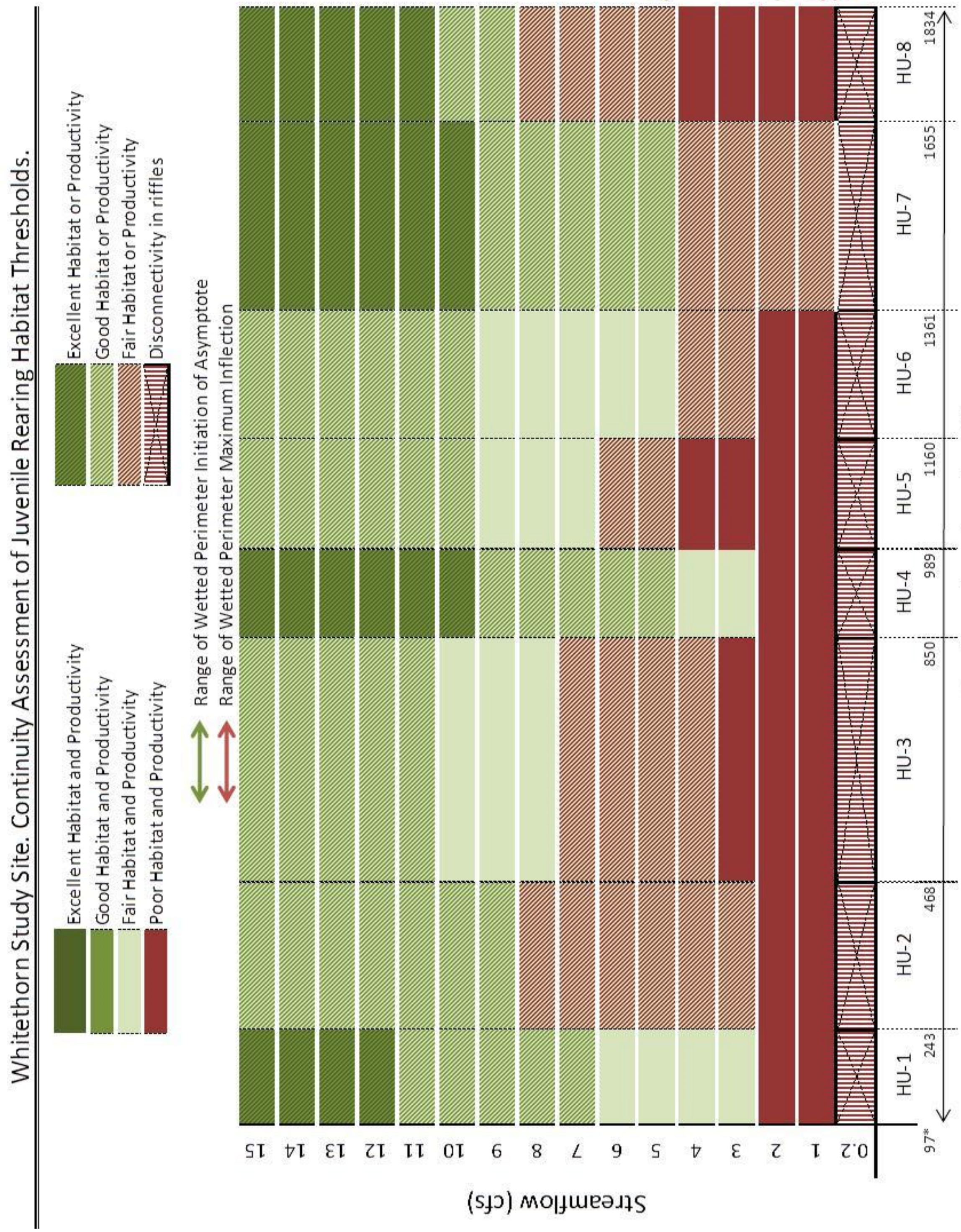

Figure 19. Whitethorn study site: Continuity assessment of hydraulic units for juvenile rearing habitat.

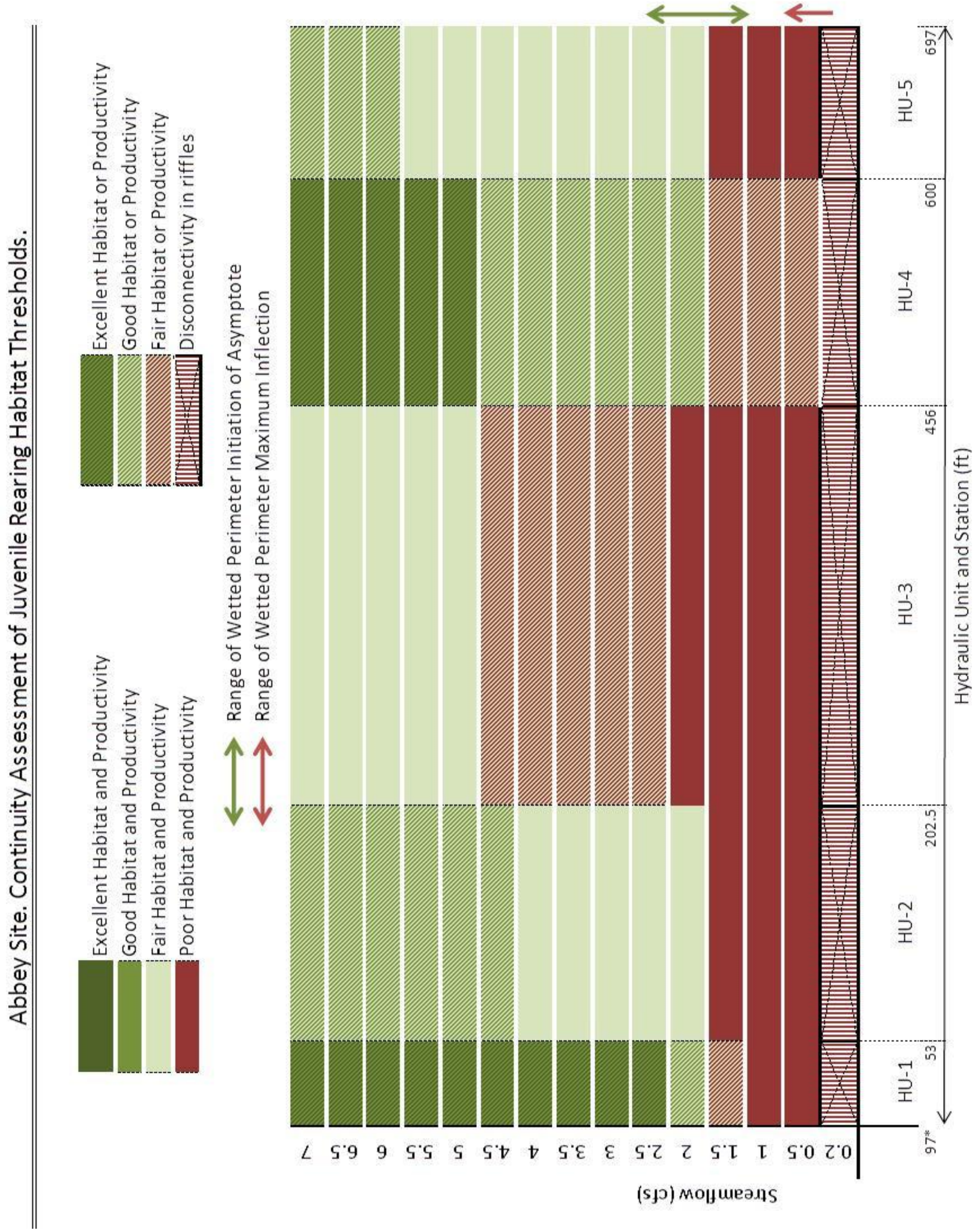

Figure 20. Upper Mainstem study site: Continuity assessment of hydraulic units for juvenile rearing habitat.

5.5 Spawning Thresholds

Spawning thresholds could only be identified on hydraulic units with spawning habitat. Q_{Smin} and $Q_{Sminpreferred}$ are presented for thirteen spawning locations in Table 9. Thresholds for Qs_{min} and $Q_{Sminpreferred}$ were also compiled in Table 10.

Table 9. Spawning Hydraulic Habitat Thresholds.

Study Site	HU	$Q_{Smin\ (cfs)}$	$Q_{Sminpreferred\ (cfs)}$
Junction	1	13	50
	2	7	16
	3	18	47
	6	19	34
	Median	**15.5**	**40.5**
	Average	**14.2**	**36.7**
Whitethorn	2	16	35
	3	8	26
	4	5.5	16
	5	11	29
	8	10	45
	Median	**10**	**29**
	Average	**10.1**	**30.2**
Upper Mainstem	1	7	15
	5	6	35
	Median	**6.5**	**25**
	Average	**6.5**	**25**
Thompson Creek	1	9	14
	4	6	13
	Median	**7.5**	**13.5**
	Average	**7.5**	**13.5**

5.6 Streamflow Thresholds

Streamflow thresholds for adult spawning and juvenile salmonid rearing from Junction Site overlaid onto 10 years of spring to summer recession hydrographs (Figure 21). As discussed in Section 3.3 these thresholds are bands, or streamflow ranges, that meet or exceed the HHT criteria in most hydraulic units within each study site identified from the continuity analysis. The middle streamflow from each band was used to assign a discrete streamflow threshold for each study site.

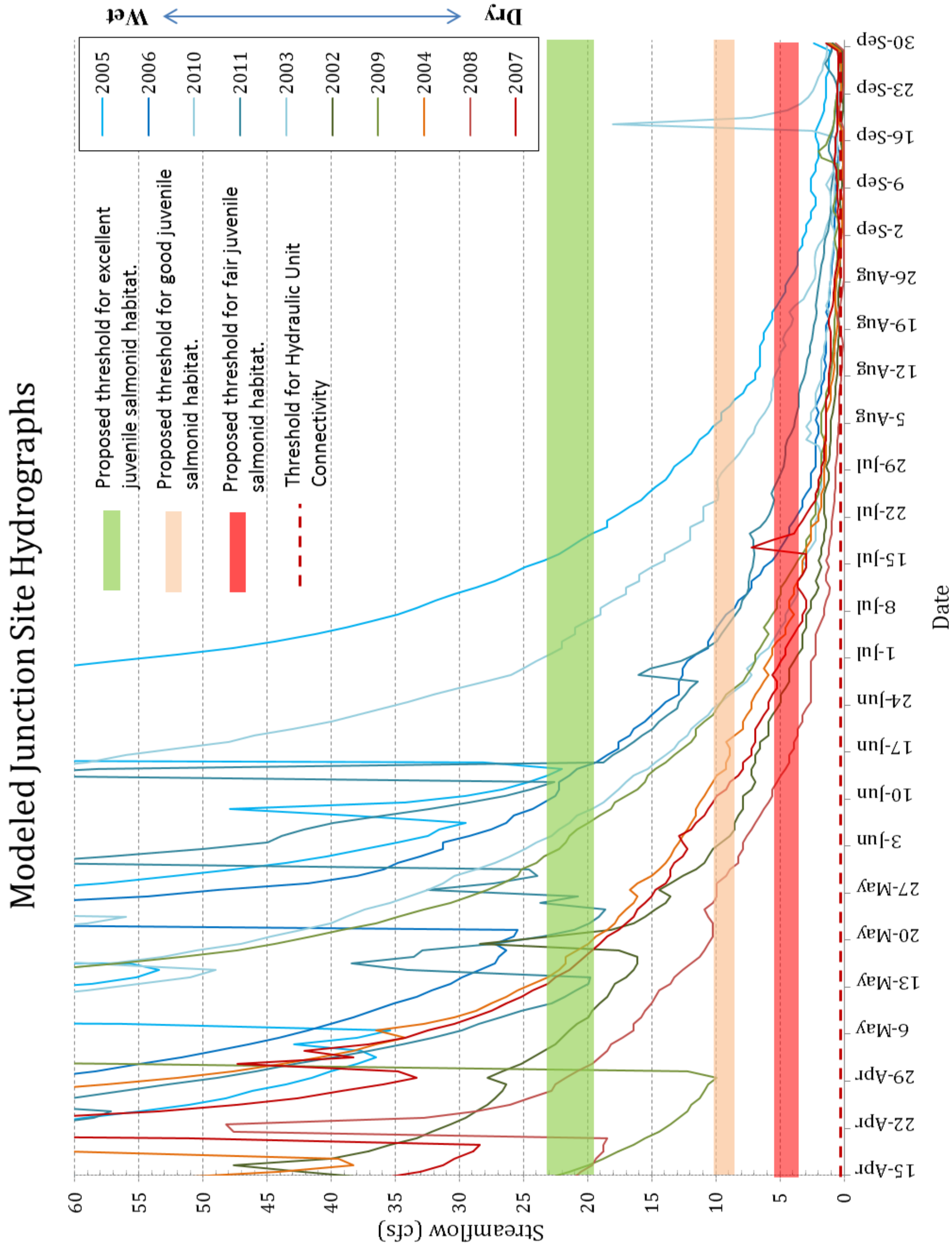

Figure 21. Spring through early- fall recession daily average hydrographs for WY 2002 through WY 2011 at the Junction study site with streamflow thresholds for EXCELLENT, GOOD, and FAIR juvenile rearing habitat conditions. Streamflow modeled by CEMAR.

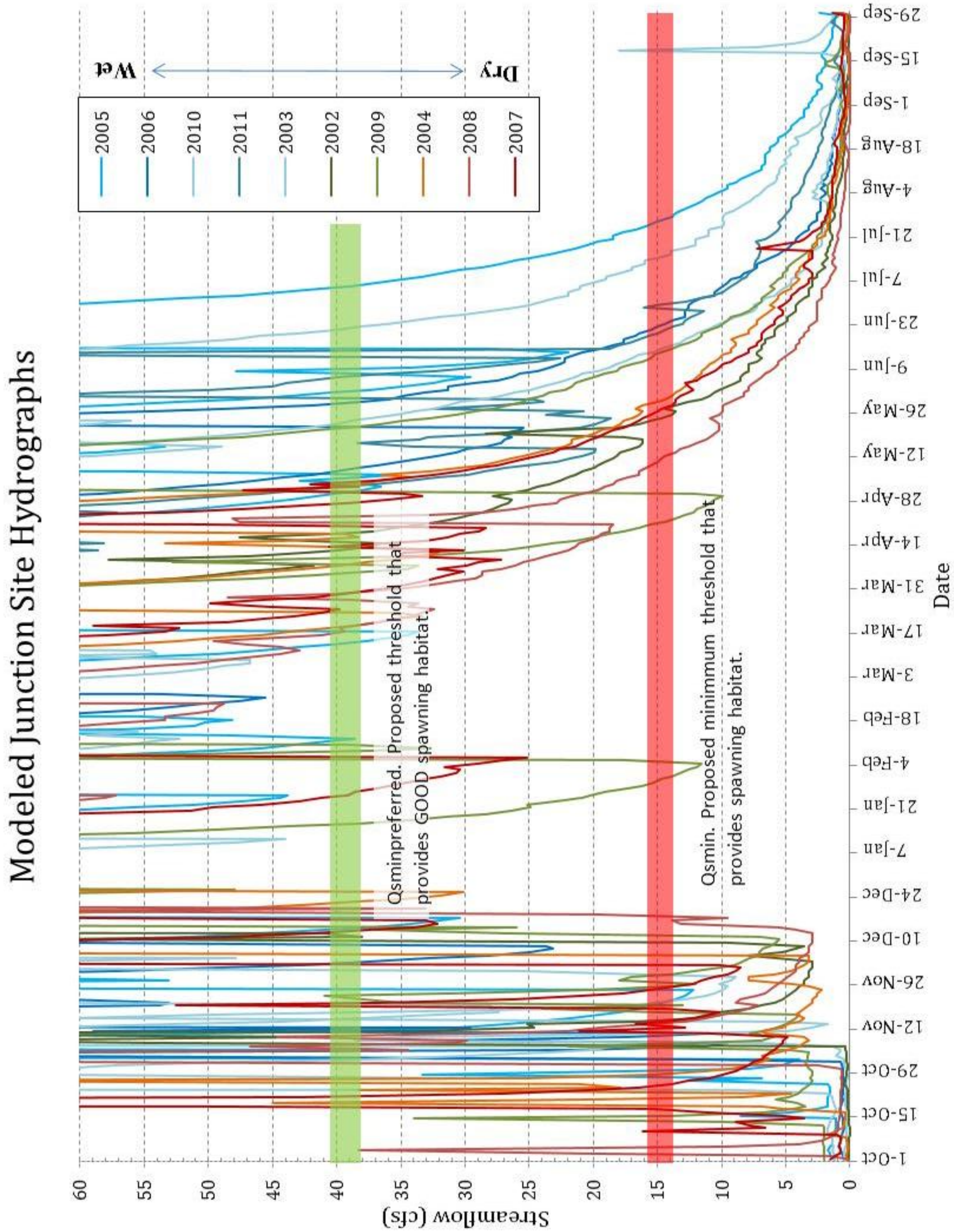

Figure 22. Annual hydrographs for WY 2002 to WY 2011at the Junction study site during the spawning season with thresholds for spawning habitat. Streamflow modeled by CEMAR.

6 RECOMMENDATIONS

Our primary study goal (Study Goal No.1) was to estimate a streamflow threshold for the summer low flow period in the Mattole River at our four study sites: from the confluence of Thompson Creek downstream to Thorn Junction (top row of Table 10). During a summer recession hydrograph, the streamflow threshold for FAIR rearing habitat for juveniles signals the start of the summer low flow period (Figure 21).

Table 10. Streamflow thresholds for juvenile and smolt rearing and adult spawning for the Mattole Headwater.

Streamflow Thresholds	Study Goals	Junction	Whitethorn	Upper Mainstem	Thompson Creek
FAIR Juvenile Rearing Habitat	1	5 cfs	4 cfs	2 cfs	1.5 cfs
GOOD Juvenile Rearing Habitat	2	9 cfs	8 cfs	5 cfs	3 cfs
Excellent Juvenile Rearing Habitat	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_{Smin}	3	16 cfs	10 cfs	7 cfs	8 cfs
Minimum preferred Spawning Habitat $Q_{Sminpreferred}$	3	41 cfs	29 cfs	25 cfs	14 cfs

Study Goal No.2 was to identify thresholds that occur before the summer low flow period that could make juvenile rearing habitat conditions vulnerable to cumulative diversions or a dry year. The streamflow thresholds for GOOD rearing habitat for juveniles establishes a window of receding baseflow 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. In addition, the streamflow threshold for GOOD juvenile salmonid rearing habitat meets or exceeds estimated streamflow thresholds for 1+ coho rearing habitat (Table 8).

Streamflow thresholds for EXCELLENT to GOOD rearing habitat establishes a window of receding baseflow 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. Diversions at streamflows above the streamflow threshold for EXCELLENT are not expected to have significant detrimental effects on juvenile rearing habitat.

Study Goal No.3 was to estimate minimum 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} (bottom two rows of Table 10).

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8 APPENDIX

8.1 HHT Data

Table A-1. HHT field measurements in the seven hydraulic units at the Junction Study Site for seven streamflow 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 A-2. HHT field measurements in the eight hydraulic units at the Whitethorn study site for seven streamflow 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

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	HU-6	HU-7	HU-8	Streamflow (cfs)
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

Point	Units	HU-1	HU-4	HU-5	HU-7	HU-8	Streamflow (cfs)
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

Point	Units	HU-1	HU-2	HU-3	HU-4	HU-5	HU-6	HU-7	HU-8	Streamflow (cfs)
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

Point	Units	HU-2	HU-3	HU-4	HU-5	HU-8	Streamflow (cfs)
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 A-3. HHT field measurements in the five hydraulic units at the Upper Mainstem study site for 6 streamflow 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 11. HHT field measurements in six hydraulic units at the Thompson Creek study site for six streamflow 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 A-5. 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. Whitethorn study 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 A-7. Upper Mainstem 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 A-8. 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