Final

Field Study Report for Volume Depletion Approach Study

Prepared for:

California State Water Resources Control Board

Division of Water Rights

March 31, 2014

Prepared by:

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in collaboration with R2 Resource Consultants, Inc.

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1 Background

On September 28, 2010, the State Water Resources Control Board (State Water Board or SWRCB) adopted the Policy for Maintaining Instream Flows in Northern California Coastal Streams (Policy; SWRCB, 2010). The Policy establishes guidelines for evaluating the potential impacts of water diversion projects on stream hydrology and biological resources. Appendix A of the Policy contains two sets of approaches for evaluating the cumulative impacts of a proposed project. One of these two approaches, known as the volume depletion approach and described in Policy Section A.1.8.3, was proposed during the Policy adoption meetings. In Policy Section 10.4.1, the State Water Board requires that a study be completed to assess the regional protectiveness of Section A.1.8.3 within five years of the Policy adoption date. The purpose of this project is to complete the required study to assess the regional protectiveness of the alternative approach known as the Volume Depletion Approach.

On June 11, 2012, the State Water Board and Stetson Engineers Inc. (Stetson) executed a contract (No. 11-130-300; Contract) to perform the Volume Depletion Approach Study (Study). R2 Resource Consultants, Inc (R2), as a subcontractor to Stetson, was retained to provide expertise in fisheries biology and geomorphology.

This report describes the field work conducted for this study in accordance with Task 3 of the Contract Scope of Work.

The Volume Depletion Approach guidelines described in Policy Section A.1.8.3 apply to water right applicants located upstream of anadromous habitat. This study focuses on how potential diversions in headwaters areas of watersheds affect downstream habitat. Three study basins representative of the Policy Area were selected in order to evaluate the regional protectiveness of the alternative guidelines. Field work was conducted in the three study basins from October 2012 through April 2013. Habitat and streamflow data were collected to support the hydrologic modeling and habitat protectiveness analysis.

2 Field Work Overview and Study Sites

Study basin selection was completed in the summer and fall of 2012 in preparation for field work in the 2012/13 winter. Study basin selection was done in three steps: (1) identification of candidate basins; (2) selection of "prioritized" basins; (3) final selection of study basins. The goal of the selection process was to choose three study basins that were representative of the Policy area with regard to basin geomorphology, hydrology and fisheries habitat.

Stetson and R2, in consultation with State Water Board staff, reviewed information on basins within the Policy area in order to arrive at a list of suitable candidate basins based on the following criteria:

- Availability of existing information on anadromous fisheries habitat;
- Availability of existing information on hydrology, including a historical record of gaged flow; and
- Feasible stream access.

Stetson and R2 worked to determine potential study areas within each prioritized basin. Stetson reviewed the hydrology of each basin, considering impairments, soils, topography and existing diversions, in order to determine reaches and drainage areas that would be suitable for field study and hydrologic modeling. R2 reviewed existing information on habitat to determine which areas of the basin contain suitable habitat and where potential study sites might be located. Once these reaches for potential study were identified, Stetson identified parcels along these reaches and researched owner contact information. After confirming the feasibility of obtaining access to enough study locations, three study basins were selected: Maacama Creek in Sonoma County, Sonoma Creek in Sonoma County and Walker Creek in Marin County. The locations of the three study basins within the Policy area are shown in Fig. 1.

Study sites were chosen in each study basin based on stream access, hydrology, habitat and other factors. Table 1 gives the list of study sites in each basin. Field work began in October 2012 and ended in May 2013. Figs. 2 through 4 show the locations of the study sites within the three study basins.

Each study basin has five or six study sites. A schematic of a study basin and the study sites is shown in Fig. 5. Each basin has two types of study sites, Class II/III streamflow gage sites and Points of Interest (POIs):

1) Class II/III sites: These are locations upstream of anadromous fisheries habitat on streams which contribute flow to Class I streams. At these sites, dataloggers were installed to continuously measure and record water depth and temperature[1] throughout the field season. Flow data from these sites will be used to calibrate the hydrologic models.
2) POI (Class I) Sites: These are locations with anadromous fisheries habitat and lie downstream of the Class II/III sites, which may potentially be impacted by cumulative diversions on upstream Class II/III streams. Flow data from these sites will be used to calibrate the hydrologic models and, along with water depth data, to evaluate passage and spawning opportunities in the protectiveness analysis.

Techniques for measuring streamflow are described in Section 3. Habitat surveys are described in detail in Section 4.

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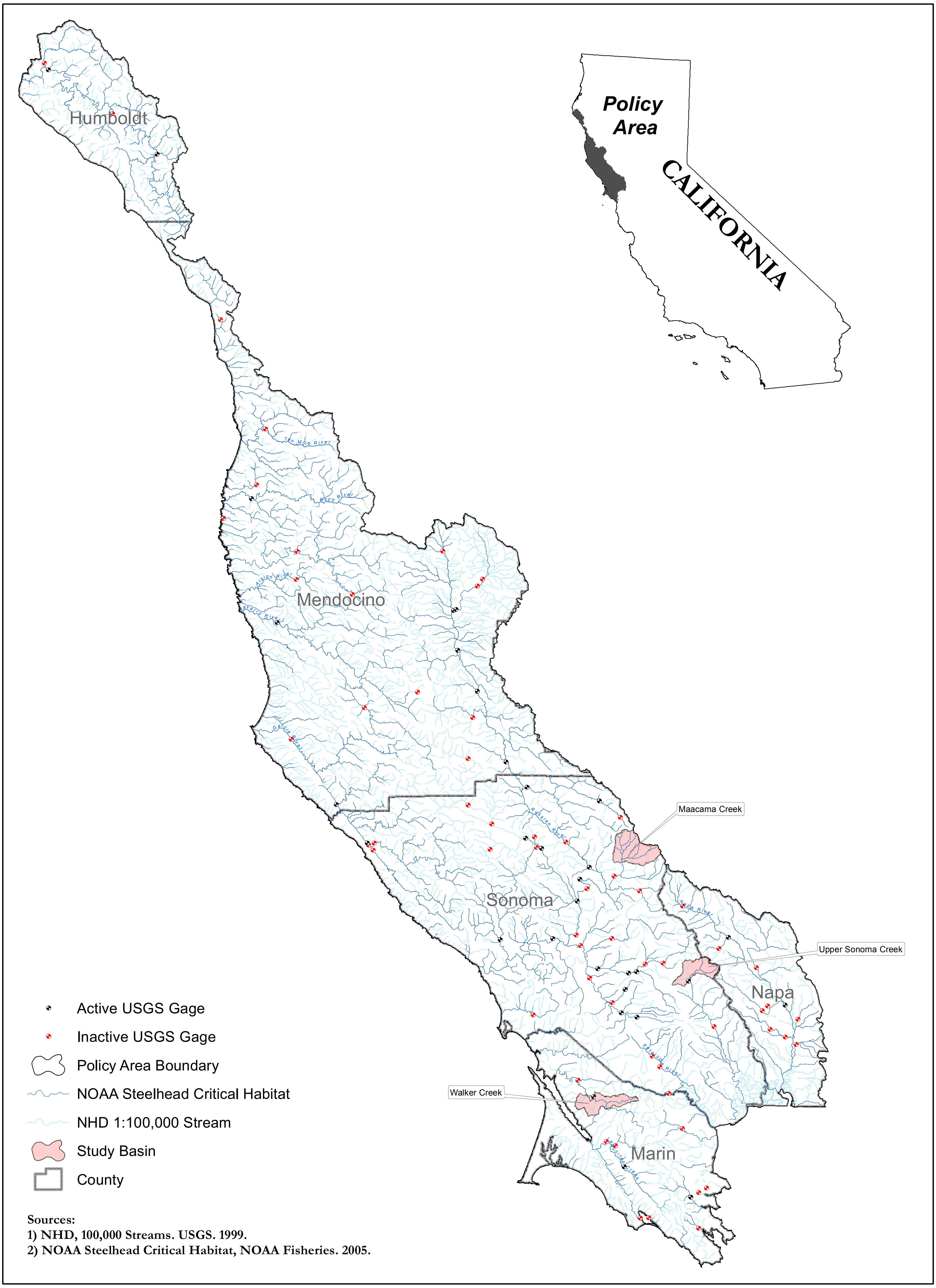
[1] A temperature analysis has been excluded from the scope of work of this study; however, the temperature data were collected.



Sources:
1) NHD, 100,000 Streams. USGS. 1999.
2) NOAA Steelhead Critical Habitat, NOAA Fisheries. 2005.

VOLUME DEPLETION APPROACH STUDY BASINS

STETSON
ENGINEERS INC.

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FIGURE 1

Table 1 - List of Selected Study Basins and Study Sites

Study Site ID	Study Location	Drainage Area (sq mi)	Streamflow Gage	Habitat Survey	Date of Gage Installation[1]
Maacama Creek					
MC1	Little Ingalls Creek	0.4	X		10/30/2012
MC2	Ingalls Creek	2.3	X	X	10/30/2012
MC3	McDonnell Cr below Ingalls Cr	5.2	X	X	10/30/2012
MC4	Briggs Cr above Maacama Cr[2]	12.4	X		11/27/2012
MC5	Maacama Cr below Briggs Cr	23.2	X	X	11/27/2012
Sonoma Creek					
SC1	Headwaters Sonoma Creek	0.6	X		11/07/2012
SC2	Unnamed trib to Sonoma Creek	0.2	X		11/07/2012
SC3	Malm Fork	0.5	X		02/06/2013
SC4	Upper Sonoma Cr above Bear Cr	3.8	X	X	12/20/2012
SC5	Lower Bear Cr	1.9	X	X	11/07/2012
SC6	Sonoma Cr near Highway 12	8.2	X	X	12/18/2012
Walker Creek					
WC1	Upper Salmon Cr	0.3	X		11/13/2012
WC2	Middle Salmon Cr[3]	1.6		X	12/17/2012
WC3	Unnamed trib to Walker Cr at Walker Ranch	0.2	X		11/13/2012
WC4	Walker Cr[4,5]	12.3		X	12/18/2012
WC5	Unnamed trib to Walker Cr d/s Walker Ranch	0.3	X		11/13/2012
WC6	Frink Cyn, lower	3.2	X	X	12/17/2012

Notes:

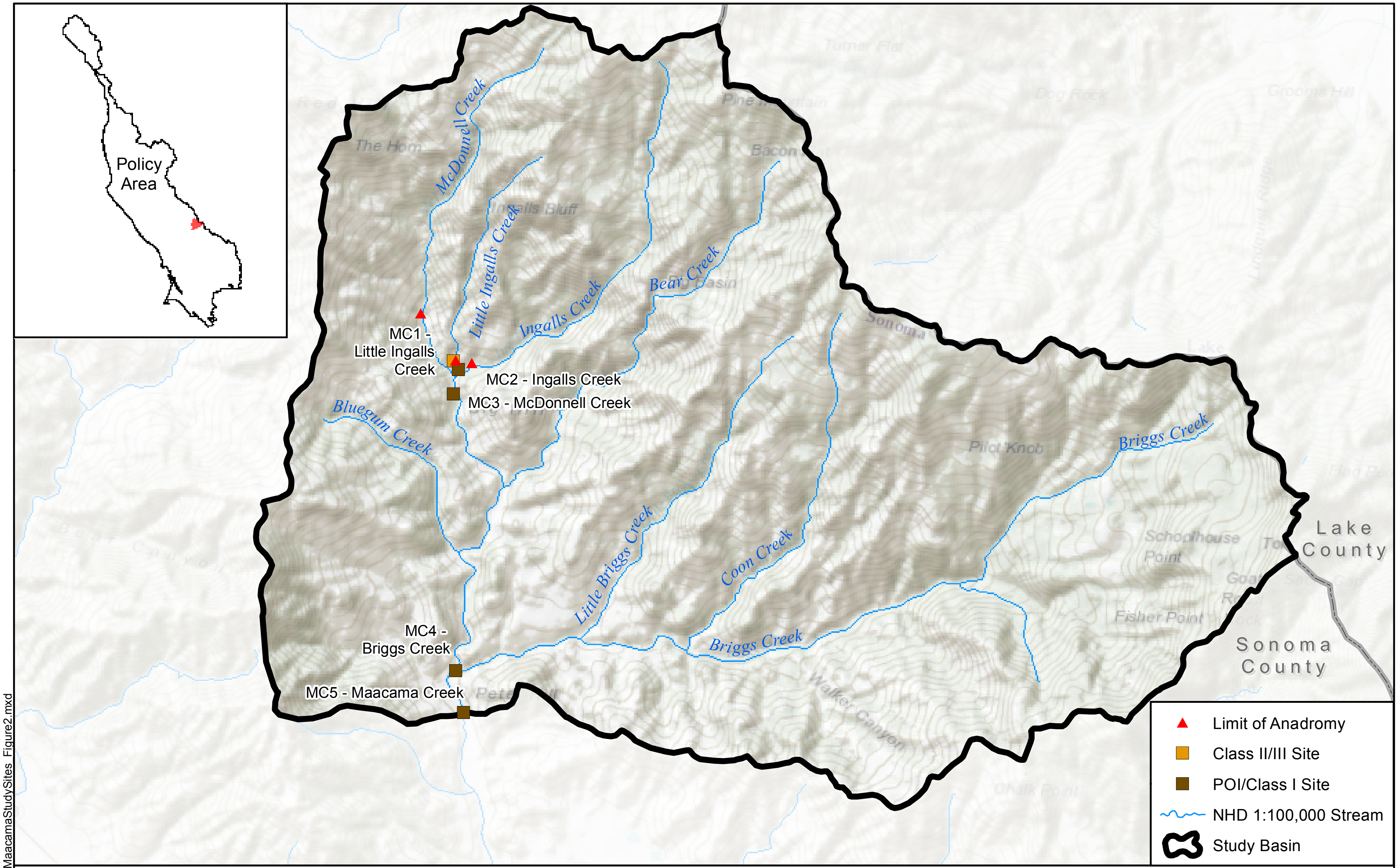
[1] If site does not have a flow gage, date shown refers to date of first habitat survey at that site.

[2] Flow measurement only; no habitat data were collected.

[3] Habitat survey only; flow was measured nearby at gage WC1.

[4] Habitat survey only; flow was measured nearby at USGS gage No. 11460750.

[5] Drainage area at the gage does not include the 19 square miles (mi^2) of land regulated by Soulajule Reservoir. The drainage area shown (12.3 mi^2) represents the drainage area on Salmon Creek, Arroyo Sausal below Soulajule Reservoir, Verde Canyon and Walker Creek.



MAP OF MAACAMA CREEK WATERSHED AND STUDY SITES

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ENGINEERS INC.

Source:
NHD, 100,000 Streams. USGS. 1999.

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Miles

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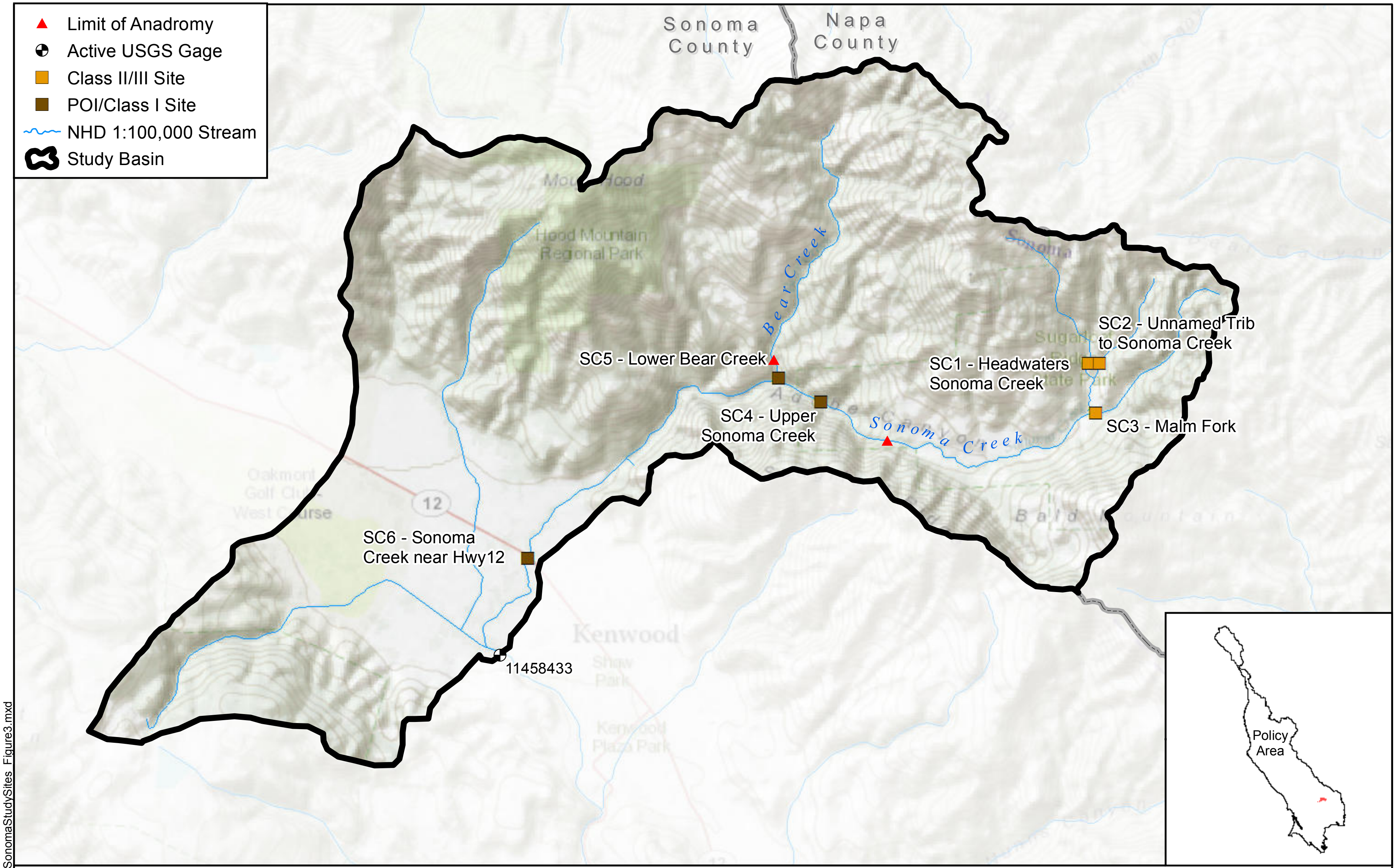
FIGURE 2



MAP OF SONOMA CREEK WATERSHED AND STUDY SITES

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N

0 0.5 1 Miles

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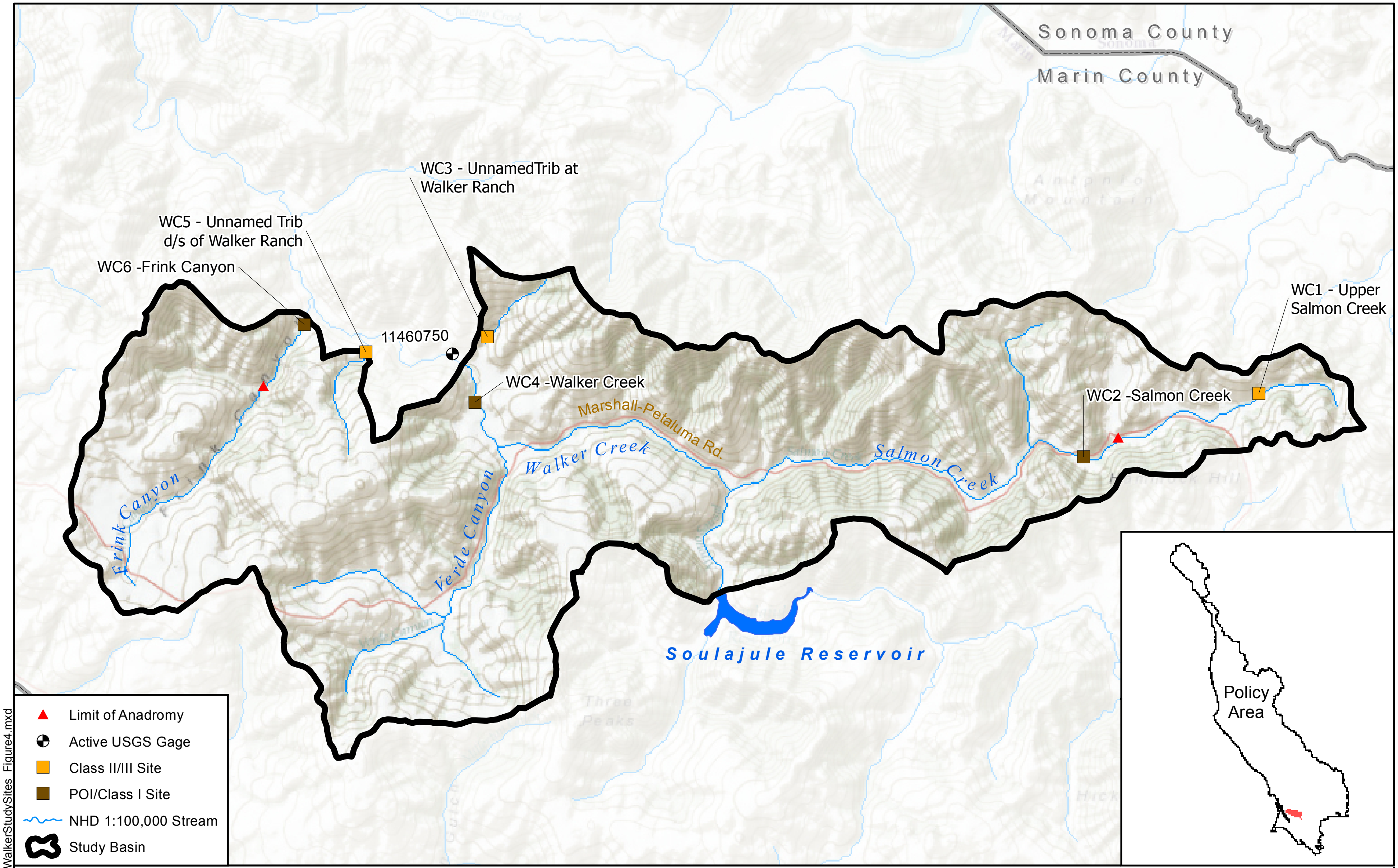
FIGURE 3



MAP OF WALKER CREEK WATERSHED AND STUDY SITES

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FIGURE 4

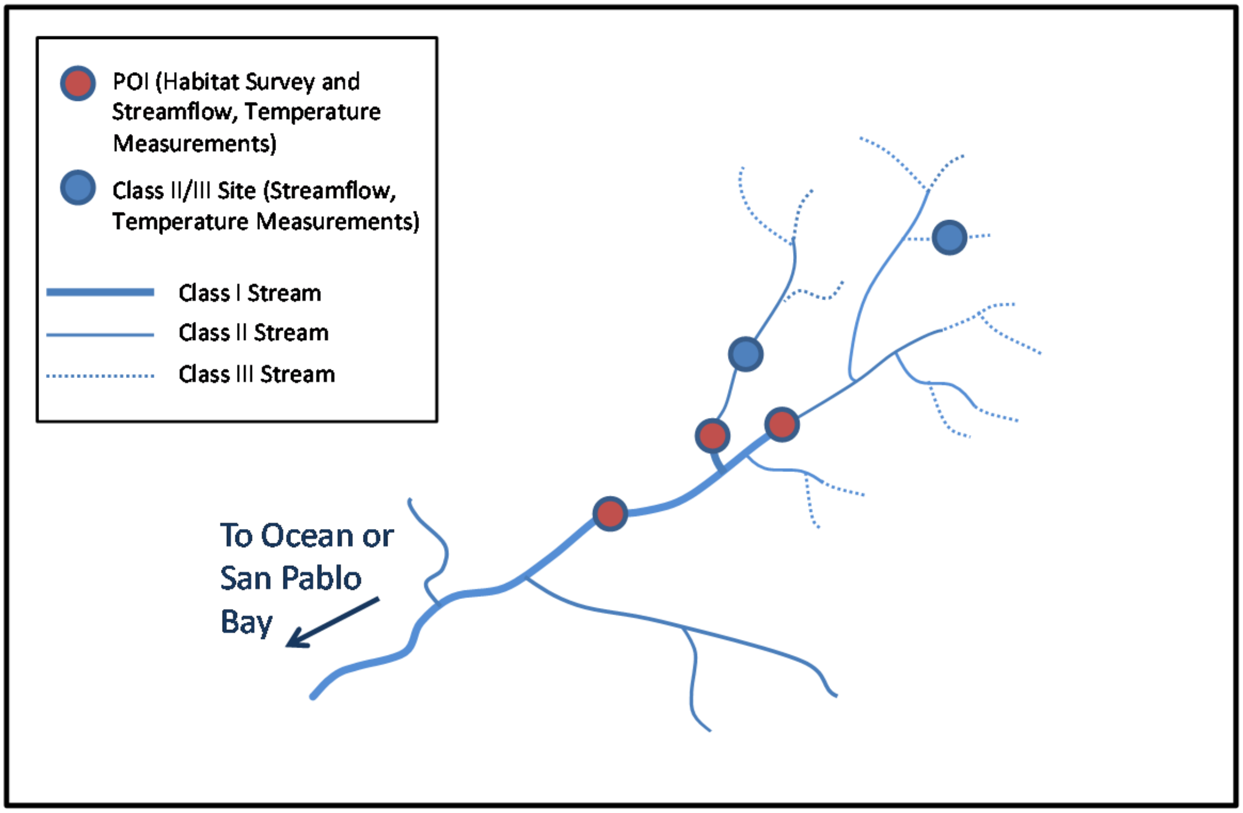

Fig. 5 - Schematic of Study Sites within a Study Basin

3 Flow Measurements

At each study site, pressure sensor dataloggers were installed to continuously measure stream stage at 10-minute intervals. Periodically, discharge measurements were taken in the field in order to relate stream stage to stream discharge. In addition, the stream cross-section was surveyed at the location of each datalogger in order to evaluate the hydraulics at that location.

3.1 Field Data Collection

Dataloggers were installed beginning in October 2012. At each site, multiple discharge measurements were taken throughout the field season. Dataloggers were removed in May 2013. The sections below describe the methods used to install dataloggers, measure discharge and conduct cross-sectional surveys.

3.1.1 Datalogger Installation

At each study site, Solinst Leveloggers® (from the Gold and Junior EDGE series) were installed to measure stage (water height) and water temperature at 10-minute intervals. The Solinst Levelogger® is a monitoring device with both pressure and temperature sensors and a built-in datalogger. The dataloggers were installed inside a one-inch diameter slotted PVC well casing. The well casing was then anchored to the stream channel using metal stakes with ties. The sensor was placed as close to the stream thalweg as possible, in order to ensure submergence throughout the monitoring period. Fig. 6 shows a typical datalogger installation. Due to varying channel characteristics, actual installations varied slightly. The dataloggers were set to record in International System (SI) units, with the pressure in meters (m) and temperature in degrees Celsius. The dataloggers have an accuracy of ±0.05% of the full scale calibrated range of the device. The full scale for the fourteen installed dataloggers ranged from 5 m to 30 m. The purpose of the datalogger pressure measurements was to establish relative water levels, not to measure absolute pressure values. Adequate device precision is necessary to capture small changes in water levels. All dataloggers recorded pressure with a precision of 0.001 m.

In each study basin, a Solinst Barologger® (Edge series) was deployed to assist with barometric correction of the stream dataloggers. In each study basin, the barologgers were tied around tree trunks and covered to prevent contact with rainfall. Barometric data were recorded in kilopascals (kPa). The barologgers have an accuracy of ±0.05 kPa.

The raw datalogger records collected at the study sites are included in Appendix A-1. The files include raw temperature and pressure data collected at 10-minute intervals. These data do not include any corrections for datalogger shifts, elevation or barometric pressure.

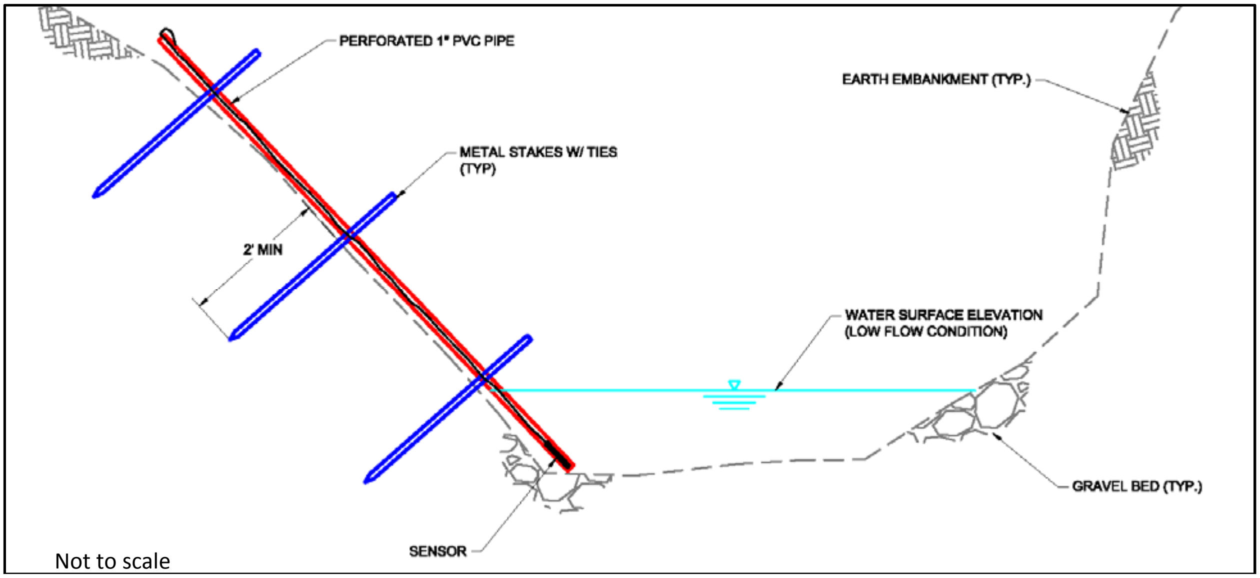

Fig.6 – Schematic of Typical Datalogger Installation

3.1.2 Discharge Measurements

Discharge measurements at study sites were taken throughout the field season. There were two types of discharge measurements:

- Flows collected to develop stage-discharge rating curves at locations of stage dataloggers and
- Flows collected to develop habitat-flow curves.

3.1.2.1 Discharge Measurements at Datalogger Locations

The flow data collected exclusively for developing a stage-discharge rating curve at the stage recorders were measured using a pygmy flow meter with a magnetic head manufactured by Rickly Hydrological Company. Measurements with the pygmy meter were conducted using a sixth-tenths wading rod, following United States Geologic Survey (USGS) flow measuring methodology (Rantz et al, 1982).

The pygmy meter was purchased in September 2012. Prior to each use, the meter was subject to a spin test to ensure proper operation. The minimum acceptable spin time was 45 seconds, though spin time generally exceeded that.

Flow measurement transects were chosen in order to optimize the flow measurement quality. Ideal transects were located where the reach exhibited uniform flow and sufficient velocity and depth to use the meter. During each flow measurement, a tape measure was stretched across the stream channel to define the transect. Due to varying flow conditions throughout the field season, flow measurements were sometimes taken at slightly different locations, though each location was in close proximity to the datalogger. At each transect, water velocity was measured across the reach by counting the number of spins at each location. Channel depth was measured using the wading rod, and the width between each measurement was taken from the measuring tape.

The velocity was then calculated using the equation provided by the pygmy meter manufacturer:

$$Velocity = \frac{Revolutions}{Observation\ Time}(0.9604)+(0.0312)$$

Velocity measurements were spaced across the transect with the target of measuring no more than 5% of the total discharge between two points. Discharge was computed at each measurement point by multiplying the velocity by the channel area at that location.

Table 2 is a summary of the computed discharge at each site. Occasionally, low flow conditions did not provide sufficient water depth to use the pygmy flow meter and flows were estimated, either by estimating the velocity and depth of the water, or by routing the stream into a tarp, collecting the water in a bucket, and measuring the volume of water collected over a specific time.

At the datalogger site on Upper Salmon Creek (WC1), the datalogger was installed in a narrow, densely vegetated channel. Due to low water depths and the dense vegetation, the pygmy meter could not be used. Instead, streamflow was measured at the site on Middle Salmon Creek (WC2), located approximately 1.4 miles downstream of WC1. To develop the rating curve at WC1, the measured flows at WC2 were multiplied by the ratio of the drainage area of WC1 to the drainage area of WC2.

3.1.2.2 Discharge Measurements at Habitat Locations

Velocity measurements collected at the habitat transects followed similar general procedures with respect to number of points sampled. The majority of velocity data at habitat transects were measured using a Swoffer Model 2100 velocity meter and top set wading rod.[2] The velocity data were then adjusted using a calibration curve (Fig. 7), which was developed in flume testing by R2 specifically for the Swoffer meter and propeller assembly used in the field. When developing the rating curves at the datalogger locations, the flows collected at habitat transects were used to supplement the flow data collected using the pygmy meter. Flows measured with the Swoffer meter are noted in Table 2.

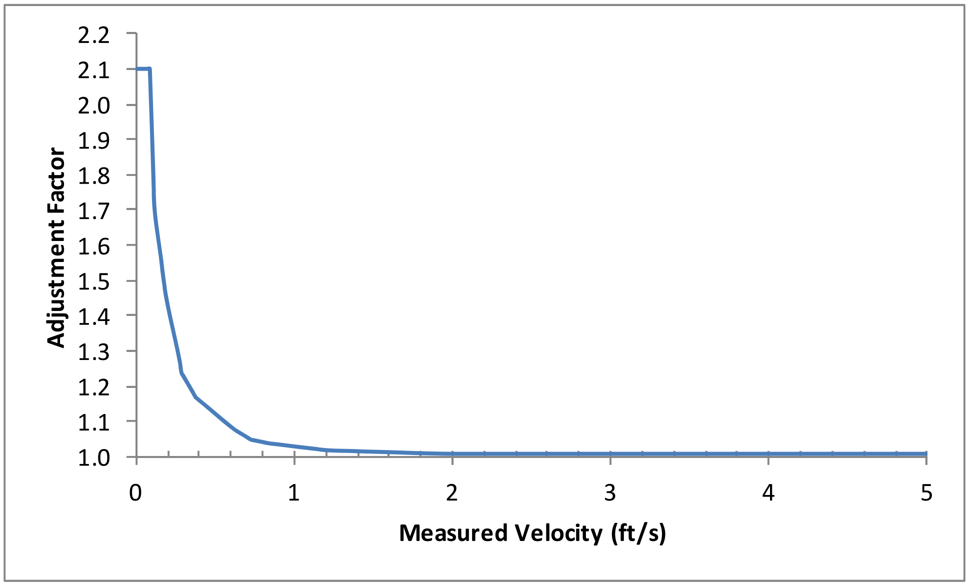

Fig. 7 - Velocity Calibration Curve for Swoffer Model 2100 Meter and Propeller Assembly Used for Flow Measurements at Habitat Sites

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[2] In a few cases, the pygmy meter was used to measure velocity at habitat transects. Though the pygmy meter and Swoffer meters have different physical means for measuring flow (the pygmy meter relies on counting rotations of a spinning cup while the Swoffer meter uses rotations of a propeller) , both meters measure velocity in the channel and are comparable methods for measuring flow.

Table 2 - Discharge Measurements at Datalogger Locations

Datalogger Site	Date	Discharge (cfs)
MC1 - Little Ingalls Creek	10/30/2012	0
	11/27/2012	0.1
	12/20/2012	0.61*
	2/27/2013	0.02*
	4/4/2013	0.4
	5/15/2013	0.015
MC2 - Ingalls Creek	10/30/2012	0.14
	11/27/2012	0.78
	12/20/2012	5.1*
	2/27/2013	0.97*
	4/4/2013	7.7
	5/15/2013	0.5
MC3 - McDonnell Cr below Ingalls Cr	10/30/2012	0.1
	11/27/2012	1.4
	12/20/2012	10.1*
	2/27/2013	1.4*
	4/4/2013	25
	5/15/2013	0.7
MC4 - Briggs Cr above Maacama Cr	11/27/2012	1.8
	2/8/2013	5.3
	4/5/2013	14.5
	5/15/2013	1.5
MC5 - Maacama Cr below Briggs Cr	11/27/2012	4.6
	12/19/2012	43.3*
	2/8/2013	10.2
	2/26/2013	8.6*
	4/5/2013	35.4
	5/15/2013	3.1
SC1 - Headwaters Sonoma Creek	11/7/2012	0.02
	2/7/2013	0.2
	4/24/2013	0.09
	5/16/2013	0.04
SC2 - Unnamed trib to Sonoma Creek	11/7/2012	0
	2/7/2013	0.04
	4/24/2013	0.004[#]
	5/16/2013	0.002[#]
SC3 - Malm Fork	2/7/2013	0.2
	4/24/2013	0.1
	5/16/2013	0.1
SC4 - Upper Sonoma Cr above Bear Cr	12/19/2012	4.5*
	12/21/2012	11.5*
	2/7/2013	1.9
	2/28/2013	1.1*
	4/3/2013	1.0
	5/16/2013	0.4
SC5 - Bear Cr near confluence at Salmon	11/7/2012	0.1
	12/19/2012	2.6*
	12/21/2012	9.9*
	2/7/2013	1.0
	2/28/2013	0.46*
	4/3/2013	0.45
	5/16/2013	0.2
SC6 - Sonoma Cr near Highway 12	12/18/2012	13.1*
	2/7/2013	2.6
	2/28/2013	1.0*
	4/3/2013	0.5
	5/16/2013	0.0
WC2 - Middle Salmon Cr[1]	12/17/2012	3.0
	12/21/2012	32
	2/26/2013	11.7
WC3 - Unnamed trib to Walker Cr at Walker Ranch	11/13/2012	0.01
	1/14/2013	0.06
	2/22/2013	0.04
	5/8/2013	0.01
WC5 - Unnamed trib to Walker Cr d/s Walker Ranch	11/13/2012	0
	1/14/2013	0.1
	2/22/2013	0.01
	4/2/2013	0.01
	5/8/2013	0
WC6 - Frink Cyn, lower	12/17/2012	3.1*
	1/14/2013	1.3
	2/22/2013	0.26
	2/26/2013	0.23*
	4/2/2013	0.22
	5/8/2013	0.06

Notes: All measurements taken using the Rickly Hydrological pygmy flow meter unless otherwise noted.

* Measurement taken with Swoffer Model 2100 flow meter.

[#] Low flow conditions did not provide sufficient water depth for pygmy meter; flow estimated.

[1] Flow measurements on Middle Salmon Creek (WC2) were used to rate the stage datalogger on Upper Salmon Creek (WC1). Due to low flows and dense vegetation, the pygmy meter could not be used at WC1.

3.1.3 Cross-section Surveys at Datalogger Locations

At each datalogger location, a survey of the channel cross-section and channel slope was conducted to provide additional information on the hydraulics. The channel cross-section and channel slope were surveyed at each datalogger location using a level transit (Topcon model AT-G2), stadia rod, and surveyors tape. Survey elevations were relative and not tied to benchmarks. Along the cross-sectional transect, elevations were surveyed at breaks in slope and at water surface elevations. Perpendicular to the cross-sections, a longitudinal transect was surveyed including stream channel bottom and water surface elevation. Survey data were collected in standard English units.

Figures of each cross-section are included in Appendix A-2.

3.2 Data Analysis

All data collected in the field were reviewed and processed. The raw datalogger records were corrected in order to obtain accurate records of stream stage. Rating curves were then created to translate stream stage into discharge.

3.2.1 Correction of Raw Data

The raw datalogger records were first corrected for shifts in datalogger elevation and then for barometric pressure.

3.2.1.1 Sensor Shifts

When a datalogger is removed from the casing and re-installed, it is not always re-installed at precisely the same elevation. To correct for this, the raw data were shifted by examining the stage before installation and after installation, and adjusting for the difference. Whenever Stetson removed a datalogger, it was done briefly (i.e. for less than 20 minutes) and during constant flows; thus, the streamflow did not change significantly during the removal and the sensor shift could be estimated from the change in recorded stage prior to and after the datalogger removal.

3.2.1.2 Barometric Correction

As with all pressure sensors used for measuring water height, the actual measurement includes the pressure of the water as well as the ambient atmospheric pressure. To compensate for this, the atmospheric pressure was measured with nearby barometers at 10-minute intervals. The atmospheric pressure was then subtracted from the total measured pressure to get the pressure due to the height of water. At gaging locations where the barometric datalogger was very close to the stream datalogger, this correction was a direct subtraction. However, at gaging locations where there was an elevation difference between the two loggers, an elevation correction was also done. This correction for barometric pressure was completed using Solinst Levelogger Software, version 4.0.3.

Appendix A-3 contains the corrected datalogger records. These files include corrections for sensor shift and barometric pressure.

3.2.2 Stage-Discharge Analysis

A stream stage-discharge rating curve was developed for each datalogger location. The measured discharge was plotted against the measured stage at the time of the discharge measurement. If the duration of each discharge measurement was longer than 10 minutes, the stage over the measurement period was averaged (i.e. if discharge was measured between 10:20am and 10:30am, the stage measurements at 10:20am and 10:30am were averaged).

The rating curve was interpolated between the measured points using straight lines. At all sites, the rating curve had to be extrapolated to higher flows since such flows were not able to be measured in the field. Each rating curve was extrapolated up to the maximum stage recorded at that site's datalogger during the 2012-2013 winter field season. The standard Manning's equation was used to extrapolate the high flows. Discharge may be estimated as:

$$Q = \frac{1.486}{n} A\, R^{2/3} \sqrt{S}$$

where Q is the discharge in cfs, A is the cross-sectional area in square feet, R is the hydraulic radius in feet and S is the slope of the energy grade line. At low flows, S and n are variable due to changing water surface elevations and substrate roughness. However, at high flows, they tend to approach constant values. Manning's equation was used to plot the values of $n/\surd S$, both for the measured discharge values and for higher flows without measurements. The quantity $n/\surd S$ can be related to area (A), discharge (Q) and hydraulic radius (R):

$$\frac{n}{S^{1/2}} = \frac{AR^{2/3}}{Q}$$

For each stage on the rating curve, A and R were calculated from the cross-sectional survey data. Q was known for each discharge measurement. For higher flows in which no measurements were available, Q was estimating by solving for Q graphically using the curve of $n/\surd S$ versus stage. An example plot of $n/\surd S$ versus stage is shown in Fig. 8. In that figure, the triangles are plotted from measured data. The two squares are extrapolated values. The triangular points show that, as stage increases, the value of $n/\surd S$ decreases and approaches a constant value. At the stage values for the two squares, discharge was estimated so that the plotted values fell onto the constant line in the figure. The maximum extent of the rating curve was defined by the maximum stage recorded in the field by the datalogger. Discharge was also estimated for one to two stage values that fell between the highest measured discharge and the discharge estimated at the maximum stage.

The rating curves for each datalogger location are given in Appendix A-4. An example rating curve is shown in Fig. 9. The red line represents the interpolated and extrapolated portions of the curve. To apply the rating curve to the measured stage time series, a straight line was assumed between all points. This was done since the measured points on the rating curves, especially at low flows, could not be defined by a single function.

3.2.1 Flow Time Series

Once the rating curves were established, flow time series were generated using the stage-discharge relationships. Discharge was calculated for each stage measurement of the corrected 10-minute record in Appendix A-3. Hourly time series of discharge were then computed by averaging the 10-minute values over each corresponding hour. The hourly flow time series are given in Appendix A-5. These data were then imported into the hydrologic models for each study basin in order to calibrate the models to the field data.

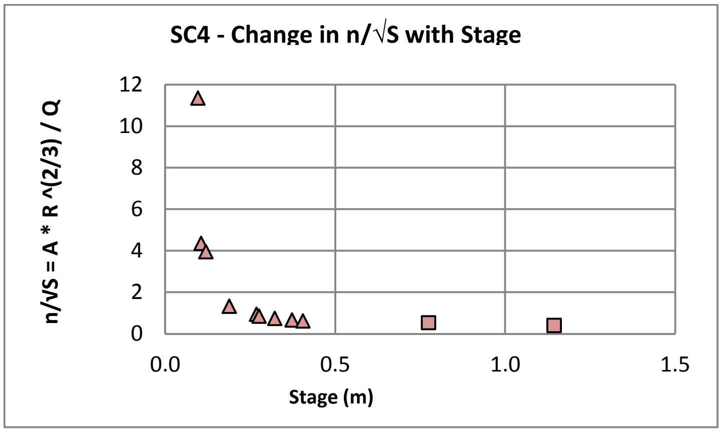

Fig. 8 - Example Plot of n/√S versus Stage

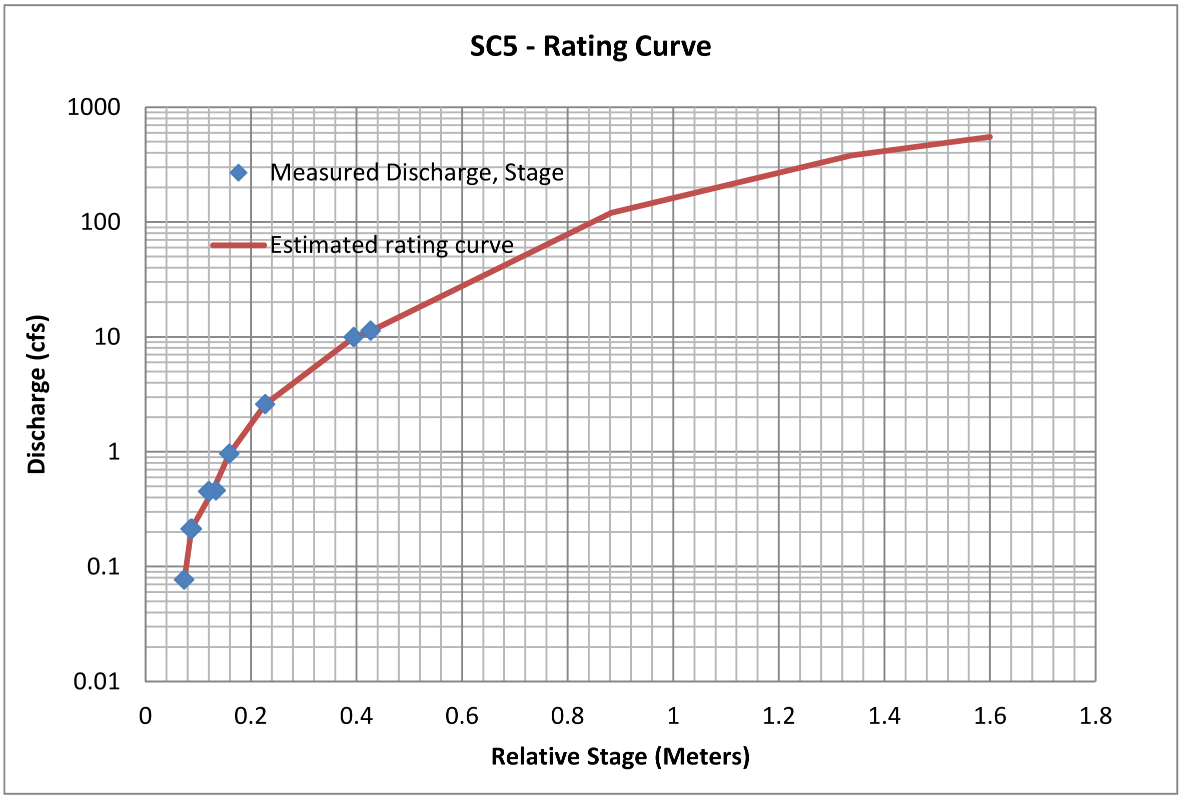

Fig. 9 - Example Rating Curve

4 Habitat-Flow Data Collection and Analysis

The purpose of the habitat surveys was to collect data needed to develop habitat-flow curves that would be used to evaluate the effects of diversions on anadromous fisheries habitat at each POI site. A similar approach was adopted as that used to establish criteria for the Policy (R2 and Stetson, 2008), though this study had more cross-sections and sampling over a range of flows. Representative habitat cross-sections, or transects, were established at potential steelhead spawning locations and at limiting upstream passage riffles, where readily discernible. Depth, velocity, and substrate data were then collected along the cross-section and analyzed in a Physical Habitat Simulation (PHABSIM) framework to generate habitat-flow curves for cross-sections as a whole, as well as for specific potential redd locations on each cross-section. Cross-section data were collected to estimate hydraulic conditions at passage locations and spawning habitats in each stream over a range of flows. Velocity distributions were measured at roughly a mid-flow level for predicting velocity distributions at other flows. Stage and discharge were measured to establish a stage-discharge curve that could be used to predict depths at any flow of interest.

4.1 Field Data Collection

4.1.1 Site Setup/Establishing Passage and Spawning Transects

R2's lead fisheries scientist and hydraulic engineer on this project, Dr. Paul DeVries PE, initially walked each site in December 2012. Several rainfall events occurred prior to the initial site visit, so flows in streams were at normal winter levels. During the initial site visit, potential spawning sites for steelhead were identified based on hydraulics, substrate size, and channel morphology. The number of spawning cross-sections reflected availability: steeper, smaller, low order streams located close to the limit of anadromy contained fewer potential spawning habitat cross-sections than lower gradient, higher order streams located farther downstream in the channel network. The same was effectively true for limiting passage transects, where passage restrictions in the smaller, steeper streams (and in Maacama Creek, which has multiple bedrock control sections below the site) were more broadly distributed and less readily analyzed. In lower gradient channels, passage transects were placed at locations that would require more flow than elsewhere in a reach to meet passage depth criteria; transects were typically placed over one to two wide, shallow riffles, where they existed.

In all channels, between three and five cross-sections were placed across likely spawning locations, with stakes placed on the left and right banks to fix the location for repeat visits. Spawning transects were located upstream of riffle crests in pool or run tails, near riffle crests, in riffles, and in hydraulically sheltered pocket gravel deposits in smaller, steeper gradient streams when the other types of spawning habitat were limited or absent. These locations are typically used by steelhead and coho in small to mid-size streams (Shapovalov and Taft 1954; Kondolf et al. 1991). Spawning transects placed near riffle crests were generally located downstream of deeper cross-sections that provided spawning habitat. The sampled locations were selected to have a lower probability of egg pocket scour based on judged potential for sediment transport rate imbalances that are the cause of deep scour (DeVries 2008).

Table 3 summarizes the number and type of transects placed at each habitat study site. A minimum of three rebar benchmarks were installed throughout each site for elevation control. The benchmarks were surveyed each time and checked for elevation. The rebar benchmarks were then used as backsights for surveying of water surface elevations (WSEs), cross-section profiles, and longitudinal (streamwise) profiles.

Table 3 - Summary of Habitat Surveys

Habitat Site ID	Study Location	Number of Passage Transects	Number of Spawning Transects	Spawning Habitat Morphology (Number of Cross-Sections)
Maacama Creek				
MC2	Ingalls Creek	0[1]	4	Pocket gravel (1), run (2), run tail (1)
MC3	McDonnell Cr below Ingalls Cr	0[2]	4	Riffle crest (1), pool tail (2), pocket gravel (1)
MC5	Maacama Cr below Briggs Cr	0[3]	5	Pool/run tail (2), run (2), pocket gravel (1)
Sonoma Creek				
SC4	Upper Sonoma Cr above Bear Cr	1	5	Run (2), run tail (1), pocket gravel (2)
SC5	Lower Bear Cr	0[1]	3	Pocket gravel (3)
SC6	Sonoma Cr near Highway 12	2	5	Riffle/Run (2), riffle (1), pool tail (2)
Walker Creek				
WC2	Middle Salmon Cr	1	4	Riffle (2), pool tail (2)
WC4	Walker Cr	1	5	Riffle (3), run tail (1), run (1)
WC6	Frink Canyon, lower	1	4	Riffle (2), pool tail (2)

Notes:

[1] No riffle transects limiting passage present; passage barriers distributed between mouth and site in the form of variable small leaping barriers and velocity chutes; spawning transects provide order of magnitude estimate of limiting passage flow, with highest estimate used to assess passage flow.

[2] Spawning transect S3 approximates a limiting riffle passage transect.

[3] Passage limited by various bedrock chutes present downstream on private property; spawning transect S1 best approximates a limiting riffle passage transect.

4.1.2 Establishing Upper Limit of Anadromy

The upper limit of anadromy for streams with habitat sites was established one of two ways depending on accessibility. Where it was feasible to safely walk upstream from a study site and not cross private land for which access permission had not been explicitly granted, the limit of anadromy was confirmed when a natural passage barrier was encountered. This was the case on Ingalls Creek, McDonnell Creek, Bear Creek, and upper Sonoma Creek. The barriers were confirmed to be a relatively short distance upstream of the respective study sites. Private land and safe access restricted visual confirmation of the upper limit of anadromy in Salmon Creek and Frink Canyon, respectively. However, based on stream size, slope, locations of tributary confluences, and historic redd surveys, the upper limit was likely no more than a mile or so upstream of each study site. The upper limits of anadromy are shown in Figs. 2 through 4.

4.1.3 Benthic Macroinvertebrate Surveys for Defining Class II/III Streams

Benthic macroinvertebrate (BMI) surveys were completed at select study sites for the purpose of assessing stream class above the limit of anadromy. The criteria used in the survey are consistent with the habitat indicators described in Section A.1.6.1 of the Policy (SWRCB, 2010). All POI sites below the upper limit of anadromy are Class I sites. Class II sites are those above the upper limit of anadromy with BMI organisms observed. Class III streams are above the upper limit of anadromy but do not have BMI organisms.

In late spring, BMI surveys were completed on the study sites located above anadromy. The surveys were completed by collecting substrate from the stream bottom (for a maximum duration of 15 minutes) and inspecting the substrate for BMIs and other aquatic organisms. Once a BMI organism was observed, the survey was halted and BMI presence was noted for the site. No individual count or species classification was conducted as part of the survey. All sites were determined to have benthic macroinvertebrates. Photos of the organisms observed are provided in Appendix A-6. Stream classes are summarized for all sites in Table 4.

Table 4 - Summary of Stream Classification at Study Sites

Study Site ID	Study Location	Anadromous (Y/N)	BMI Survey (Y/N)	BMI Survey Date	BMI Survey Results (Present/ Absent)	Stream Class
Maacama Creek						
MC1	Little Ingalls Creek	N	Y	4/4/2013	PRESENT	II
MC2	Ingalls Creek	Y	N	n/a	n/a	I
MC3	McDonnell Cr below Ingalls Cr	Y	N	n/a	n/a	I
MC4	Briggs Cr above Maacama Cr	Y	N	n/a	n/a	I
MC5	Maacama Cr below Briggs Cr	Y	N	n/a	n/a	I
Sonoma Creek						
SC1	Headwaters Sonoma Creek	N	Y	4/24/2013	PRESENT	II
SC2	Unnamed trib to Sonoma Creek	N	Y	4/24/2013	PRESENT	II
SC3	Malm Fork	N	Y	4/24/2013	PRESENT	II
SC4	Upper Sonoma Cr above Bear Cr	Y	N	n/a	n/a	I
SC5	Lower Bear Cr	Y	N	n/a	n/a	I
SC6	Sonoma Cr near Highway 12	Y	N	n/a	n/a	I
Walker Creek						
WC1	Upper Salmon Cr	N	Y	4/2/2013	PRESENT	II
WC2	Middle Salmon Cr	Y	N	n/a	n/a	I
WC3	Unnamed trib to Walker Cr at Walker Ranch	N	Y	5/8/2013	PRESENT	II
WC4	Walker Cr	Y	N	n/a	n/a	I
WC5	Unnamed trib to Walker Cr d/s Walker Ranch	N	Y	4/2/2013	PRESENT	II
WC6	Frink Cyn, lower	Y	N	n/a	n/a	I

Note:
'n/a' indicates no BMI survey was conducted because site has anadromous habitat and therefore is Class I.

4.1.4 Stage-Discharge Data at Habitat Transects

Each habitat site was visited three times with the goal of sampling at three different flow levels. Sampling occurred during December 2012, February 2013, and April 2013. The water surface elevation was surveyed near the left and right banks, and in some cases near the channel center. Discharge was measured at a uniform flow location during two of the three visits, and at all transects when cross-section profile habitat data were collected. The data were collected for the purpose of establishing a stage-discharge rating curve for each transect that would be used to predict depths and velocities at sampled points across the section, over a range of flows.

Since one field visit (December 2012) occurred during a rainfall event in which streamflow conditions changed quickly, it was possible to collect a fourth set of stage discharge data at all three transects in Bear Creek, and at three safely accessible transects in Walker Creek during high flow.

4.1.5 Depth, Velocity and Substrate Measurements at Transects

Flows that occurred during the field visit in December 2012 were considered suitable for collecting habitat at that time. The data collected included:

- Cross-section bed profiles and depth/velocity distributions along tapes strung between the left and right bank stakes. Upper bank profiles were surveyed with an autolevel and stadia rod at enough point locations to define the profile as it broadly influenced the conveyance at high flow. Within the wetted channel, points were either surveyed with an autolevel when dry, or depths and mean column velocities were measured with a topset rod and velocity meter approximately every 0.5-3.0 ft. along the tape between the stream bank toes. Distance between points depended on channel width such that approximately 20 to 25 wetted locations were measured at each cross-section.
- WSEs. WSEs were surveyed as described above, for use in computing bed elevation of wetted verticals (i.e., wetted bed elevation = WSE-depth).
- Visual assessment of substrate suitability for spawning. An assessment was performed across the channel based on dominant grain size (i.e., small-large gravel mix with a particle size range suitable for spawning by steelhead, $D_{50} \approx 10\text{-}40$ mm; Kondolf and Wolman 1993) and refinement as to whether the substrate patch viewed would be expected to support a redd based on flow level and previous spawning survey experience (as corroboration, some cross-sections were indeed later situated on or just upstream or downstream of redds constructed by steelhead or resident trout that winter).
- Grain size distribution characteristics in the reach. 100-stone pebble counts were used for evaluating substrate mobility at redd sites and channel forming flows. A pebble count was performed in each site over a homogeneous patch of material, across a spawning habitat.
- Longitudinal profiles. Longitudinal profiles of the thalweg and water surface elevations were surveyed using similar methods as those for the cross-section. These data were collected for estimating slopes to be used in hydraulic analyses.
- Stage of zero flow (SZQ). SZQ was surveyed as either (i) the lowest point on the cross-section when there was no low-flow hydraulic control backing water upstream over the cross-section, or (ii) at the lowest elevation point at the location of a hydraulic control that would continue to back water upstream over the cross-section when stream flow ceases in the site. The SZQ measurement was used in developing the stage-discharge curves.

Data were recorded in Rite-in-the-Rain field books. All but the grain size data were collected in standard English units; pebble counts measured each selected stone's intermediate axes to the nearest millimeter.

4.2 Data Analysis

4.2.1 Data Entry and QA/QC

All wetted data were entered into Excel spreadsheets and checked for data entry errors. The survey and wetted vertical data were entered separately to reflect the difference in data collection procedures.

4.2.2 Data Reduction

The survey data were reduced to station and elevation at each survey point. In most sites, the benchmarks were sufficiently close that it was possible to tie them to a common local datum, with one benchmark assigned an elevation of 100.00 ft. In any case, a consistent elevation datum was used for each transect over all three flows sampled. The depth data were converted to elevation using either an average of the left and right bank WSE's at the time of measurement, or the value for a single consistent location across the channel when the water surface profile across the channel was not approximately uniform.

The survey and wetted vertical data were combined into a single spreadsheet, and the cross-section profiles plotted to identify any potential errors that occurred during reduction or data entry.

The discharge in December 2012 was calculated for each transect, and the site discharge was set to either the average of those transects that were judged to be most uniform in cross-section profile, or in cases where the stage recorder indicated sufficiently unsteady flow, to the individual transect value. In some cases, the approximate time when a transect was measured was used to identify the corresponding water level at the stage recorder, and the datalogger rating curve used to determine the site flow at that time. A single discharge measurement was made at each site at the other flows sampled, at either one of the habitat transects or at a location with most uniform flow conditions.

Stage-discharge pairs were then compiled and plotted for each transect to identify potential surveying or data entry errors. Table 5 lists the resulting flows and WSEs.

4.2.3 Stage-Discharge Analysis

The stage discharge analysis for the habitat transects used a different method from the datalogger rating curves described in Section 3.2.2. The datalogger transects are different from habitat transects, in that habitat transects were selected for specific passage and spawning characteristics, while datalogger transects were selected to best measure streamflow. At habitat sites, the datalogger transect, though nearby, is not located at the same location as a habitat transect. Moreover, the datalogger transects generally have more discharge measurements than the habitat transects. The habitat rating curves are based on fewer data over the range of flows than the datalogger rating curves. As a consequence, a rating curve method used traditionally in instream flow habitat studies was used.

At the habitat transects, a standard logarithmic transform regression relationship was used to develop a rating curve for modeling and predicting WSE as a power function of stream flow:

$$Q = a * \left(WSE - SZQ\right)^{b}$$

where Q is the discharge (or flow), WSE is the stage (or water surface elevation), SZQ is the stage of zero flow, and a and b are regression parametersdetermined through the logarithmic regression procedure. For each transect, the stage of zero flow was initially set at the surveyed value, and then revised through an iterative process with the goal of maximizing the correlation (as measured by r^2) between stage and discharge.

The three measured flows provided good definition of the stage-discharge curve over the low-mid flow range. However, it was determined through a preliminary evaluation that the range of spawning flows in most cases extended to much higher flows than measured, with the exception being Salmon Creek and the lower transects on Walker Creek. A fourth point was subsequently defined for the stage-discharge regression based on Manning's equation:

$$V = \frac{1.486}{n} R^{2/3} \sqrt{S}$$

where V is the mean channel flow velocity, n is Manning's coefficient, R is the channel hydraulic radius, and S is the streamwise slope estimated from the longitudinal profile surveying. Manning's n was estimated for each transect by (i) first using the guidelines of Hicks and Mason (1998) and/or Barnes (1967), and then (ii) calculating the observed Manning's n using the estimated slope and observed high flow water surface elevation. The calculated value was compared to the guideline value, and the smaller of the two generally selected given that Manning's n decreases with increasing discharge (because of reduced relative roughness at higher flow).

Table 5 - Measured Flows and Water Surface Elevations (WSEs) at Habitat Transects

		Transect S1		Transect S2		Transect S3		Transect S4		Transect S5		Transect P1		Transect P2	
Study Site	Date	Q (cfs)	WSE (ft)	Q (cfs)	WSE (ft)	Q (cfs)	WSE (ft)	Q (cfs)	WSE (ft)	Q (cfs)	WSE (ft)	Q (cfs)	WSE (ft)	Q (cfs)	WSE (ft)
MC2 - Ingalls Cr	12/20/2012	5.1	92.19	5.1	95.44	5.1	95.37	5.1	95.47	--	--	--	--	--	--
	2/27/2013	0.97	91.93	0.97	94.98	0.97	94.98	0.97	95.15	--	--	--	--	--	--
	4/4/2013	5.5	92.27	5.3	95.41	5.3	95.39	6.8	95.57	--	--	--	--	--	--
MC3 - McDonnell Cr	12/20/2012	10.1	93.64	10.1	94.48	10.1	92.74	10.1	92.33	--	--	--	--	--	--
	2/27/2013	1.4	93.13	1.4	93.99	1.4	92.26	1.4	91.87	--	--	--	--	--	--
	4/4/2013	22.7	94.68	24.7	94.94	24.6	92.89	24.6	92.75	--	--	--	--	--	--
MC5 - Maacama Cr below Briggs Cr	12/19/2012	43.3	93.66	40	94.28	38.6	94.31	37.3	94.31	37.3	94.28	--	--	--	--
	2/26/2013	8.6	93.28	8.6	93.73	8.6	93.73	8.6	93.73	8.6	93.71	--	--	--	--
	4/5/2013	35.4	93.72	35.4	94.34	35.4	94.34	35.4	94.34	35.4	94.39	--	--	--	--
SC4 - Upper Sonoma Cr above Bear Cr	12/21/2012	11.5	95.70	13.1	95.85	19.2	94.04	26.6	98.53	32.6	94.18	11.5	95.70	--	--
	2/28/2013	1.1	95.31	1.1	95.48	1.1	93.62	1.1	97.84	1.1	92.97	1.1	95.33	--	--
	4/3/2013	1	95.30	1	95.46	1	93.50	0.9	97.77	0.8	92.94	1	95.29	--	--
SC5 - Lower Bear Cr	12/19/2012	2.6	95.19	2.6	91.72	2.6	89.64	--	--	--	--	--	--	--	--
	12/21/2012	9.9	95.73	11.3	92.33	12.5	90.29	--	--	--	--	--	--	--	--
	2/28/2013	0.46	94.99	0.46	91.49	0.46	89.40	--	--	--	--	--	--	--	--
	4/3/2013	0.1	94.89	0.1	91.40	0.1	89.35	--	--	--	--	--	--	--	--
SC6 - Sonoma Cr near Hwy 12	12/18/2012	13.1	94.98	13.1	96.67	13.1	97.57	13.1	97.88	13.1	94.77	13.1	94.97	13.1	96.64
	2/28/2013	1.0	94.48	1.0	96.43	1.0	96.84	1.0	97.14	1.0	94.47	1.0	94.48	1.0	96.41
	4/3/2013	0.5	94.44	0.5	96.38	0.5	96.80	0.5	97.10	0.5	94.43	0.5	94.42	0.5	96.39
WC2 - Middle Salmon Creek	12/21/2012	32.0	92.66	32.0	92.50	32.0	92.02	32.0	91.96	--	--	32.0	92.00	--	--
	12/17/2012	3.0	91.92	3.0	91.73	3.0	91.07	3.0	90.90	--	--	3.0	91.02	--	--
	2/26/2013	0.15	91.48	0.15	91.42	0.15	90.91	0.15	90.70	--	--	0.15	90.88	--	--
WC4 - Walker Creek	12/21/2012	544	98.53	544	98.51	30.6	95.91	30.6	95.81	30.6	95.74	544	98.53	--	--
	12/18/2012	30.6	95.55	30.6	95.57	11.7	95.36	11.7	95.36	11.7	95.34	30.6	95.53	--	--
	2/26/2013	11.7	95.27	11.7	95.26	11.3	95.32	11.3	95.30	11.3	95.29	11.7	95.23	--	--
	4/2/2013	11.3	95.24	11.3	95.22	--	--	--	--	--	--	11.3	95.22	--	--
WC6 - Frink Canyon	12/17/2012	3.1	94.81	3.1	94.41	3.1	94.38	3.1	94.29	--	--	3.1	95.20	--	--
	2/26/2013	0.23	94.29	0.23	94.13	0.23	94.09	0.23	94.08	--	--	0.23	94.85	--	--
	4/2/2013	0.22	94.27	0.22	94.12	0.22	94.07	0.22	94.06	--	--	0.22	94.86	--	--

The high flow WSE was then estimated using Manning's equation and continuity (*Q=A * V* where *A* = cross-section area) at a discharge associated with a predicted water level that roughly approximated the surveyed limit of the cross-section profile and/or was close to or equaled the 1.5 year flood magnitude; the primary objective was to estimate a water level that was well above the expected limiting spawning flow. The resulting estimate was then added to the three measured stage-discharge pairs and the relation regressed again.

Finally, as QA/QC, the stage of zero flow (SZQ) was adjusted slightly so that the resulting predicted regression lines for nearby transects did not cross at lower or higher flows. The final relations are depicted in Appendix A-7 along with the measured and estimated stage-discharge pairs The resulting stage-discharge relations were used to predict water surface elevations at thirty flows, and the predictions imported into the hydraulic modeling program input files (see next section).

Table 6 presents estimated and calculated values of Manning's *n* along with the reach slope used in Manning's equation, and the stage of zero flow value used in the regressions. Notes are provided where the high flow Manning's *n* was selected for a transect based on additional site-specific considerations.

4.2.4 Velocity and Depth Simulations

The reduced cross-section data and thirty predicted stage-discharge pairs were exported from Excel to ASCII files, which were then processed into the appropriate format for analysis by the U.S. Fish and Wildlife Service (USFWS) microcomputer software PHABSIM (DOS Version 2.1). We did not use the Windows version because it contains numerous programming bugs that may result in spurious results. Each transect was analyzed separately using the IFG4 hydraulic model, with user-supplied stage-discharge data. Two runs were performed for each transect, as explained below.

The 1-velocity set option was modeled first using the IFG4 hydraulic simulation program. This option uses the measured cross-section velocity distribution to calculate a Manning's *n* value for each cell, and relies on the calculated values to distribute flow and thus velocity across the channel at other simulation flows. The hydraulic output was brought back into proprietary Excel spreadsheets that facilitated rapid review of the simulation predictions for velocity distributions, water surface elevation predictions, and variation in selected flow parameters including Manning's *n*, Froude number, and velocity adjustment factors (calculated by IFG4 to ensure mass balancing at all simulation flows). The results generally appeared reasonable over the lower range of simulation flows, and no significant adjustments were deemed necessary to the simulations. The results of the hydraulic modeling using the measured velocity data to predict cross-section velocity profiles at other flows are presented in Appendix A-8.

The transect data were analyzed a second time using IFG4, but this time the velocity simulations were based on a channel average Manning's *n* value. The distribution of flow and thus velocities is based on the depth at each modeled location on the cross-section profile. Effectively, this amounts to a depth-based distribution of velocities across the channel. The 27th largest flow in the 30 flow set was selected arbitrarily from the largest simulation flows (for ease of automated processing) as the 'calibration' flow for calculating a channel average Manning's *n*. This approach provided a smoother cross-section distribution of velocities at higher flows, which is typically more realistic than predictions based on velocities measured at low to moderate flow levels when irregularities in the channel profile and relative roughness have a proportionately greater effect than at high flow. The results of the hydraulic modeling using the channel average Manning's n approach to predict cross-section velocity profiles are presented in Appendix A-9.

Table 6 - Hydraulic Parameters Used in Stage-Discharge Analyses at Habitat Transects

				Manning's n at High Flow			High Flow Estimates	
Study Site	**Transect**	**SZQ (ft)**	**Slope**	**Calculated**	**Guidelines**	**Selected[1]**	**Flow (cfs)**	**WSE (ft)**
MC2 - Ingalls Cr	S1	91.43	0.05200	0.21000	0.150	0.150	52.1	93.18
	S2	94.52	0.00200	0.06700	0.150	0.033[2]	92.4	97.25
	S3	94.63	0.00200	0.03300	0.150	0.033	72.0	97.07
	S4	94.59	0.00820	0.03000	0.150	0.033[2]	86.7	96.40
MC3 - McDonnell Cr below Ingalls Cr	S1	92.14	0.01000	0.11440	0.065	0.065	186	96.10
	S2	93.48	0.00940	0.06100	0.065	0.061	180	97.03
	S3	91.02	0.00940	0.05900	0.065	0.061[3]	180	94.81
	S4	91.48	0.00940	0.06050	0.065	0.061[3]	181	94.73
MC5 - Maacama Cr below Briggs Cr	S1	92.56	0.00250	0.02300	0.038	0.026[4]	349	95.06
	S2	93.19	0.00050	0.01140	0.038	0.026[4]	350	97.04
	S3	93.19	0.00050	0.02030	0.038	0.026[4]	350	97.43
	S4	93.19	0.00050	0.02750	0.038	0.026[4]	349	97.23
	S5	93.19	0.00050	0.02610	0.038	0.026	350	96.78
SC4 - Upper Sonoma Cr above Bear Cr	S1	95.20	0.00160	0.02860	0.061	0.029	100	97.54
	S2	95.38	0.00160	0.02700	0.061	0.029[5]	100	97.72
	S3	93.30	0.03100	0.08400	0.130	0.076[6]	100	95.02
	S4	97.67	0.02200	0.07600	0.130	0.076	100	99.68
	S5	92.51	*Exhibited significant loss of gravel; not used in analysis*					
	P1	95.20	*n/a[7]*					
SC5 - Lower Bear Cr	S1	94.85	0.00550	0.07100	0.150	0.071	58.6	97.00
	S2	91.35	0.00550	0.08300	0.150	0.083	57.2	94.00
	S3	89.30	0.00550	0.12400	0.150	0.124	50.9	92.00
SC6 - Sonoma Cr near Hwy 12	S1	94.26	0.00610	0.04100	0.035	0.035	99.9	95.98
	S2	96.33	0.00610	0.03700	0.035	0.035	100.0	97.73
	S3	96.45	0.00610	0.02440	0.035	0.028[8]	99.9	98.56
	S4	97.80	0.00610	0.02060	0.035	0.028[8]	99.2	98.82
	S5	94.35	0.00530	0.02800	0.035	0.028	99.8	95.72
	P1	94.26	*n/a[7]*					
	P2	96.33	*n/a[1,7]*					
WC2 - Middle Salmon Creek	S1	91.25	*n/a[9]*					
	S2	91.31	*n/a[9]*					
	S3	90.80	*n/a[9]*					
	S4	90.55	*n/a[9]*					
	P1	90.77	*n/a[7]*					
WC4 - Walker Creek	S1	94.80	*n/a[9]*					
	S2	94.80	*n/a[9]*					
	S3	94.06	*n/a[9]*					
	S4	94.46	*n/a[9]*					
	S5	94.67	*n/a[9]*					
	P1	94.80	*n/a[7]*					

Study Site	Transect	SZQ (ft)	Slope	Manning's n at High Flow			High Flow Estimates	
				Calculated	Guidelines	Selected[1]	Flow (cfs)	WSE (ft)
WC6 - Frink Canyon	S1	94.20	*Transect exhibited rating shift; not used in analysis*					
	S2	93.98	0.00840	0.02000	0.085	0.025[10]	33.3	95.19
	S3	93.92	0.00840	0.02500	0.085	0.025	27.3	95.14
	S4	93.99	0.00840	0.04400	0.085	0.044	33.2	95.29
	P1	94.76	*n/a*[7]					

Notes:

[1] In all cases, stage-discharge curves were also calibrated to ensure transect-specific curves did not cross one another and generally tracked the same trend, where the magnitude of the regression parameters compensated for any potential error in selection of high flow Manning's n.

[2] S2 in same channel unit as S3 but is deeper, thus used S3 value; S4 in similar morphology as S3, again used S3 value for consistency.

[3] S2, S3, S4 transects more similar, used S2 value which was closer to guidelines value.

[4] S2, S3, S4 transects under influence of same high flow control located proximal to S5, used S5 value; S1 value close to S5, used S5 for consistency.

[5] S2 under same high flow hydraulic control as S1, which is closer, thus used S1 value.

[6] S3 similar morphology as S4, but calculated Manning's n appears to be biased high by presence of gravel bar.

[7] High flow estimate not necessary at passage transects.

[8] Calculated values for concentrated flow at S3, S4 not representative of spread out conditions under higher flows; used similar value to S5 with more similar high flow morphology.

[9] High flow estimate not necessary since range of spawning flows did not exceed measured flow at that transect.

[10] Transects S2 and S3 in same channel unit, used value for S3 which is downstream of S2 and is closer to hydraulic control at higher flows.

5 Summary

The field studies described in this report were completed to support the Volume Depletion Approach Study. The Study is required by the North Coast Instream Flow Policy and will evaluate whether the guidelines in Policy Section A.1.8.3 are protective of anadromous fisheries habitat.

Three regionally representative study basins were selected for field data collection. From October 2012 through May 2013, streamflow and habitat data were collected at 17 locations within the three study basins. Dataloggers were installed at 15 locations in order to measure stream stage. Periodic discharge measurements were made at those sites so that rating curves could later be prepared. From the stage records, discharge time series were generated. These time series will be used in hydrologic modeling to assist with calibration.

At nine of the sites, instream flow data were collected to describe the relation between flow and physical habitat availability for anadromous salmon and steelhead trout. Stream cross-sections were surveyed at potential steelhead spawning locations and at limiting upstream passage riffles for coho salmon and steelhead. Depth, velocity, and substrate data were collected at each cross-section. The measured depth, flow and velocity data were used in a PHABSIM framework to estimate velocities at other ranges of flows. The resulting data will be used to create habitat flow curves which will be used to assess whether the alternative guidelines in Policy Section A.1.8.3 are protective of anadromous fisheries habitat.

6 References

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