FINAL REPORT ◦ JANUARY 2014

San Luis Obispo County Regional Instream Flow Assessment

PREPARED FOR

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A Note on Units of Measurement

This study integrates findings from a number of different disciplines, including hydrology, freshwater ecology, and water quality. Each of these disciplines has a "habitual" system of measurement, whether the English system (e.g., the United States Geological Survey's reporting of discharges in cubic feet per second) or the metric system (e.g., the concentration of water-quality parameters are commonly presented as milligrams per liter). This document makes no effort to translate units from the various systems of measurement into a common framework, but instead maintains the common units of measurement for the physical attribute being described or as used in the original data set. For those readers wishing to make conversions, the following table is provided.

Metric/English unit conversions (abbreviations in parentheses).

Metric	English
1 degree Centigrade (°C)	1.8 degrees Fahrenheit (°F)
1 centimeter (cm)	0.39 inch (in)
1 cubic meter per seconds (cms)	35.3 cubic feet per second (cfs)
1 hectare-meter (hm)	8.10 acre-feet (ac-ft) [1.98 ac-ft = 1 cfs × one day]
1 kilometer (km)	0.62 mile (mi) 3,280 feet (ft)
1 meter (m)	3.28 feet (ft)
1 meter per second (m/s)	3.28 feet per second (ft/s)
1 milligram per liter (mg/L)	1 part per million (ppm)
1 milligram per milliliter (mg/mL)	1 part per thousand (ppt)
1 millimeter (mm)	0.04 inch (in)

EXECUTIVE SUMMARY

Introduction

San Luis Obispo County (SLO, or County) has developed a Master Water Report (MWR) of the current and future water resource management activities being undertaken by various entities within the County (SLO County Water Resources 2012). In addition to total water demand (which includes urban, rural, and agricultural needs), the MWR includes an estimate of *Environmental Water Demand* (EWD), which is defined (MWR Section 4.6.5.1) as, "the amount of water needed in an aquatic ecosystem, or released into it, to sustain aquatic habitat and ecosystem processes." The MWR selected the federally threatened South-Central California Coast steelhead (*Oncorhynchus mykiss)* as the target species for analysis, based on their adequacy as an indicator species (i.e., a species whose habitat requirements are sensitive enough to allow for successful identification of environmental problems, yet broad enough to adequately represent a wide array of aquatic species). However, the MWR did not provide EWD estimates for specific seasons or subwatersheds, and recommended additional analysis. The objectives of this study are to further develop EWD estimates based on the recommendations of the MWR, including producing:

1. a County-wide assessment of instream flow requirements for steelhead based on existing instream flow assessments;
2. an assessment of data needs to support EWD estimates;
3. initial EWD estimates for the County;
4. a prioritization of streams for which detailed instream flow assessments would be most useful; and
5. recommendations for technically appropriate approaches to produce detailed and site-specific instream flow assessments.

The purpose of this analysis is to provide a preliminary estimate of the magnitude and timing of instream flows that would support steelhead in creeks of San Luis Obispo County. This initial assessment is not intended to provide sufficient precision or detail from which to establish regulatory or mandatory water permit limits. In addition, these estimates of EWD are minimum values to maintain aquatic systems and should not be interpreted as "enough" water to support long-term, sustainable steelhead populations or the complex ecosystem in which they live.

Approach

For this analysis, EWD was defined in relation to steelhead life history requirements during the two most flow-sensitive periods for minimum flows, namely the spring period and the summer period. Portions of many County rivers are naturally dry each summer. We recognize that there is no value in predicting summer flow requirements for steelhead in the portion of a creek that is naturally dry during part of the year. Therefore results from a National Oceanic and Atmospheric Administration (NOAA) analysis (Boughton and Goslin 2006) were used to limit analysis of EWD to portions of each watershed determined to have a high potential for steelhead rearing to occur based on intrinsic watershed characteristics, including perennial flows.

Available hydrologic and physical terrain data and available instream flow assessments were reviewed and analyzed to explore appropriate watershed stratification and to assess the ability to extrapolate existing instream flow analyses throughout all watersheds of the County. All available hydrologic and physical terrain data were evaluated to assess patterns of instream flows and stream morphological characteristics, such as channel gradient, channel width, and geologic terrain. Because few existing instream flow analyses are available, a field-based instream flow assessment was conducted in numerous County streams. A predictive model was developed based on results of the field assessment to estimate EWD for the remaining watersheds in the County. A framework for improving these estimates is described, and high-priority data needs and watersheds to focus on are identified.

Results

Twelve sites were evaluated during mid-April 2013, and six of these sites were re-evaluated during early September 2013 to estimate both spring and summer flow requirements. Based on measurements of suitable habitat for specific steelhead life stages, flows to support steelhead in County streams during spring range from 0.5 cfs to 4 cfs. Flows of this magnitude during spring were sufficient to provide fry and juvenile rearing and feeding habitat, migratory connectivity for juveniles between habitat units, and benthic macroinvertebrate production. Flows to support steelhead during summer were observed to range from 0.25 cfs to 1 cfs. Flows of this magnitude provided sufficient water depth to provide fry and juvenile rearing habitat.

Analysis points were established within all County Analysis Watersheds with delineated high potential steelhead rearing habitat. Predictive models were developed based on field assessments and watershed characteristics, including drainage area. Based on the models, EWD was estimated for each Analysis Point based on spring and summer flow requirements. Due to the large number of locations for which EWD is estimated throughout the County, an interactive web-based map was developed, and is available at:
http://geo.stillwatersci.com/maps/slo_rifa/instreamflowassessment.html

To compare EWD estimates with existing conditions, streamflow data were examined for 16 USGS and two County-maintained gages. EWD for spring flows are mostly achieved on average at all gage locations over the period of record, whereas summer flows are either barely achieved, or not at all.

Discussion and Recommendations

Overall, it appears that spring flows are sufficient to provide steelhead habitat in many Analysis Watersheds under existing conditions. However, summer flows are not sufficient to support steelhead in most Analysis Watersheds, despite the NOAA analysis of Boughton and Goslin (2006) results that indicated these watersheds have a high potential for steelhead rearing to occur based on intrinsic watershed characteristics, including perennial flows. It also appears based on channel morphology that even relatively low flows (e.g., <0.5 cfs) during summer allow steelhead to persist in Analysis Watersheds throughout the County.

In summary, we recommend the following:

- Broaden the definition of EWD to consider additional natural resources, especially in the County's 26 coastal lagoons where tidewater goby occur.
- Analyze current streamflow conditions compared with historical streamflow conditions, with consideration for water year type (i.e., wet, normal, or dry) and EWD. This would include the compilation and maintenance of daily mean discharge data for current County stream gaging stations.
- Monitor streamflows in all 25 Analysis Watersheds during spring and summer to determine which streams are exceeding EWD estimates and which are not. Monitoring could include establishment of additional gages, or periodic direct measurements of streamflow during spring and summer.

- Determine if Analysis Watersheds not achieving predicted EWD are mischaracterized in the NOAA analysis as having a high potential to support rearing steelhead, or if other factors are causing flow reductions. Results could be used by resource managers to inform the prioritization of streams for protection, habitat restoration, and/or streamflow enhancement.
- Conduct intensive and more accurate estimates of steelhead habitat relationships with instream flows within those watersheds with high steelhead rearing potential and water management implications.

1 INTRODUCTION AND PURPOSE

San Luis Obispo County (SLO, or County) has developed a Master Water Report (MWR) of the current and future water resource management activities being undertaken by various entities within the County (SLO County Water Resources 2012). The MWR calculates the total County water demand for specific Water Planning Areas. In addition to total water demand (which includes urban, rural, and agricultural needs), the MWR includes an estimate of *Environmental Water Demand* (EWD), which is defined (MWR Section 4.6.5.1) as, "the amount of water needed in an aquatic ecosystem, or released into it, to sustain aquatic habitat and ecosystem processes." The MWR selected the federally threatened South-Central California Coast steelhead (*Oncorhynchus mykiss)* (herein referred to as "steelhead") as the target species for analysis, based on their adequacy as an indicator species (i.e., a species whose habitat requirements are sensitive enough to allow for successful identification of environmental problems, yet broad enough to adequately represent a wide array of aquatic species).

To calculate EWD in the MWR, a methodology developed by Hatfield and Bruce (2000), *Predicting Salmonid Habitat-Flow Relationships for Streams from Western North America*, was applied. The Hatfield and Bruce (2000) methodology uses relationships from studies conducted throughout the western United States to predict annual flow requirements in any watershed for which flows are measured or estimated. However, this approach did not provide estimates for specific seasons or subwatersheds. In addition, the flow estimate is expressed as an annual volume of water, which does not take into account seasonal fluctuations in flow or support real-time flow monitoring. For example, a creek could be dry all summer, effectively extirpating steelhead, and then achieve its annual flow requirement during winter floods, and thus be considered to have met its EWD for the year.

The MWR (Section 5.2.1) concludes that to improve estimates of the EWD, an analysis of the instream flows needed to support steelhead habitat and watershed functions in County rivers and streams is needed. This study was proposed to the Integrated Regional Water Management (IRWM) program with the stated goal to estimate EWD in the County. We originally presumed that this study would be conducted in two stages: Stage 1 – watershed stratification, instream flow study prioritization, and proof of concept; and Stage 2 – instream flow study implementation, data repository, and environmental water demand calculation. Although only the first stage was funded by Department of Water Resources through the IRWM program, during this study we were able to develop estimates of EWD for County streams. These estimates are intended to inform water supply planning efforts by the SLO IRWM participants to better understand environmental instream flows in the County. The EWD estimates developed in this study are not related to any instream flow policy or regulation. The objectives, methods, and results of this analysis were presented to the San Luis Obispo County Flood Control and Water Conservation District Water Resources Advisory Committee.

The specific objectives of this study are to produce:

1. a County-wide assessment of instream flow requirements for steelhead based on existing instream flow assessments;
2. an assessment of data needs to support EWD estimates;
3. initial EWD estimates for the County;
4. a prioritization of streams for which detailed instream flow assessments would be most useful; and

5. recommendations for technically appropriate approaches to produce detailed and site-specific instream flow assessments.

The purpose of this analysis is to provide a preliminary estimate of the magnitude and timing of instream flows that would support steelhead in creeks of San Luis Obispo County. This initial assessment is not intended to provide sufficient precision or detail from which to establish regulatory or mandatory water permit limits. In addition, these estimates of EWD are minimum values to maintain aquatic systems and should not be interpreted as "enough" water to support long-term, sustainable steelhead populations or the complex ecosystem in which they live.

2 APPROACH

For this analysis, Environmental Water Demand (EWD) was defined in relation to specific steelhead life history requirements. Available hydrologic and physical terrain data and available instream flow assessments were reviewed and analyzed to explore appropriate watershed stratification and to assess the ability to extrapolate existing instream flow analysis throughout all watersheds of the County. A California State interagency watershed mapping committee, CalWater, divides California into ten Hydrologic Regions (HR). Each HR is progressively subdivided into six smaller, nested levels: the Hydrologic Unit (HU, major rivers), Hydrologic Area (HA, major tributaries), Hydrologic Sub-Area (HSA), Super Planning Watershed (SPWS), and Planning Watershed (PWS). To support our analysis, we divided all streams in the County into Analysis Watersheds based Hydrologic Areas, Hydrologic Sub-Areas, and Planning Watersheds. For streams in the interior of the County where steelhead streams have a low density, Analysis Watersheds were larger, and based on Hydrologic Areas or Hydrologic Sub-Areas. On the coast of the County where steelhead streams have a higher density, Analysis Watersheds were smaller, and designated based on Planning Watersheds. Streams networks used for analysis were from the National Hydrography Dataset (NHD) at a scale of 1:24,000.

Portions of many County rivers are naturally dry each summer. We recognize that there is no value in predicting flow requirements for steelhead in the portion of a creek that is naturally dry during part of the year. Therefore results from a National Oceanic and Atmospheric Administration (NOAA) analysis (Boughton and Goslin 2006) were used to limit analysis of EWD to portions of each watershed determined to have a high potential for steelhead rearing to occur based on intrinsic watershed characteristics, including perennial flows.

All available hydrologic data and physical terrain information was evaluated to assess patterns of instream flows and stream morphological characteristics, such as channel gradient, channel width, and geologic terrain. Because few existing instream flow analyses are available, a field-based instream flow assessment was conducted in numerous County streams. A predictive model was developed based on results of the field assessment to estimate EWD for remaining watersheds in the County. A framework for improving these estimates is described, and high-priority data needs and watersheds to focus on are identified. Details on this approach are described below.

2.1 Defining Environmental Water Demand

The MWR defines EWD as "…the amount of water needed in an aquatic ecosystem, or released into it, to sustain aquatic habitat and ecosystem processes." In Appendix D of the MWR for the purposes of estimating EWD, "…the federally threatened South-Central California Coast steelhead was used as the primary indicator species. Although numerous other listed and nonlisted native aquatic species occur throughout the County, a large proportion of these species typically thrive in water bodies known to support steelhead. Furthermore, the threatened status of steelhead requires careful consideration."

Consistent with the MWR, this analysis thus defines EWD as equivalent to the instream flow requirements of steelhead. In addition, occurrences of the federally endangered tidewater goby (*Eucyclogobius newberryi*) are considered qualitatively. Since this approach is based on assessing instream flow requirements primarily for steelhead, all streams and creeks within the County that were identified in a NOAA analysis (Boughton and Goslin 2006) as having a high potential for steelhead to occur based on intrinsic (unmanaged, unimpaired) watershed characteristics (stream gradient, hydrology, air temperature, and channel morphology) were included, regardless of actual current habitat conditions or steelhead distribution. For this analysis, the spatial data from the NOAA (Boughton and Goslin 2006) report were acquired from that study's authors and used to delineate potential steelhead distribution within Analysis Watersheds for all streams in the County (Figure 1).

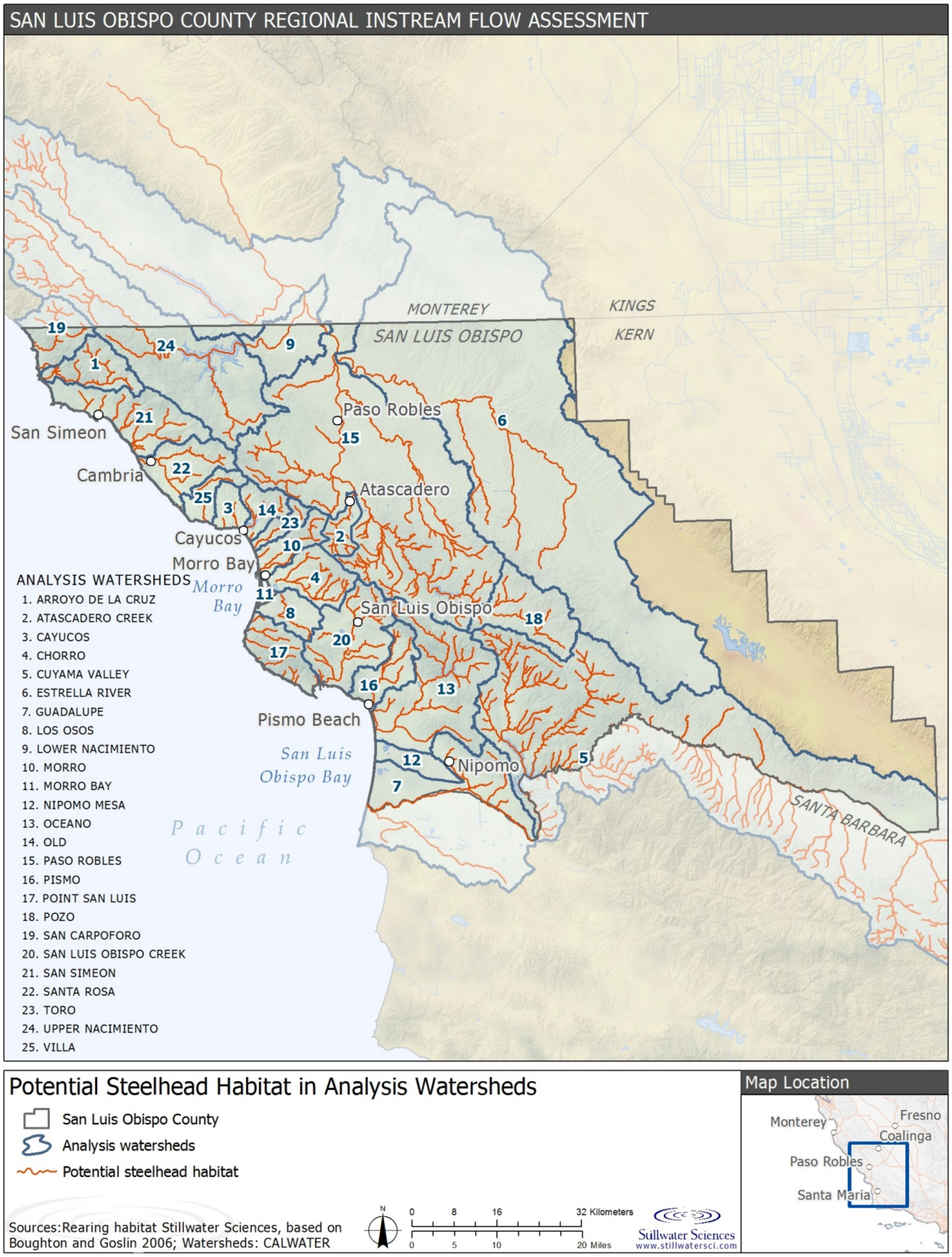


Figure 1. Potential steelhead habitat in San Luis Obispo County.

In addition to steelhead, this analysis also qualitatively considers the freshwater flow requirements of tidewater goby. For all lagoons where tidewater goby currently or historically occur, based on USFWS (2005) (Figure 2), EWD requirements to support suitable habitat were assessed.

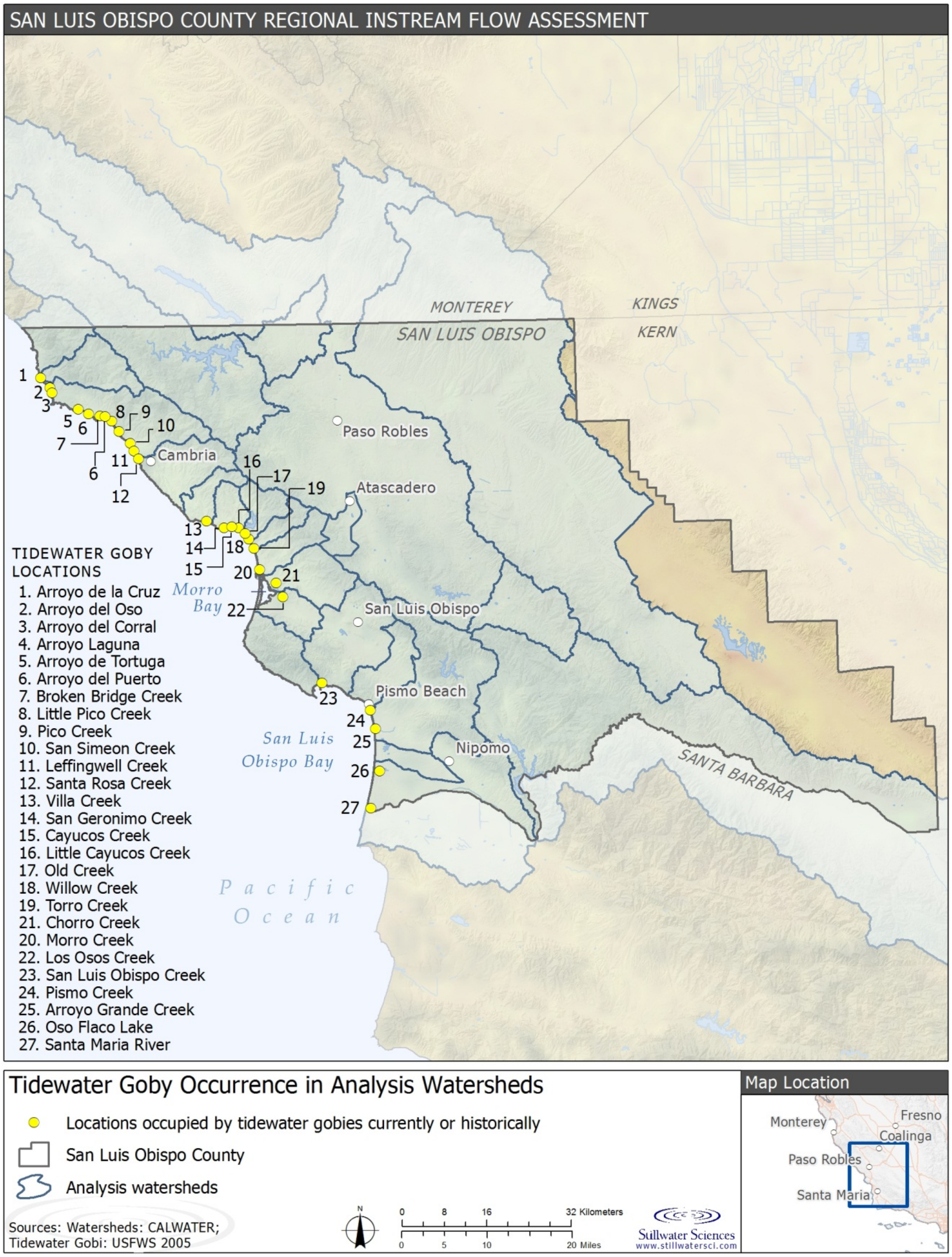


Figure 2. Tidewater goby occurrence in San Luis Obispo County.

2.2 Available Data

All available instream flow analysis, physical terrain, hydrology, and stream network data were assessed and summarized to inform EWD assessments, as described below.

2.2.1 Instream flow analyses

All available instream flow analyses in the County were compiled. Results of each available study were summarized based on common metrics, including the drainage area of study reach and the flow requirements for fish passage, spring rearing, summer rearing, and lagoon function. Based on the limited number of studies conducted, it was not possible to extrapolate results to non-studied watersheds. Therefore, a quantitative field analysis was conducted, as described in Section 2.3.3 below, to collect uniform data throughout the County.

2.2.2 Watershed groupings

Existing spatial data were used to demarcate the geologic/topographic/hydrologic "Physical Landscape Units" (PLU) within the County (Figure 3). These units were defined by their underlying geology and hillslope gradient, grouped into 21 separate classes using the categories developed for the Central Coast Regional Water Quality Control Board in support of their hydromodification control criteria (Stillwater Sciences and Tetra Tech 2012; termed "Physical Landscape Zones" in that document). Using spatial analysis in a Geographic Information System (GIS), the PLU was identified for each stream reach in the County.

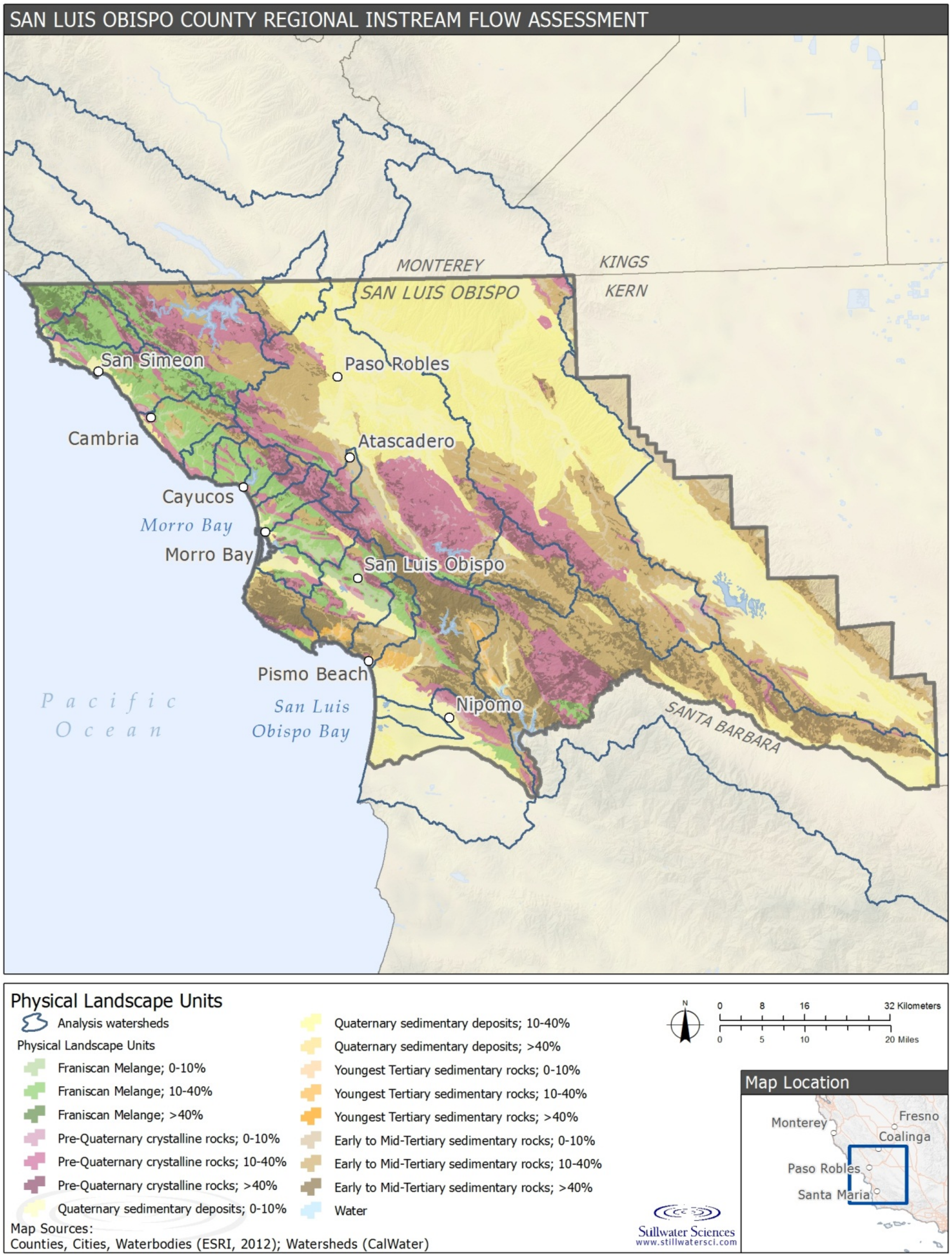


Figure 3. Physical Landscape Units in San Luis Obispo County (Stillwater Sciences and Tetra Tech 2012).

2.2.3 Hydrology

All available United States Geological Survey (USGS) and County streamflow gage data for the County were compiled. Existing flow data were used to examine potential relationships between flows and physical landscape characteristics such as channel slope, channel width, drainage area, and PLUs.

2.3 Quantitative Assessment of Steelhead Flow Requirements

Flow requirements were defined and quantified for steelhead based on their life history, particularly during the two most flow-sensitive periods for minimum flow requirements (Figure 4), namely: (1) the spring period, when sufficient flows are required not only to prevent desiccation but also to provide for production of aquatic macroinvertebrate food source and downstream migration of juveniles; and (2) the summer period, when sufficient flows are required to prevent desiccation of habitat. For the purposes of this analysis, “fry” are considered steelhead recently emerged from the gravel and in their first spring or summer of life, and “juveniles” are steelhead that have resided in freshwater for at least one year.

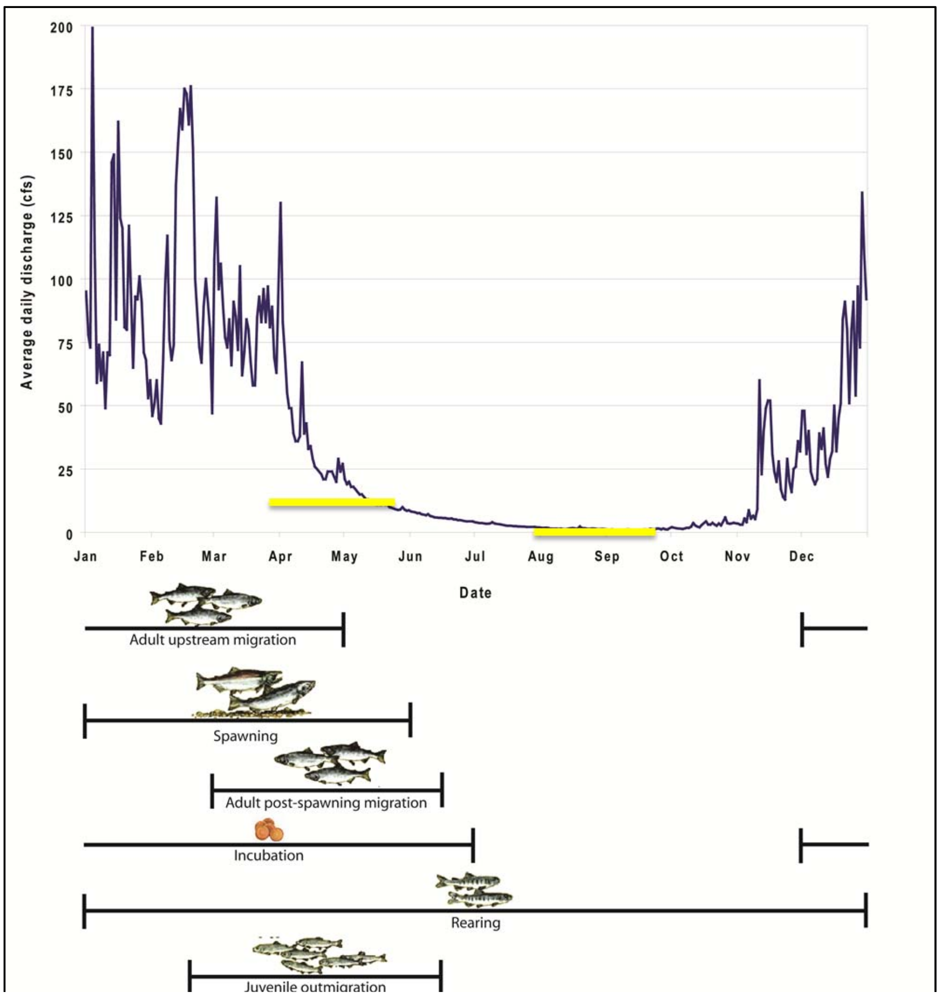


Figure 4. Steelhead life history and hypothetical annual hydrograph. Sensitive time periods are shown in yellow, corresponding to the spring (April through May) and summer (August through September) flow periods.

2.3.1 Spring flows

Spring flows were defined as the mean discharge during the months of April and May, when flows are needed to support the survival, growth, and migration of steelhead. Steelhead can only survive the intrinsically harsh conditions of summer in central California watersheds if conditions to support growth are sufficient during the preceding spring (Harvey et al. 2006, Stillwater Sciences 2007, Sogard et al. 2009). Productive benthic macroinvertebrate (BMI) habitat is considered the most direct measure of the ability of a stream to provide food resources to rearing salmonids, which also is directly affected by instream flows (Harvey et al. 2006). Adequate flows are needed to provide for the production of macroinvertebrates in riffle habitat, as well as the drift of macroinvertebrates from riffles downstream to pools where steelhead rear and feed. In addition, flows of sufficient magnitude are necessary to support downstream migration of juveniles to the ocean.

Flows during spring were assumed to be sufficient if flatwater habitats (e.g., pools and runs) had adequate water depths and velocities for steelhead fry and juveniles, riffles had adequate water depths and velocities to provide productive BMI habitat, and shallow riffles were deep enough to allow migratory connectivity between habitats (Table 1).

Table 1. Summary of habitat criteria values for steelhead rearing during spring.

Life stage	Habitat characteristic	Range of suitable values	Supporting literature
Fry rearing	Depth	0.1–1.5 ft	Sheppard and Johnson (1985), Bugert (1985), Moyle and Baltz (1985)
	Velocity	<0.5 ft/s	Bjornn and Reiser (1991), Dolloff (1983)
Juvenile rearing	Depth	>1.0 ft	Everest and Chapman (1972), Shirvell (1990)
	Velocity	0.5–2.7 ft/s	Everest and Chapman (1972), Smith and Li (1983), Shirvell (1990)
Juvenile migration	Depth	>0.3 ft	CDFG 2013
BMI production	Substrate	Gravel/cobble	Orth and Maugham (1983), Gore et al. (2001), Taylor et al. (2009)
	Depth	Inundate average particles	
	Velocity	> 1.0 ft/s	

2.3.2 Summer flows

Consistent with the approach of Goslin and Boughton (2006), summer flows were defined as the mean discharge during the months of August and September, when flows are needed to support survival of steelhead fry and juveniles. During summer, flows in many central California streams become low, intermittent, or dry up completely (Spina et al. 2005). Summer rearing habitat related to instream flows is therefore thought to be an important limiting factor for steelhead populations in central and southern California (Spina et al. 2005, NMFS 2013), and the shortage of summer habitat restricts steelhead distribution in this region more than available habitat during other seasons (Goslin and Boughton 2006). Although higher flows would be preferred by steelhead to support growth and migration during summer, research has demonstrated that steelhead can survive during summer with minimum flows that prevent desiccation in areas with suitable water temperatures (Harvey et al. 2006, Stillwater Sciences 2007, Sogard et al. 2009). Flows during summer were assumed to be sufficient if there were adequate water depths for steelhead fry and juveniles, as well as the apparent connectivity of water flowing between habitat units (Table 2).

Table 2. Summary of habitat criteria values for steelhead rearing during summer.

Life stage	Habitat characteristic	Range of suitable values	Supporting literature
Fry rearing	Depth	> 0.3 ft	Everest and Chapman (1972), Johnson and Kucera (1985), Sheppard and Johnson (1985)
	Velocity	0.0–0.8 ft/s	Everest and Chapman (1972), Smith and Li (1983), Sheppard and Johnson (1985)
Juvenile rearing	Depth	>1.0 ft	Everest and Chapman (1972), Shirvell (1990)
	Velocity	0.0–2.7 ft/s	Everest and Chapman (1972), Smith and Li (1983), Shirvell (1990)

2.3.3 Field assessment

Because instream flow data in the County are very limited (Section 2.2.1), a field assessment was conducted to evaluate the relationship between instream flows and habitat for steelhead during spring and summer. Field assessment sites were selected to represent a range of watershed areas, instream flows, PLUs, and locations within the County (Figure 5). Twelve sites were evaluated during mid-April 2013, and six of the twelve sites were re-evaluated during early September 2013. An additional ten sites were visited during spring and summer 2013 but had insufficient flow to support assessments.

All observations were made during 2013, which was classified by the California Department of Water Resources as an extreme drought in San Luis Obispo County. Field assessments of steelhead habitat were conducted to determine the relationship between channel characteristics and minimum flow requirements for steelhead, and were not affected by the occurrence of the drought. However, during summer 2013 field visits many sites no longer had visible surface flow, and thus no useful field data could be collected.

Field evaluations were conducted to consider habitat/flow relationships during the season of interest. During each field visit, a study area of approximately 20 channel widths was identified within the stream channel, a rough channel sketch was created (e.g., Figure 6), and flows were measured following the methods of Rantz (1982). Suitable habitat for steelhead was delineated at each field site based on the criteria defined for summer and spring flows, described above (Tables 1 and 2). Suitable habitat areas that met all of the habitat criteria for a specific life stage and season were delineated on channel sketch maps (e.g., Figure 6). Based on this mapping, the minimum flow required to meet the criteria for EWD for both spring and summer was estimated. For example, at some locations, a flow that provided spring habitat was achieved, and not substantially exceeded, and thus the observed flow at time of visit was considered suitable for spring requirements. In other locations, spring flow requirements were substantially exceeded, and a spring flow requirement was estimated to be a lower flow than was observed during the field visit. Nearly all field sites were visited at both spring and summer flow conditions in an attempt to more accurately estimate flow requirements in both seasons (Figure 5). However, many of the sites were dry or had zero flow (wetted with no water velocity) during summer and thus could not be assessed during both seasons.

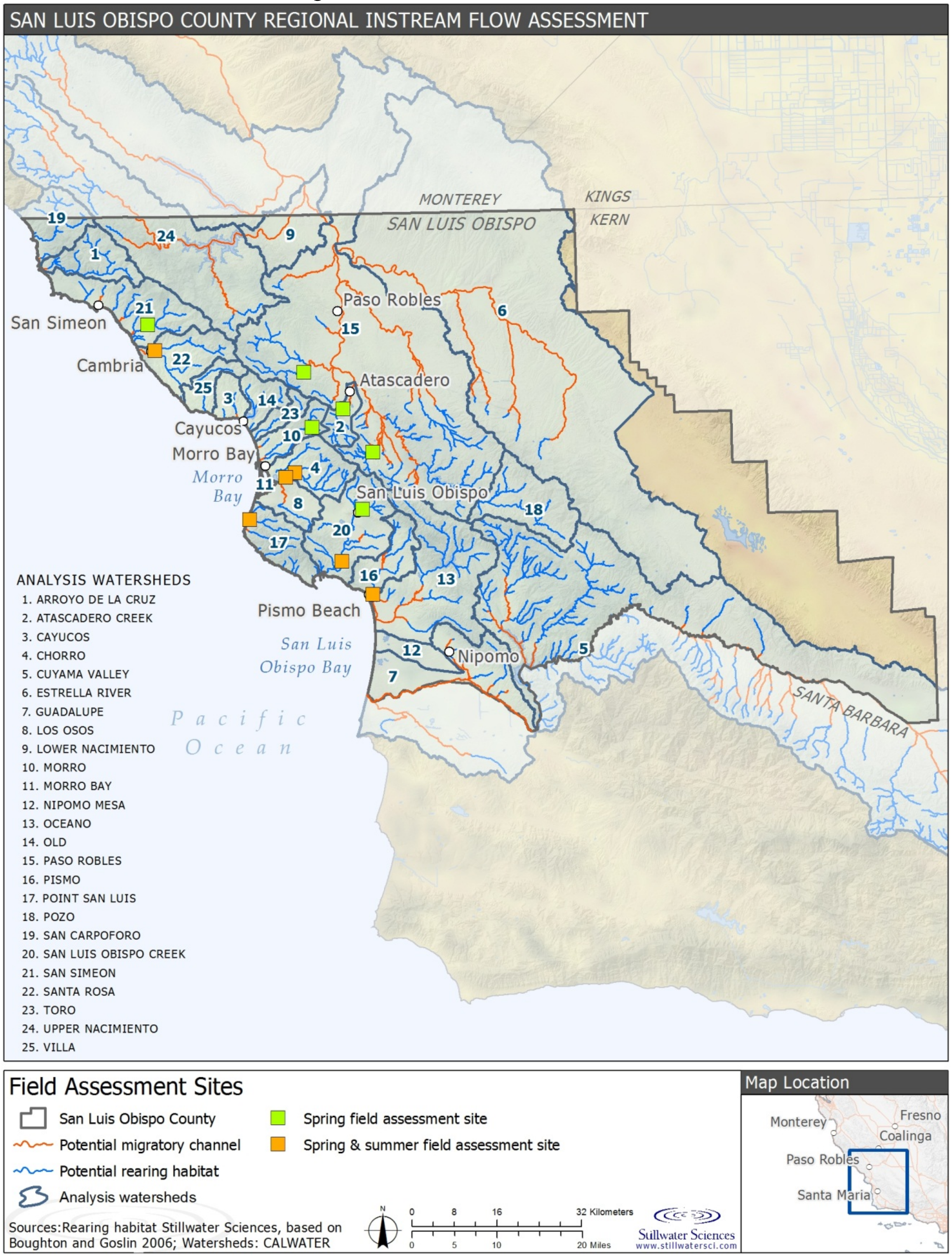
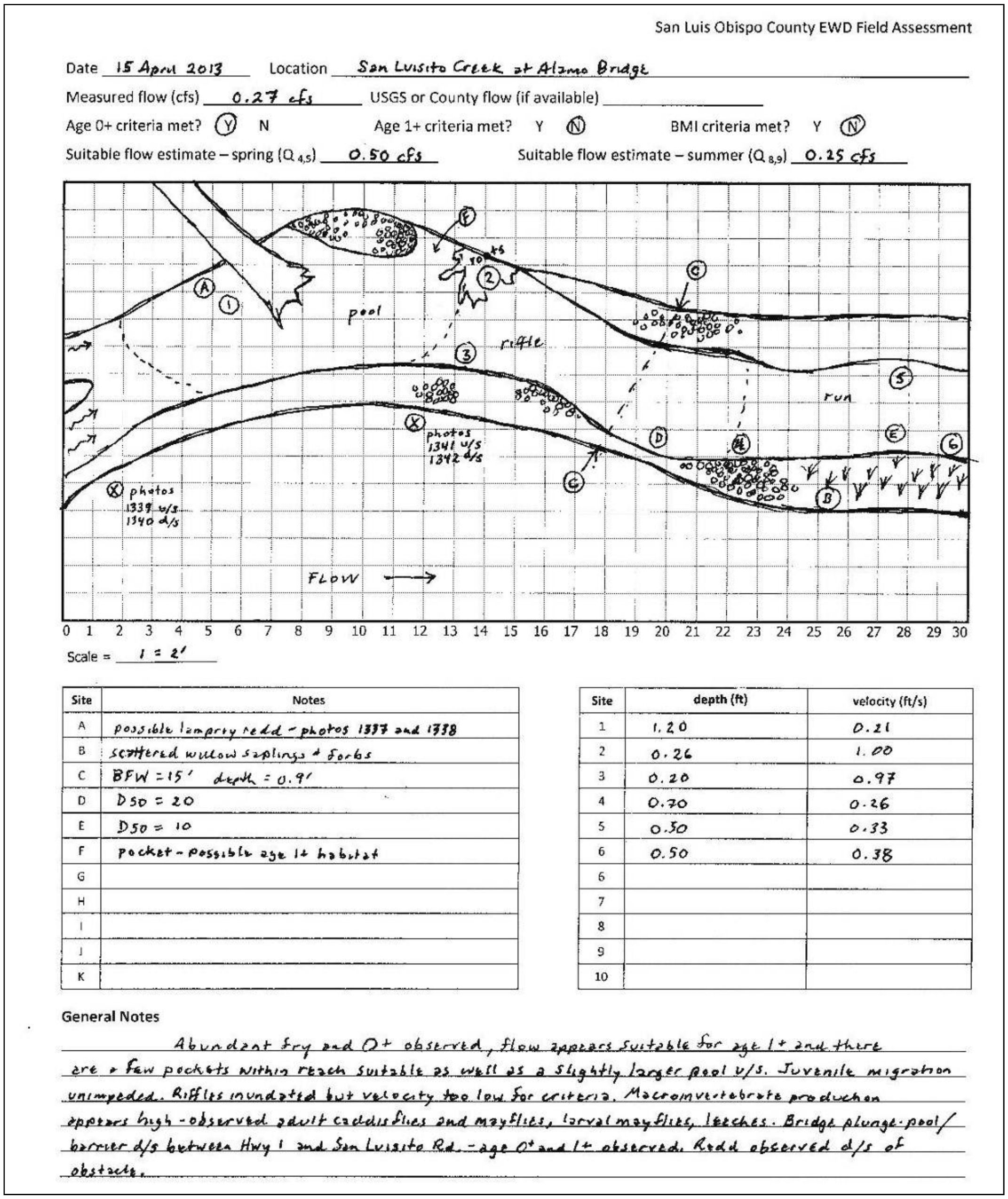


Figure 5. Field assessment sites from spring and summer 2013.



San Luis Obispo County EWD Field Assessment

Date 15 April 2013 Location San Luisito Creek at Alamo Bridge

Measured flow (cfs) 0.27 cfs USGS or County flow (if available) ________

Age 0+ criteria met? (Y) N Age 1+ criteria met? Y (N) BMI criteria met? Y (N)

Suitable flow estimate – spring ($Q_{4,5}$) 0.50 cfs Suitable flow estimate – summer ($Q_{8,9}$) 0.25 cfs

Scale = 1 = 2'

Site	Notes
A	possible lamprey redd – photos 1337 and 1338
B	scattered willow saplings + forbs
C	BFW = 15' depth = 0.9'
D	D50 = 20
E	D50 = 10
F	pocket – possible age 1+ habitat
G	
H	
I	
J	
K	

Site	depth (ft)	velocity (ft/s)
1	1.20	0.21
2	0.26	1.00
3	0.20	0.97
4	0.70	0.26
5	0.30	0.33
6	0.50	0.38
6		
7		
8		
9		
10		

General Notes

Abundant fry and 0+ observed, flow appears suitable for age 1+ and there are a few pockets within reach suitable as well as a slightly larger pool u/s. Juvenile migration unimpeded. Riffles inundated but velocity too low for criteria. Macroinvertebrate production appears high - observed adult caddisflies and mayflies, larval mayflies, leeches. Bridge plunge-pool/barrier d/s between Hwy 1 and San Luisito Rd. - age 0+ and 1+ observed. Redd observed d/s of obstacle.

Figure 6. Example data sheet and channel sketch created during field evaluations.

The following is a list of the habitat characteristics that were measured in the field and a brief description of the methods that were used to determine habitat suitability.

- *Water depth.* Water depth was measured to assess suitable habitat using a stadia rod.
- *Water velocity.* Mean water column velocity was measured with a Marsh-McBirney velocity meter at 0.60 of water column depth. For fry and juvenile rearing habitat, water velocity measurements were taken in the focal position of rearing juvenile fish.
- *Productive BMI habitat.* Average water column velocity was measured using Marsh-McBirney velocity meter. Riffles were described based on areas that were fully wetted and met water velocity criteria for spring (Table 1).

2.3.4 Analyses

"Analysis Points" were identified within Analysis Watersheds in the County for all locations where environmental conditions warranted predictions of EWD (Figure 7). These included stream channels identified by Boughton and Goslin (2006) as having a high potential for steelhead rearing. Since the EWD estimates relate to steelhead rearing life history requirements, Analysis Points were located within stream channels designated as steelhead migration habitat. In smaller watersheds typically one location is identified, whereas in larger watersheds lower, middle, and upper locations were typically identified. Wherever possible, Analysis Points were located at existing gages to support comparisons of EWD predictions with existing flow conditions. Preference was also given to locating Analysis Points where access is better, such as road crossings, to support potential future monitoring efforts.

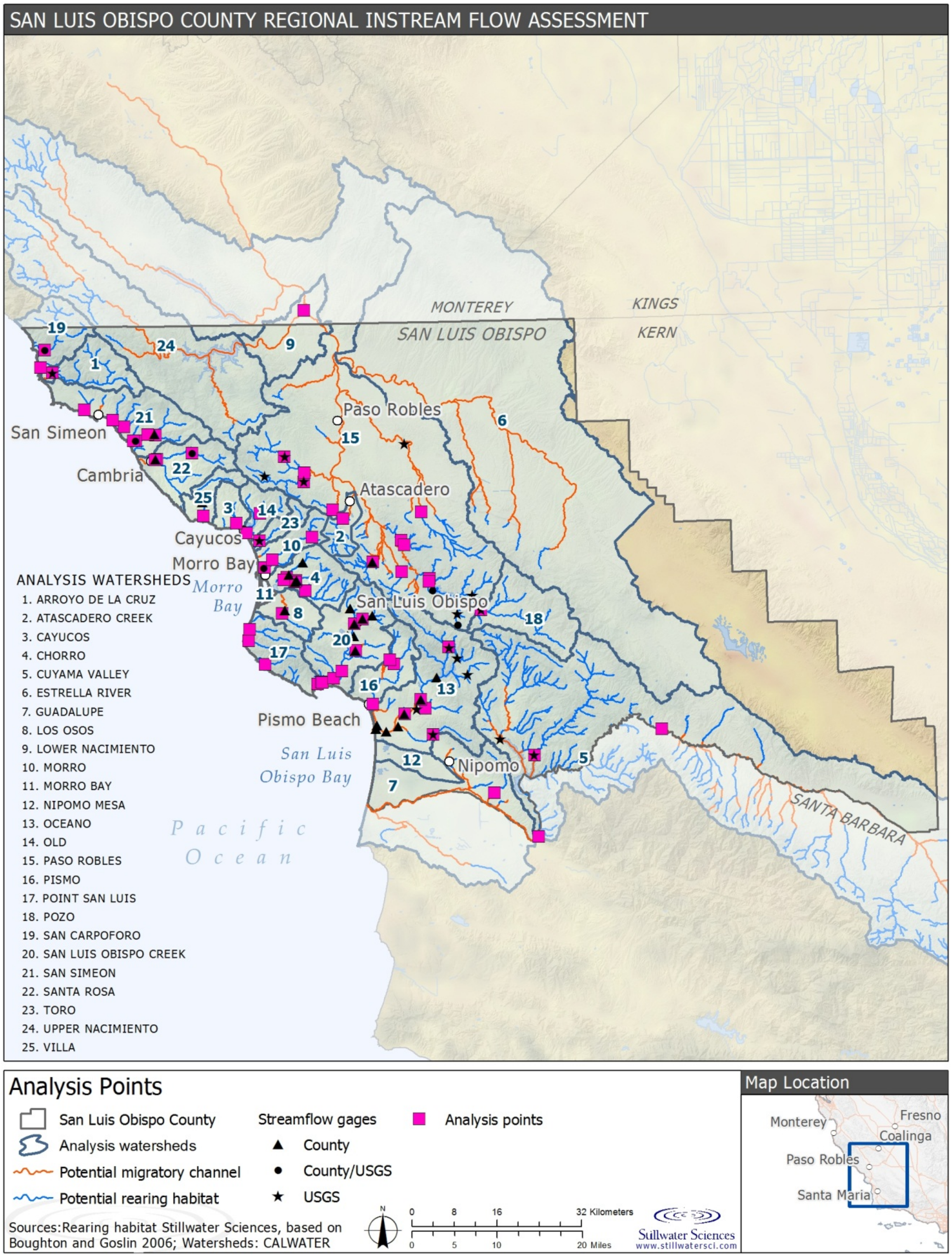


Figure 7. Analysis Points established for SLO County watersheds.

Analyses were conducted to: (1) evaluate patterns between hydrology and watershed characteristics, (2) evaluate relationships between estimated EWD and watershed characteristics,

(3) develop a predictive model of EWD, and (4) apply the predictive model to all Analysis Points. Results of analyses were used to identify gaps in available data, prioritize watersheds for additional focused studies, and recommend methods for subsequent focused studies.

Patterns between watershed hydrology and watershed characteristics in the County were evaluated to identify measureable variables that could be used to predict EWD. All available hydrology data from USGS and County streamflow gages located within steelhead potential rearing habitat were used, and average values for spring flows (average for April through May), and summer flows (average for August through September) were calculated for each gage. Potential patterns between hydrology and watershed characteristics were then evaluated by comparing average spring and summer flows with watershed area, PLU, and an index of the presumptive bankfull channel width (presumed proportional to the square root of drainage area; Dunne and Leopold 1978) for each gage location. Based on this evaluation, watershed characteristics were identified that were related to hydrologic patterns.

The estimated values for EWD based on the field assessment (Section 2.3.3) were compared with watershed characteristics found to be related to hydrologic patterns, including drainage area, channel gradient, channel slope, and valley width. Regression analysis was conducted to identify the variables that best described EWD for both spring and summer, and based on these a predictive model was developed for each season. We observed that a simple linear regression model fit our observed data well, which gave support to its broader application to identify the key variables and predict EWD for all streams not evaluated in the field.

Watershed characteristics were determined for each Analysis Point, including drainage area, PLU, and channel gradient. The predictive model was used to estimate EWD for all Analysis Points. All results were summarized in a web-based interactive map.

2.4 Qualitative Assessment

In addition to quantifying EWD to support specific steelhead life stages as described above, other critical functions of flows to support aquatic ecosystems were qualitative considered. These include fish passage flows, spawning flows, geomorphic flows, and lagoon inflows. For each of these critical flow functions, existing information from within the County was summarized to evaluate whether there are sufficient flows to support aquatic ecosystems in County watersheds.

3 RESULTS

3.1 Field Assessment

Twelve sites were evaluated during mid-April 2013, and six of these sites were re-evaluated during early September 2013 to estimate both spring and summer flow requirements (Figure 5). During spring 2013 visits, the observed flows ranged from 0 cfs (wetted with no water velocity) to 6 cfs; and during summer 2013, 0 cfs to 5.8 cfs (Table 3).

Table 3. Field observations and EWD estimates in spring and summer 2013.

Site	Drainage Area (mi^2)	Date	Measured Flow (cfs)	Estimated EWD (cfs)	
				Spring	Summer
Santa Rita Creek	65.7	5/1/2013	0.29	3.00	1.00
Lower Santa Rosa Creek	45.6	4/18/2013	1.62	3.00	0.75
		9/06/2013	0.00		

Site	Drainage Area (mi^2)	Date	Measured Flow (cfs)	Estimated EWD (cfs)	
				Spring	Summer
San Simeon Creek	24.3	4/18/2013	0.99	1.50	0.50
Lower San Luis Obispo Creek	67.9	4/17/2013	6.04	4.00	1.00
		9/11/2013	5.78		
Islay Creek	9.3	5/03/2013	1.13	1.25	0.33
		9/12/2013	0.76		
Lower Pismo Creek	37.8	4/17/2013	0.46	2.00	0.75
San Luisito Creek	7.4	4/17/2013	0.28	0.50	0.25
		9/10/2013	0.08		
Chorro Creek	21.9	5/3/2013	1.20	1.25	0.50
		9/11/2013	0.62		
Tassajara Creek	2.2	5/1/2013	0.15	0.50	0.20
Upper San Luis Obispo Creek	11.5	4/17/2013	0.51	0.75	0.25
		9/11/2013	0.0		
Atascadero Creek	13.7	4/18/2013	0.09	0.75	0.50
		9/12/2013	0.0		
Upper Morro Creek	9.1	5/1/2013	0.44	0.75	0.25

Based on measurements of suitable habitat for specific steelhead life stages, flows to support steelhead during spring range from 0.5 cfs to 4 cfs (Table 3). Flows of this magnitude were sufficient to provide fry and juvenile rearing and feeding habitat, migratory connectivity for juveniles between habitat units, and benthic macroinvertebrate production. Water depth was adequate in most habitats, and overall suitability was typically limited by water velocity. In some locations, such as San Luisito Creek (Figure 8), the estimated spring Environmental Water Demand (EWD) (0.5 cfs) is relatively low, due to a confined, moderate gradient channel that consolidates available surface flow. In contrast, river channels such as lower San Luis Obispo Creek are relatively unconfined, semi-alluvial gravel-dominated streams in which a higher spring EWD (4 cfs) is required to provide sufficient spring steelhead habitat (Figure 9). In general, the larger, low-gradient channels yield larger spring EWD values. Exceptions included highly incised channels (e.g., lower Pismo Creek) where relatively low flows remained confined and maximized available habitat. In most of the stream channels that were not carrying sufficient flows to provide steelhead habitat, habitat units were hydrologically connected but flows had insufficient water velocity to support food delivery or to provide migration among habitat units (e.g., Atascadero Creek, Figure 10).

Figure 8. San Luisito Creek, with nearly sufficient flows to provide steelhead habitat during spring 2013.

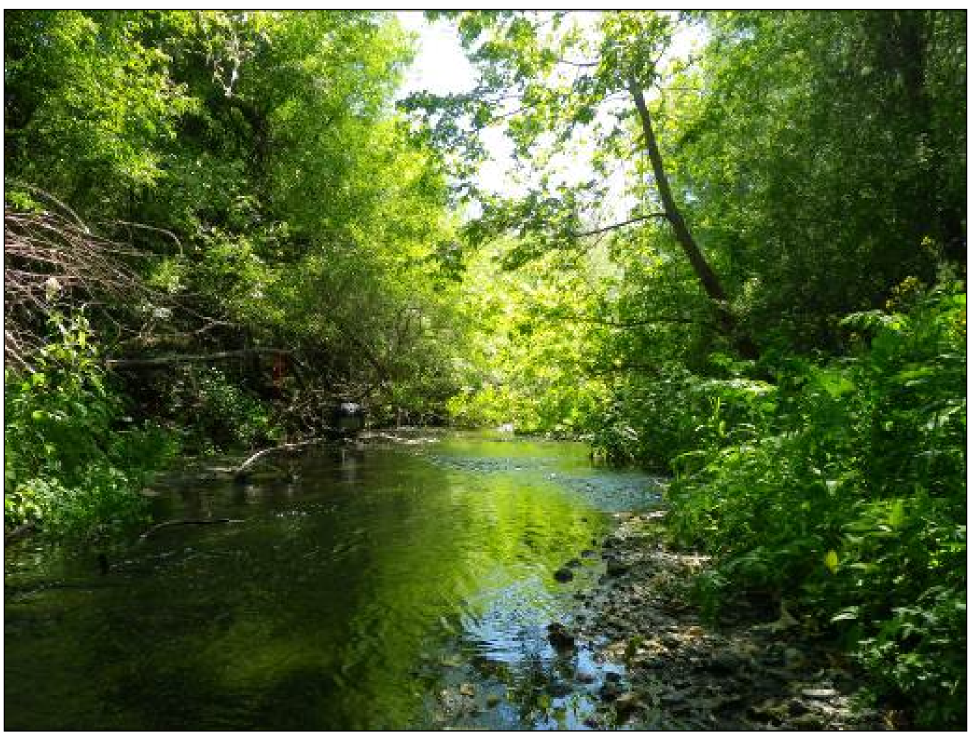


Figure 9. Lower San Luis Obispo Creek, with sufficient flows to provide steelhead habitat during spring 2013. Note that flows are dominated by San Luis Obispo's Water Reclamation Facility releases.

Figure 10. Middle Atascadero Creek, with insufficient flows to provide steelhead habitat during spring 2013. Note that 2013 was an extreme drought in the County.

Based on measurements of suitable habitat for specific steelhead life stages, flows to support steelhead during summer were observed to range from 0.25 cfs to 1 cfs. Flows of this magnitude provided sufficient water depth to provide fry and juvenile rearing habitat, and water velocity is considered less critical during summer than during spring. These EWD flows are typically half or less than that estimated during spring for the same channel. In some locations, such as lower Islay Creek (Figure 11), summer flows needed to support steelhead habitat (0.3 cfs) are relatively low, due to a bedrock-dominated confined channel that supports sufficient pool depths at very low flows. In most cases, the channels that were not providing sufficient summer habitat had intermittent, disconnected habitats, such as lower Santa Rosa Creek (Figure 12).

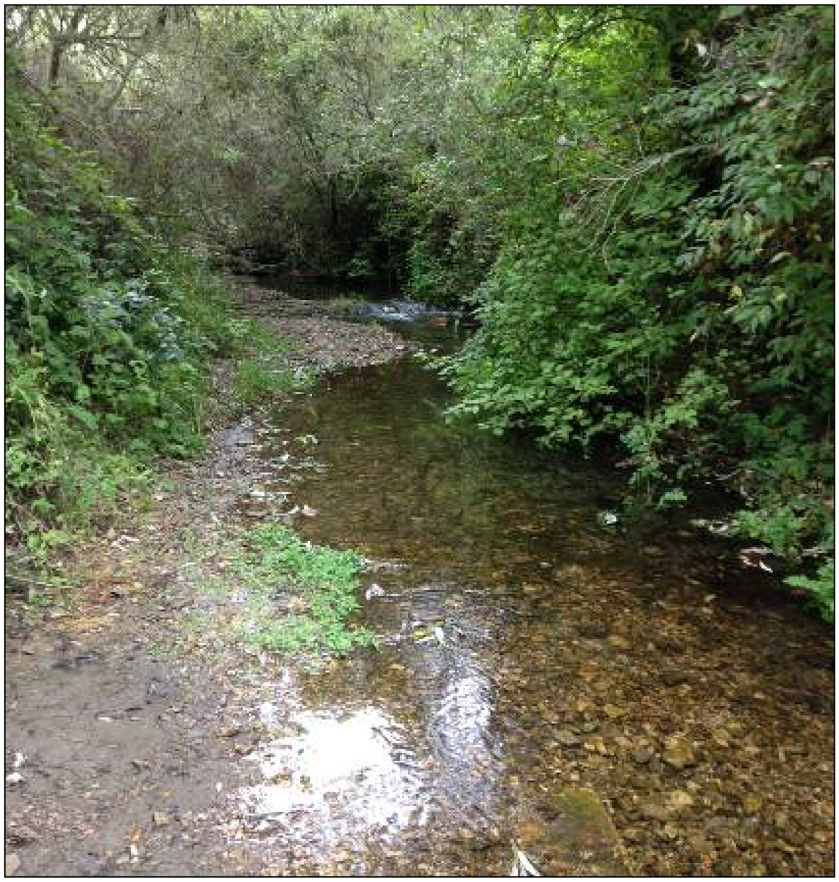


Figure 11. Lower Islay Creek, with sufficient flows to provide steelhead habitat during summer 2013.

Figure 12. Lower Santa Rosa Creek, with no flow and thus no steelhead habitat during summer 2013. Note that 2013 was an extreme drought in the County.

3.2 Environmental Water Demand Model Development

Results from the field assessment (Table 3) were compared with watershed characteristics. We found that of the variables analyzed, drainage area was the only factor that was consistently strongly correlated (Figures 13 and 14) with estimated spring and summer flows to support steelhead habitat. This is likely due to the overarching importance of channel size (and, specifically, channel width) as a function of drainage area. Lower gradient channels, which are also associated with larger drainage areas, require less water to provide suitable water depth to meet EWD than steeper gradient channels. However, drainage area also correlates with wider channels that require more water to provide suitable water *velocity* to meet EWD. Our field observations indicated that water velocity more often limited suitable habitat than water depth, thus explaining the strong, positive proportionality between EWD and drainage area as a consequence of increasing channel width. Locations with larger drainage areas had both lower gradients and wider channels, and they consistently required higher flows to meet EWD (e.g., Figure 15). Stream channels with a smaller contributing drainage area tend to be higher gradient but relatively confined, and thus they require less flow to meet EWD (e.g., Figure 16).

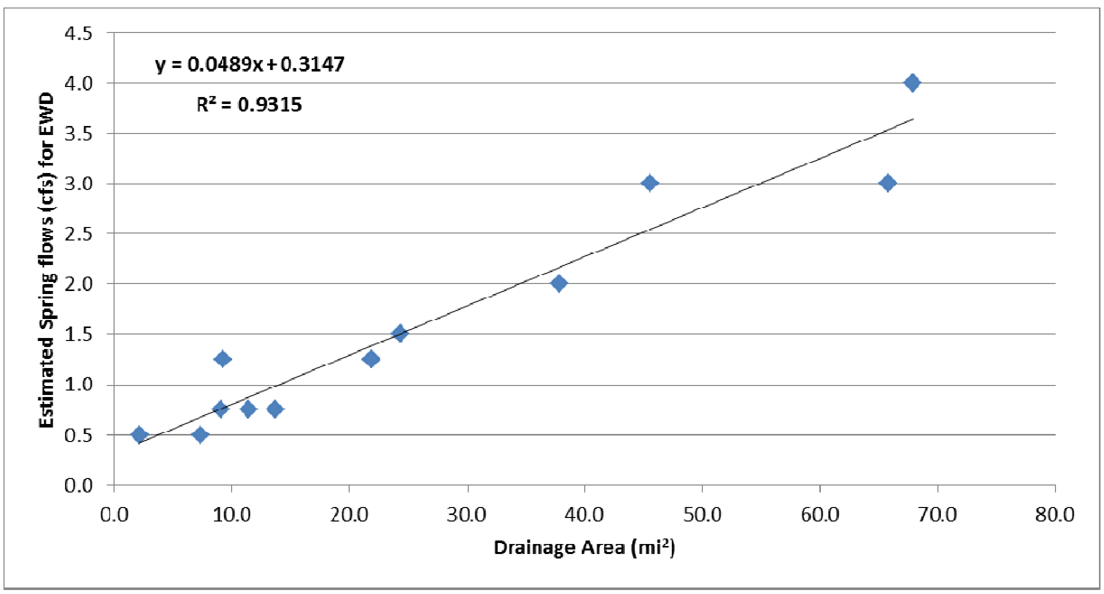


Figure 13. Estimated spring flows for EWD based on field assessments compared with drainage area.

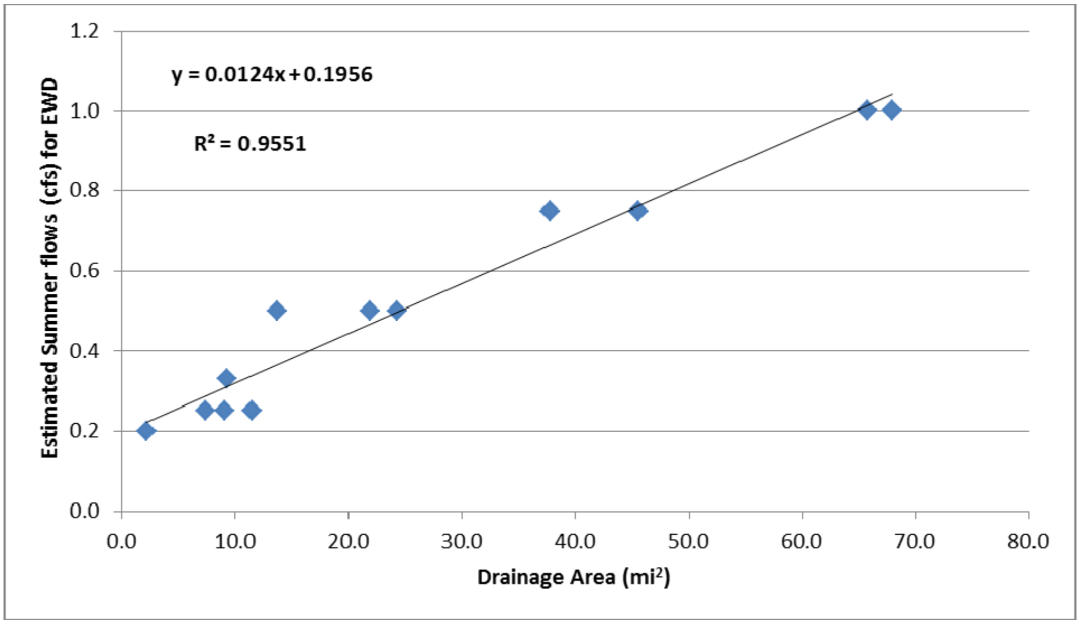


Figure 14. Estimated summer flows for EWD based on field assessments compared with drainage area.

Figure 15. San Simeon Creek with a large drainage area, low gradient, and broad channel; it requires more flow to provide sufficient velocity to meet minimum habitat requirements.

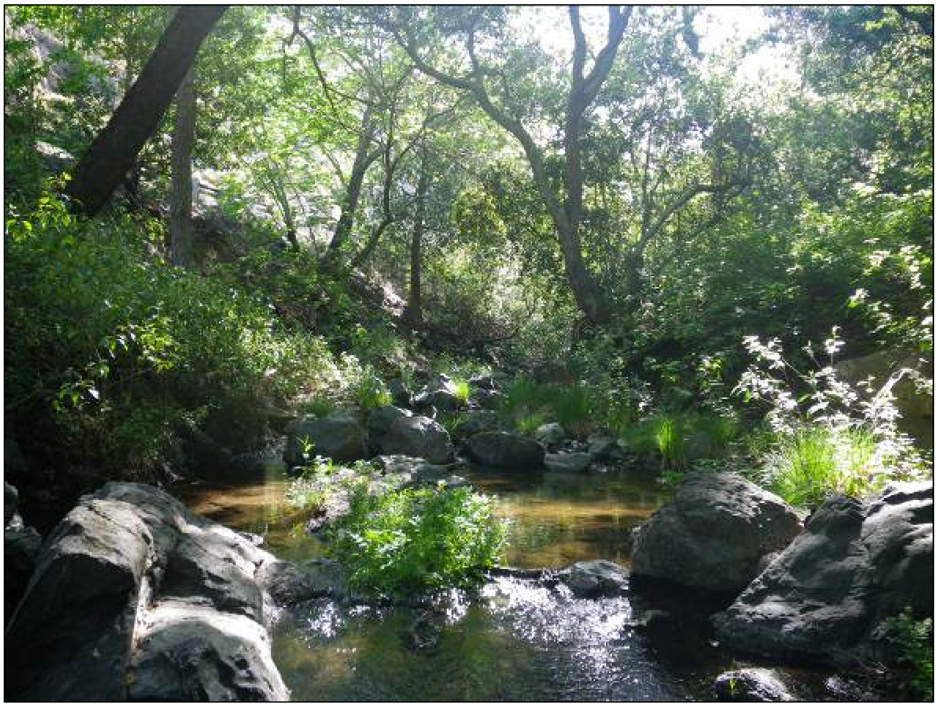


Figure 16. Upper Morro Creek with a small drainage area, high gradient, and confined channel; it requires less flow to provide sufficient depth to meet minimum habitat requirements.

Based on the comparisons of steelhead flow requirements and all assessed variables, estimates for spring flow requirements were best explained by the model $y=0.049x + 0.31$, where x is drainage area in square miles and y is the estimated EWD spring flow in cfs. This model has an R^2 of 0.93.

Based on the comparisons of steelhead flow requirements and all assessed variables, estimates for summer flow requirements were best explained by the model $y = 0.012x + 0.20$, where x is drainage area in square miles and y is the estimated EWD summer flow in cfs. This model has an R^2 of 0.96.

For both seasonal assessments, we encountered no channel that maintained sufficient habitat with less than 0.5 cfs (spring) or 0.2 cfs (summer). This corresponds to the smallest measured channel, supported by the smallest drainage area of 2.2 mi^2 in our sample set. It is unlikely that these simple linear relationships would hold for even smaller drainage basins, and so these results should be extrapolated only cautiously to yet smaller basins and their channels unless additional field calibration has been done.

3.3 Environmental Water Demand Model Application

Analysis points were established within all County watersheds with delineated high potential steelhead rearing habitat (Figure 7). Based on the models described above, the EWD was estimated for each Analysis Point based on spring and summer flow requirements (Table 4). Due to the large number of locations for which EWD is estimated throughout the County, an interactive web-based map was developed, and is available at:
http://geo.stillwatersci.com/maps/slo_rifa/instreamflowassessment.html

Table 4. EWD predications for Analysis Points in SLO County.

Analysis Point	Analysis Watershed[2]	Drainage Area (mi^2)	EWD (cfs)	
			Spring	Summer
Alamo Creek[1]	Alamo Creek Watershed	83.9	4.4	1.2
Arroyo De La Cruz	Arroyo De La Cruz Watershed	41.2	2.3	0.7
Arroyo De Los Chinos Creek[1]	San Carpoforo Watershed	1.8	0.4	0.2
Arroyo Grande Creek, lower	Arroyo Grande Creek Watershed	102	5.3	1.5
Arroyo Grande Creek, middle	Arroyo Grande Creek Watershed	78.3	4.1	1.2
Arroyo Grande Creek, upper	Arroyo Grande Creek Watershed	20.8	1.3	0.5
Atascadero Creek	Atascadero Creek Watershed	13.7	1	0.4
Huerhuero Creek	Huerhuero Creek Watershed	23.7	1.5	0.5
Cayucos Creek	Cayucos Creek Watershed	10.4	0.8	0.3
Chorro Creek, lower	Morro Bay Watershed	40.5	2.3	0.7
Chorro Creek, middle	Morro Bay Watershed	21.9	1.4	0.5
Chorro Creek, upper	Morro Bay Watershed	17.7	1.2	0.4
Calf Canyon	Atascadero Creek Watershed	3.5	0.5	0.2
Coon Creek	Irish Hills Coastal Watersheds	7.9	0.7	0.3
Cuyama River, lower[1]	Cuyama River Watershed	1,143.7	56.2	14.4
Cuyama River, upper[1]	Cuyama River Watershed	796.2	39.3	10.1
Diablo Creek	Irish Hills Coastal Watersheds	5	0.6	0.3
East Corral De Piedra	Pismo Creek Watershed	4.8	0.5	0.3
East Fork SLO Creek	San Luis Obispo Creek	10.2	0.8	0.3
Graves Creek, upper	Lower Salinas River – Paso Robles Creek Area Watersheds	6.7	0.6	0.3
Islay Creek	Irish Hills Coastal Watersheds	9.3	0.8	0.3
Jack Creek	Atascadero Creek Watershed	25.3	1.6	0.5
Little Morro Creek	Morro Creek Watershed	5.2	0.6	0.3
Little Pico Creek	San Simeon – Arroyo de la Cruz Creek Watersheds	6	0.6	0.3
Los Berros Creek	Arroyo Grande Creek Watershed	15.1	1.1	0.4
Los Osos Creek	Morro Bay Watershed	7.1	0.7	0.3
Moreno Creek	Atascadero Creek Watershed	4.3	0.5	0.2
Morro Creek, lower	Morro Creek Watershed	17.9	1.2	0.4
Morro Creek, upper	Morro Creek Watershed	7	0.7	0.3
Nacimiento Creek[1]	Nacimiento River Watershed	369.7	18.4	4.8
Oak Knoll Creek	San Simeon – Arroyo de la Cruz Creek Watersheds	6.4	0.6	0.3
Old Creek, lower	Old Creek Watershed	20.4	1.3	0.4
Old Creek, upper	Old Creek Watershed	10.6	0.8	0.3

Analysis Point	Analysis Watershed[2]	Drainage Area (mi^2)	EWD (cfs)	
			Spring	Summer
Paso Robles Creek	Lower Salinas – Paso Robles Area Watersheds	40.6	2.3	0.7
Perry Creek	Santa Rosa Creek Watershed	44.5	2.5	0.7
Pico Creek	San Simeon – Arroyo de la Cruz Creek Watersheds	13	0.9	0.4
Pilitas Creek	Atascadero Creek Watershed	6.9	0.7	0.3
Pismo Creek	Pismo Creek Watershed	37.9	2.2	0.7
Salinas River	Salinas River Watershed	70.2	3.7	1.1
San Bernardo Creek	Morro Bay Watershed	8.4	0.7	0.3
San Carpoforo Creek	San Carpoforo Creek Watershed	34.5	2	0.6
San Luis Obispo Creek at Avila[1]	San Luis Obispo Creek Watershed	81.4	4.3	1.2
San Luisito Creek[1]	Morro Bay Watershed	0.6	0.3	0.2
San Simeon Creek, lower	San Simeon Creek Watershed	26.2	1.6	0.5
San Simeon Creek, middle	San Simeon Creek Watershed	24.3	1.5	0.5
San Simeon Creek, upper	San Simeon Creek Watershed	9.8	0.8	0.3
Santa Margarita Creek	Atascadero Creek Watershed	10.1	0.8	0.3
Santa Rita Creek	Atascadero Creek Watershed	18.6	1.2	0.4
Santa Rosa Creek, lower	Santa Rosa Creek Watershed	44.8	2.5	0.8
Santa Rosa Creek, upper	Santa Rosa Creek Watershed	12.5	0.9	0.4
See Canyon Creek	San Luis Obispo Creek Watershed	72.1	3.8	1.1
SLO Creek, lower	San Luis Obispo Creek Watershed	67.9	3.6	1
SLO Creek, upper	San Luis Obispo Creek Watershed	11.8	0.9	0.3
Stenner Creek	San Luis Obispo Creek Watershed	10.9	0.8	0.3
Suey Creek	Nipomo-Suey Creeks Watersheds	11.5	0.9	0.3
Tar Spring Creek	Arroyo Grande Creek Watershed	4	0.5	0.2
Toro Creek	Toro Creek Watershed	14.2	1	0.4
Trout Creek	Atascadero Creek Watershed	6.4	0.6	0.3
Unnamed Eastside Trib to Salinas River	Salinas River Watershed	3.4	0.5	0.2
Van Gordon Creek	San Simeon Creek Watershed	2.7	0.4	0.2
Villa Creek	Villa Creek Watershed	14.5	1	0.4
West Corral De Piedra	Pismo Creek Watershed	6.4	0.6	0.3
Wild Cherry Canyon[1]	Irish Hills Coastal Watersheds	1.5	0.4	0.2

[1]Extrapolated values lie beyond the observed range of Figures 13 and 14; values are thus more uncertain. Particular caution should be used in interpreting results for Lower Nacimiento Creek and Upper and Lower Cuyama Creek, which exceed the measured range by more than 5-fold.

[2] Analysis watershed names use local naming conventions, Hydrologic Area or Hydrologic Sub Area names depending on what seemed the most descriptive to the reader.

3.3.1 Comparison with other instream flow evaluations

EWD predictions were compared with the few previous instream flow evaluations that have been conducted in the County (Table 5). In particular, the Instream Flow Incremental Methodology (IFIM) analysis of Thomas R. Payne & Associates (TRPA) (1994) evaluated steelhead suitability in San Luis Obispo Creek. TRPA used the IFIM to generate curves of wetted usable area (WUA) at increasing flows. This analysis allowed the determination of the maximum WUA for steelhead fry, juvenile, and spawners in three reaches of San Luis Obispo Creek. They found that flows of around 6 cfs in lower San Luis Obispo Creek provide maximum habitat for steelhead fry, and substantial amounts of habitat for juveniles. However, habitat for juveniles continued to increase at higher flows up the maximum flow modeled of 20 cfs. In comparison, we estimated EWD as 3.6 cfs for sufficient spring habitat, and 1 cfs for sufficient summer habitat in lower San Luis Obispo Creek. The results of TRPA (1994) corroborate EWD estimates for San Luis Obispo Creek, and they also highlight that EWD estimates are not estimates of the flows that would maximize habitat availability, but rather the flows that would provide a minimum sufficient level of habitat.

Table 5. Instream flow analyses conducted in SLO County.

Location	Drainage Area (mi^2)	Life stage and flow estimate (cfs)				Source
		Fish passage	Spawning	Spring rearing	Summer rearing	
Santa Maria River mainstem	1,860	250	n/a	n/a	n/a	Stillwater Sciences and Kear Groundwater (2012)
San Luis Obispo Creek	68	n/a	20[a]	6	n/a	TRPA (1994)
Santa Rosa Creek	45	34–60	n/a	n/a	n/a	D. W. Alley and Associates (1993)
San Simeon	26	21–67.5	n/a	n/a	n/a	D. W. Alley and Associates (1992)
		40	n/a	n/a	n/a	Water Resource Associates (1990)
Arroyo Grande Creek	102	20	6	3	3	Stetson Engineers, Inc. et al. (2004)

[a] Highest flow modeled/observed
n/a Not assessed

During development of the Arroyo Grande Habitat Conservation Plan (HCP), Stetson Engineers, Inc. et al. (2004) evaluated all life stages of steelhead in Arroyo Grande Creek downstream of Lopez Dam (impassable barrier) using unspecified methods involving qualitatively evaluating streamflow requirements for steelhead spawning and juvenile rearing. Based on observations of habitat conditions during field surveys, flows of 6 cfs were recommended for spawning, and 3 cfs for spring and summer rearing (with exceptions based on Lopez Lake reservoir storage). In comparison, we estimated EWD as 5.3 cfs for spring and 1.5 cfs for summer in Arroyo Grande Creek.

3.4 Qualitative Flow Assessment

3.4.1 Fish passage flows

In addition to flows to support rearing, adult steelhead require sufficient flows to migrate upstream from the ocean to suitable spawning and rearing habitat during winter, and juvenile require sufficient flows to migrate downstream to the ocean as smolts during spring. Adult fish passage flow requirements are typically much higher than flows required for rearing. We identified the portions of each watershed that are potential critical migratory channels. These channels were delineated based on assuming that any river channel that is not identified as having a high potential for rearing habitat but is downstream of a NOAA-identified reach with high rearing potential (Boughton and Goslin 2006) would need to provide flows sufficient to support upstream migration of adult steelhead and downstream migration of juvenile steelhead, at some (indeterminate) frequency and duration. This approach is not precise, and very likely there are river channels identified as migratory habitat that could support rearing, and vice versa. However, this approach identified the general segments of the channel network that should be considered for fish passage flows, such as the low-gradient, lower reaches of large watersheds. In general, migratory channels have local channel gradients less than 1%, are composed of valley-bottom Quaternary deposits, and have an unconfined valley setting.

Conditions necessary to provide fish passage have been identified, and methods exist to determine flows required to achieve passage based on channel conditions (e.g., Thompson 1972, CDFG 2013). However, based on the scope and timeframe of this analysis, it was not possible to conduct site-specific fish passage flow assessments. Existing fish passage and flow analysis that has been conducted in the County includes the Santa Maria River, San Simeon Creek, Santa Rosa Creek and Arroyo Grande Creek, each of which is further discussed below.

Stillwater Sciences and Kear Groundwater (2012) identified the flow necessary to promote and provide effective passage of steelhead to and from the Pacific Ocean into areas of documented spawning and rearing habitat in upper parts of tributaries to the Santa Maria watershed. Based on a combination of field measurements and hydraulic calculations, the study concluded that a discharge of 250 cfs consistently provided adult steelhead passage throughout the critical passage reach of the Santa Maria River, and that 150 cfs would meet the criteria for downstream (juvenile) passage, based on available information. The study also concluded that even under unimpaired conditions, flows are insufficient in most years to provide fish passage.

D. W. Alley and Associates (1992) assessed fish migration streamflow requirements in San Simeon Creek. They surveyed the creek from the mouth to nearly 4 miles upstream and identified critical riffles most likely to limit fish passage. A model for water-surface elevation based on transect data was used in conjunction with the Thompson (1972) method for determining minimum fish passage flows, which specifies water depths within shallow riffles to achieve passage. D.W. Alley estimated that adult upstream migration in San Simeon Creek required between 21 and 67.5 cfs, depending on the critical riffle location. Flows to allow post-spawning adults to migrate downstream were estimated between 7.2 and 19 cfs, and 3.5 to 11 cfs to support downstream migration of juveniles and smolts. These results were consistent with the earlier analysis of Water Resource Associates (1990), who estimated that 40 cfs was required for adult upstream migration by assessing one critical riffle in lower San Simeon Creek.

In Santa Rosa Creek during drier winters, lower reaches may significantly delay or prevent adult steelhead from accessing, and smolts from emigrating from, the upper reaches (Nelson et al. 2009). D. W. Alley and Associates (1993) assessed fish migration streamflow requirements in

Santa Rosa Creek using the same approach described above for San Simeon Creek. They estimated that between 34 and 60 cfs would be required to allow adult steelhead to migrate upstream in Santa Rosa Creek, depending on the critical riffle location. Flows to allow post-spawning adults to migrate downstream were estimated between 13 and 25 cfs depending on the riffle location, and 5.8 to 17 cfs to support downstream migration of juveniles and smolts.

Stetson Engineers, Inc. et al. (2004) assessed fish passage in Arroyo Grande Creek at a low-flow road crossing and at seven additional transects using the Thompson (1972) approach. Analysis indicated that steelhead passage criteria would be met at flows from 10 to 20 cfs at transects, and at 30 cfs at the low-flow road crossing. Based on these results, a release of 20 cfs was the HCP's preferred alternative in Arroyo Grande Creek to achieve fish passage.

Based on existing data, flows to achieve fish passage in County streams range from 20 to 250 cfs (Table 5). These results were assessed to determine if there is a relationship between drainage area (and other metrics) and flow requirements that could be used to predict fish passage requirements in non-studied watersheds. Although in general the designated migratory channels in large rivers such as the Santa Maria River require substantially more flow to provide passage than smaller channels such as lower San Simeon Creek (Table 5), there is no robust association between channel width or drainage area and flow requirements. This is because fish passage flow requirements are site-specific. In low-gradient migratory channels such as the Santa Maria River, adequate flow is required to provide passage through long, shallow riffles, whereas in higher gradient channels adequate flow is required to provide passage past steep, rocky features (Figure 17). Flows required to provide passage past these site-specific features do not relate in a predictable way with any watershed characteristics, such as drainage area. Therefore a predictive model could not be developed to estimate EWD for fish passage requirements, and site-specific evaluations will be necessary to identify watershed-specific fish passage flow requirements.

Despite the importance of fish passage, the definition of EWD used in this study does not include requirements for fish passage flows. However, in general, fish passage flows are not as sensitive to management as other life stages. In most watersheds, fish passage for adults will occur during winter rainfall events, when increased precipitation results in high instream flows. The frequency and duration of rainfall events sufficient to support fish passage flows will depend on specific watershed conditions. There are very few watersheds in the County where water management is capable of storing enough flow to prevent rainfall events from increasing instream flows. Therefore in most County watersheds natural rainfall-driven flows continue, and thus we would expect fish migration is generally not affected. Exceptions include watersheds such as the Santa Maria River, Arroyo Grande Creek, Pismo Creek, Salinas River, Nacimiento River, and Old Creek where reservoirs are capable of storing precipitation. There are also other river reaches where groundwater pumping and water diversions are likely increasing the amount of water required to result in surface flow.

Figure 17. Flow-related critical fish passage features from (a) low-gradient shallow riffles, and (b) high-gradient features.

3.4.1.1 Lagoon sandbars

Although estuary or lagoon sandbars may also prevent fish passage, existing assessments in the County suggest that estuary outlets rarely limit upstream adult fish passage, since flows sufficient to provide passage are also sufficient to open the sandbar (Stillwater Sciences and Kear Groundwater 2012, D. W. Alley and Associates 1992, Figure 18). However, this is typically not the case for downstream-migrating juveniles. Even under unimpaired conditions, downstream migrating juveniles can become "trapped" in lagoons without open bars to the ocean, stressing the importance of the habitat quality in lagoon environments (discussed below).

Figure 18. Lagoon sandbars at (a) Santa Rosa Lagoon, annually closed, and (b) Islay Creek Lagoon, perennially open.

3.4.2 Spawning flows

In addition to flows to support migration, adult steelhead require sufficient flows to spawn. Conditions necessary to support spawning have been identified, and methods exist to determine spawning flows. However, spawning flows are not as sensitive or critical to steelhead life history as flow requirements for rearing. Flows to support spawning in the County are often similar or lower in magnitude than those needed for adult fish passage. Therefore in general when steelhead have sufficient flows to access habitat, there are also typically sufficient flows for spawning. As described above for fish passage flows, spawning flows occur during rainfall events, are not as sensitive to management as other life stages, and are typically similar to fish passage flows.

3.4.3 Geomorphic function

Instream flows provide for the long-term maintenance and creation of functional habitat. This includes transporting excess sediment, creating riffles, and maintaining pools. Functional "geomorphic flows" are defined based on magnitude (e.g., higher than 1,000 cfs), frequency (e.g., occurring every other year on average during spring), and duration (e.g., lasting from hours to weeks). Within a watershed of a particular size, flows capable of transporting sediment or inundating floodplain habitat will have a definable magnitude, frequency, and duration. Based on the scope and timeframe of this analysis, it was not possible to identify geomorphic flows for County watersheds. As described for fish passage flows, geomorphic flows are not as sensitive to management as life-stage-specific fish flows. In most watersheds, geomorphic flows will occur during rainfall events, when increased precipitation results in high instream flows. With a few exceptions where dams impound large reservoirs (e.g., Salinas River and Arroyo Grande Creek), watersheds in the County generally lack enough storage to prevent significant rainfall events from increasing flows to levels that initiate geomorphic processes on the stream channel.

3.4.4 Lagoon habitat quality and instream flows

As discussed above, when steelhead juveniles migrate downstream they enter lagoon habitat and can either voluntarily rear there or may become "trapped" by closed sandbar conditions. Steelhead rearing in lagoons has been shown to be greatly enhanced under appropriate lagoon conditions (Hayes et al. 2008, Bond et al. 2008). In addition, tidewater goby reside in coastal County lagoons (Figure 2) and are dependent on the availability of suitable habitat in lagoons (Smith 1990), which is directly related to freshwater inflow. Reduced freshwater inflows may delay the conversion from salt to brackish water (Capelli 1997). This delay causes the estuary to remain stratified, with saltwater along the bottom and freshwater along the surface, longer into the late spring and early summer. The stratified water column, with salt water on the bottom, collects and stores heat because the saltwater layer cannot lose the heat to the surface like the overlying freshwater, causing sub-optimal to lethal temperatures (up to 30°C [86°F]) along the estuary bottom (Capelli 1997, USFWS 2005).

Few analyses of habitat conditions in County lagoons have been conducted. Stillwater Sciences (2012) found that habitat quality in the Pismo Creek lagoon is strongly influenced by upstream conditions. Much of the lower Pismo Creek watershed is developed and the lower Pismo Creek channel and the upper estuary are constrained by levees, bridge abutments, and other infrastructure. These combined factors decrease floodwater storage and infiltration and increase flow confinement and channel incision, which, when combined with water diversions and groundwater extraction within the watershed, have resulted in decreased local groundwater elevations and a subsequent decrease in baseflows into the lagoon during the drier months compared with historical conditions. Although the presence of a large population of tidewater goby and one healthy smolt-sized steelhead in May 2005 (Hagar Environmental Services 2005) suggests that the estuary currently provides suitable aquatic rearing habitat, recent data and observations suggest that usage (particularly for steelhead) is likely limited by summer and fall inflows entering the lagoon, resulting in low dissolved oxygen concentration, excess nutrients and bacteria, and inadequate habitat features.

In Santa Rosa Creek, it has also been observed that lagoon conditions are worsened by low stream flows resulting from excessive groundwater pumping and diversions (Rathbun et al. 1991, Yates and Van Konyenburg 1998, D. W. Alley and Associates 2008). Reduced freshwater inflows result in water temperatures and dissolved oxygen levels in the lagoon, particularly at the bottom, that can frequently exceed lethal limits for steelhead in the summer and fall (Stillwater Sciences et al. 2012). In some lower flow years such as 2003 and 2004, entire sections of the lower lagoon dried up, reducing the area of suitable steelhead rearing habitat (D. W. Alley and Associates 2008), a condition that was also observed in fall 2013 (Figure 19). When Santa Rosa Creek lagoon inflows ceased entirely in summer 2013, steelhead (adults and presumably juveniles) were observed trapped in a pool that decreased dramatically in extent and water quality.

Site-specific long-term monitoring of lagoon berm formation and lagoon water quality (e.g., water temperature, dissolved oxygen, and salinity profile) in relation to lagoon inflows is needed to inform minimum instream flow requirements for watersheds to maintain and protect lagoon habitat, which was outside the scope and timeline of this analysis.

Figure 19. Santa Rosa Lagoon in (a) June and (b) September.

3.5 Comparison of Environmental Water Demand Estimates with Existing Flows

To compare EWD estimates with existing conditions, streamflow data were examined for 16 USGS and two County-maintained gages (Table 6). All gages were located within potential steelhead rearing habitat for which streamflow data were available for analysis. There are additional gages that were not considered, either because they are located within migratory habitat only or because available records were not organized in a manner that supported analysis. Average spring summer flows were summarized for all suitable gages based on the available period of record and were compared with EWD estimates. EWD for spring flows are mostly achieved on average at all gage locations over the period of record, whereas summer flows are either barely achieved, or not at all. This suggests that in many Analysis Watersheds, spring flows are sufficient to support a steelhead population and that summer flows may be a limitation on survival, consistent with the observations of Spina et al. (2005). However, the period of record for available gages ended over 20 years ago for most locations and in many watersheds, water demand for urban, rural, and agricultural needs may have changed, thus altering the amount of surface flow in streams. Although surface flows have undoubtedly declined in many watersheds since gaging has ended, there are also examples of surface flows increasing over what was occurring during the gaging record. These include lower San Luis Obispo Creek, where the City's Water Reclamation Facility has a required release, downstream of the Pismo Creek Oil Refinery discharge in Pismo Creek, and Arroyo Grande Creek downstream of Lopez Dam.

Table 6. Comparison of streamflow measurements at stream gages with EWD estimates. Results are also summarized in an interactive map at http://geo.stillwatersci.com/maps/slo_rifa/instreamflowassessment.html.

Gage station	USGS ID	Period of record	Drainage Area (mi^2)	Spring flow		Summer flow	
				Gage	EWD[1]	Gage	EWD[1]
Alamo Creek near Nipomo	11137400	1959–1978	83.3	5.7	4.4	0	1.2
Arroyo De La Cruz near San Simeon	11142500	1950–1979	41.2	32.8	2.3	0.2	0.7
Arroyo Grande Creek at Arroyo Grande	11141500	1939–1986	102.0	27.5	5.3	3.8	1.5
Arroyo Grande Creek near Arroyo Grande	11141300	1958–1966	68.3	1.5	5.3	0	1.5
Jack Creek near Templeton	11147000	1949–1978	25.3	11.1	1.6	0	0.5
Lopez Creek near Arroyo Grande	11141280	1967–2013	20.9	10.4	1.3	2.8	0.45
Los Berros Creek near Nipomo	11141600[a]	1969–2001	15.0	2	1.1	0.15	0.4
Los Osos Creek at Los Osos Valley Road	County	1977–2002	7.1	2.74	0.7	0	0.3
Morro Creek near Morro Bay	11142080[a]	1977–2004	24.0	9.7	1.2	0.51	0.4
Salinas River near Pozo	11143500	1942–1983	70.3	16.6	3.7	0.5	1.1
Santa Rita Creek near Templeton	11147070	1961–1994	18.2	9.1	1.2	0	0.4
Santa Rita Creek tributary near Templeton	11147040	1967–1972	3.0	0.6	1.2	0	0.4
Santa Rosa	County	1987–2004	44.8	13.3	2.5	1.2	0.8

Gage station	USGS ID	Period of record	Drainage Area (mi²)	Spring flow		Summer flow	
				Gage	EWD[1]	Gage	EWD[1]
Creek at Main Street in Cambria							
Santa Rosa Creek near Cambria	11142200[a]	1958–1994	12.5	9.2	0.9	0.2	0.4
Tar Spring Creek near Arroyo Grande	11141400	1967–1979	18.2	2.1	0.5	0.3	0.2
Toro Creek near Morro Bay	11142100	1970–1978	14.0	2.4	1	0.5	0.4

[1]EWD values greater than measured flows are shown in red.

[a] Currently maintained by County.

4 DISCUSSION AND RECOMMENDATIONS

Overall, it appears that spring flows are sufficient to provide steelhead habitat in many Analysis Watersheds under existing conditions. However, summer flows are not sufficient to support steelhead in most Analysis Watersheds, despite the NOAA analysis of Boughton and Goslin (2006) results that indicated these watersheds have a high potential for steelhead rearing to occur based on intrinsic watershed characteristics, including perennial flows. It also appears that based on channel morphology that even relatively low flows (e.g., <0.5 cfs) during summer will allow steelhead to persist in Analysis Watersheds throughout the County. These results are consistent with the analysis of Boughton and Goslin (2006), who reported steelhead occurring during summer in streams with flows as low as 0.25 cfs.

This study focused on estimating EWD based on the flow requirements of steelhead, consistent with the County Master Water Report (SLO County Water Resources 2012). However, there are many other environmental resources that rely on surface flow to persist, including other fish species, amphibians, macroinvertebrates, and riparian communities. Since steelhead can potentially occur in most watersheds in the County, EWD for steelhead will also protect other resources. In the streams where steelhead do not potentially occur, we recommend broadening the definition of EWD to include other natural resources requiring protection. It is more challenging to estimate EWD for other resources, since criteria defining the flow needs of other species are less available than for steelhead. For example, in this study we attempted to qualitatively assess flow needs for coastal lagoons to support tidewater goby, and found that available data were not sufficient to estimate EWD in these habitats. Despite these challenges, we recommend that EWD inflows into coastal lagoons, and in particular within the 27 Analysis Watersheds identified as currently or historically supporting tidewater gobies, be investigated to determine minimum flows to support populations of this endangered species (Figure 2).

Although EWD is estimated for numerous watersheds, there are very few watersheds with established gages recording current stream flow conditions to monitor existing conditions. Consistent with the SLO County Flood Control and Water Conservation District Data Enhancement Plan (2008), we recommend establishing additional gages to monitor baseflows within major streams in the County. The Data Enhancement Plan identifies numerous uses for gage data. We recommend monitoring of Analysis Watersheds during both spring and summer to determine which ones are exceeding EWD requirements and which are not. For those that are not, there may be intrinsic watershed characteristics that limit surface flow, or upstream water management may be influencing streamflows and potential steelhead habitat. In particular, we recommend monitoring spring and summer flows at Analysis Points where existing gaging or direct observations made during this study indicate that flows are less than EWD within high potential steelhead rearing habitat, as summarized in Table 7. Site visits in spring and summer 2013 were conducted during an extreme drought, so these sites are assumed to have higher flows during most years. Site visits at remaining Analysis Points and under more conditions are recommended to determine which are exceeding EWD requirements and which are not.

Table 7. Summary of Analysis Points documented to have existing spring or summer flows less than EWD. Not all Analysis Points have existing gaging data or were visited in 2013.

Analysis point	Spring flow (cfs)		Summer flow (cfs)		Notes
	EWD	Existing condition	EWD	Existing condition	
Alamo Creek	4.4	5.7	1.2	0	Based on USGS gaging to 1978.
Arroyo De La Cruz	2.3	32.8	0.7	0.2	Based on USGS gaging to 1979.
Arroyo Grande	5.3	1.5	1.5	0	Based on USGS gaging to 1966. Water releases from Lopez Lake have changed.
East Corral De Piedra	0.5	0	0.3	0	Based on measurements in 2013.[a]
Jack Creek	1.6	11.1	0.5	0	Based on USGS gaging to 1978.
Los Berros Creek	1.1	2	0.4	0.15	Based on USGS gaging to 2001. Observed dry in summer 2013
Los Osos Creek	0.7	2.7	0.3	0	Based on County gaging to 2002.
Lower Atascadero Creek	1	0.09	0.4	0	Based on measurements in 2013.[a]
Lower Morro Creek	1.2	0	0.4	0	Based on measurements in 2013.[a]
Lower Pismo Creek	2.2	0.48	0.7	0.48	Based on measurements in 2013.[a]
Lower Santa Rosa Creek	2.5	1.66	0.8	0	Based on measurements in 2013.[a]
Middle San Simeon Creek	1.5	0.99	0.5	n/a	Based on measurements in 2013.[a]
San Luisito Creek	0.3	0.28	0.2	0.08	Based on measurements in 2013.[a]
Santa Rita Creek	1.2	9.1	0.4	0	Based on USGS gaging to 1994.
See Canyon Creek	3.8	n/a	1.1	0	Based on measurements in 2013.[a]
Suey Creek	0.9	n/a	0.3	0	Based on measurements in 2013.[a]
Upper Salinas River	3.7	16.6	1.1	0.5	Based on USGS gaging to 1983.
Upper SLO Creek	0.9	0.51	0.3	0	Based on measurements in 2013.[a]
West Corral De Piedra	0.6	0	0.3	0	Based on measurements in 2013.[a]

n/a No data collected

[a] 2013 was an extreme drought in the County, and therefore these sites are assumed to have higher flows in most years.

For those gages for which historical and current information is available (e.g., Morro Creek, Santa Rosa Creek, Los Berros Creek, Los Osos Creek), we recommend analysis of the current conditions compared with historical conditions. This analysis should also be summarized based on water year type, to assess differences in EWD between normal, wet, and dry water years. The County is currently maintaining many gages that were previously operated by USGS. However, we were not able to efficiently use these data. Consistent with the SLO County Data Enhancement Plan (SLO County Flood Control and Water Conservation District 2008), we recommend that the County compile and maintain daily mean discharge data for active stream gauging stations. Most mean daily flow data appear to end in 2006 or earlier but raw stage and discharge data appear to be available. In addition, we recommend that the County database be organized to make daily mean discharge data available in two-column format suitable for import into standard statistical software (i.e. date in one column and flow in another column).

Based on the limited data on existing conditions, EWD is currently exceeded in some Analysis Watersheds during spring, summer, or both, within at least portions of the watershed. These areas are likely providing a disproportionate amount of the suitable steelhead rearing habitat in the County, and thus are potentially high priority areas for protection and habitat enhancement. Although not all Analysis Point were monitored or visited, examples include:

- Islay Creek (based on measurements in spring and summer 2013),
- Lower Arroyo Grande Creek (based on measurements in spring and summer 2013),
- Lower San Luis Obispo Creek (based on measurements in spring and summer 2013),
- Middle Chorro Creek (based on measurements in spring and summer 2013),
- Tar Spring Creek (based on USGS gaging to 1979), and
- Torro Creek (based on USGS gaging to 1978).

Based on available data, EWD is not achieved in spring, summer, or both in many County streams. Closer examination of these streams may indicate that water management is reducing surface flow, or that intrinsic watershed conditions limit available flows. In streams with less than sufficient flows, we suggest that streamflow enhancement to protect steelhead is a higher priority than habitat restoration, since without sufficient flows any other restoration efforts are not likely to succeed. These include the following streams:

- Alamo Creek (based on USGS gaging to 1978),
- Arroyo De La Cruz (based on USGS gaging to 1979),
- Arroyo Grande (based on USGS gaging to 1966, existing conditions have changed),
- Jack Creek (based on USGS gaging to 1978),
- Los Berros Creek (based on USGS gaging to 2001),
- Los Osos Creek (based on USGS gaging to 2002),
- Salinas River (based on USGS gaging to 1983),
- Santa Rita Creek (based on USGS gaging to 1994), and
- Santa Rosa Creek (based on measurements in spring and summer 2013).

As noted above, most Analysis Watersheds do not have current stream flow monitoring, and thus it is not possible to compare EWD with existing conditions. We would expect that as current data on these other streams become available, many more streams could be classified as either achieving or not achieving EWD. That information would support a comprehensive County-wide prioritization of streams for habitat restoration, and streamflow protection and/or enhancement.

Streams with Analysis Points for which nearly very little or no data on existing conditions are available include:

- Alamo Creek (no gaging data for over 30 years),
- Arroyo De La Cruz (no gaging data for over 30 years),
- Arroyo De Los Chinos Creek,
- Atascadero Creek,
- Cayucos Creek,
- Chorro Creek,
- Calf Canyon,
- Coon Creek,
- Cuyama Creek,
- Cuyama Creek,
- Diablo Creek,
- East Corral De Piedra,
- East Fork SLO Creek,
- Graves Creek,
- Huerhuero Creek,
- Islay Creek,
- Jack Creek (no gaging data for over 30 years),
- Little Morro Creek,
- Little Pico Creek,
- Moreno Creek,
- Nacimiento Creek,
- Oak Knoll Creek,
- Old Creek,
- Old Creek,
- Paso Riverobles Creek,
- Perry Creek,
- Pico Creek,
- Pilitas Creek,
- Pismo Creek,
- San Bernardo Creek,
- San Carpoforo Creek,
- San Luisito Creek,
- San Simeon Creek,
- Santa Margarita Creek,
- Santa Rita Creek (no gaging data for over 30 years),
- See Canyon Creek,
- Stenner Creek,

- Suey Creek,
- Tar Spring Creek (no gaging data for over 30 years),
- Toro Creek (no gaging data for over 30 years),
- Trout Creek,
- Van Gordon Creek,
- Villa Creek,
- West Corral De Piedra, and
- Wild Cherry Canyon.

In Analysis Watersheds that have substantial amounts of steelhead habitat, where EWD is typically not achieved, and can be influenced by water diversions or water management, we recommend more intensive evaluations of steelhead habitat relationships with instream flows. This would include:

- Chorro Creek,
- Pismo Creek, and
- Santa Rosa Creek.

There are technically appropriate approaches to develop site-specific instream flow recommendations. Traditionally used approaches to studying instream flows and newly applied approaches are available, including IFIM and one-dimensional (1D) PHABSIM, two-dimensional (2D) hydrodynamic modeling, habitat criteria mapping, expert habitat mapping, and macroinvertebrate community assessments. All of these methods are only useful if they are applied to specific and appropriate questions. Many of the disadvantages of these approaches can be avoided by clearly identifying the questions for the project, and applying the methods in a directed way. In addition, these approaches are typically more successful when used in conjunction with other approaches. The following link to the Instream Flow Council website provides detailed information on instream flow methods, including case histories, key considerations, bibliographies, and related issues: http://www.instreamflowcouncil.org/resources/

Instream flow studies consistent with these recommendations have been conducted in San Luis Obispo Creek (TRPA 1994) and is occurring in Pismo Creek. The methods applied in Arroyo Grande Creek (Stetson Engineers, Inc. et al. 2004) are not clearly explained and did not appear to determine the relationship between flow and available habitat. Results from more precise studies can address one of the limitations of the EWD estimates by determining the flows that would maximize habitat availability for steelhead, rather than the minimum flows required to maintain habitat. Results of these types of site-specific studies have greater accuracy than the EWD results reported here and thus would be more appropriate for the development of target instream flows and management actions to achieve them.

In summary, we recommend the following:

- Broaden the definition of EWD to include consideration for additional natural resources, especially in the County's 26 coastal lagoons (Figure 2) where tidewater goby occur.
- Analyze current streamflow conditions compared with historical streamflow conditions, with consideration for water year type (i.e., wet, normal, or dry) and EWD. This would include the compilation and maintenance of daily mean discharge data for current County stream gauging stations.

- Monitor streamflows in all 25 Analysis Watersheds (Figure 1) during spring and summer to determine which streams are exceeding EWD estimates and which are not. Monitoring could include establishment of additional gages, or periodic direct measurements of streamflow during spring and summer.
- Determine if Analysis Watersheds not achieving predicted EWD are mischaracterized in the NOAA analysis as having a high potential to support rearing steelhead, or if other factors are causing flow reductions. Results could be used by resource managers to inform the prioritization of streams for protection, habitat restoration, and/or streamflow enhancement.

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