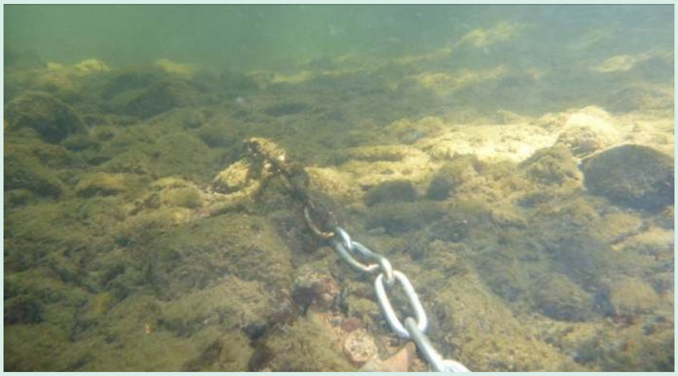
FINAL TECHNICAL MEMORANDUM ◦ SEPTEMBER 2013

Napa River Sediment TMDL Monitoring Program: Summary Report of Pilot Implementation



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Cover photos:

Upper left: Photographic view of gravel substrates at scour-chain site M5-2 on the middle Napa River (photo taken on May 7, 2013 by Stillwater Sciences)

Upper right: Photographic view of high-water survey in reach M2 on the upper Napa River (photo taken December 14, 2012 by Napa County RCD)

Bottom left: Underwater photographic view of exposed scour chain at site M2-1 on the middle Napa River (photo taken on May 14, 2013 by Napa County RCD)

Bottom right: Photographic view of permeability measurements at site M5-1 on the middle Napa River (photo taken on December 12, 2012 by Stillwater Sciences)

Disclosure:

Funding for this project has been provided in full or in part through an agreement with the State Water Resources Control Board and the U.S. Environmental Protection Agency under the Federal Nonpoint Source Pollution Control Program (Clean Water Act Section 319). The contents of this document do not necessarily reflect the views and policies of the State Water Resources Control Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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1 INTRODUCTION AND BACKGROUND

Based on threats to aquatic habitat from erosion throughout the watershed, in 1990 the California Regional Water Quality Control Board, San Francisco Region (Water Board) listed the Napa River as impaired by sediment under Section 303(d) of the Clean Water Act. Based on information and studies identifying likely factors limiting populations of steelhead (*Oncorhynchus mykiss*) and Chinook salmon (*O. tshawytscha*) in the watershed (Stillwater Sciences and Dietrich 2002), the Water Board concluded that water quality standards for sediment and for salmonid population and community ecology are not being met. Because of this finding, the Water Board developed a sediment total maximum daily load, or TMDL, for the Napa River watershed (Napolitano et al. 2009). The Napa River Sediment TMDL and Habitat Enhancement Plan (Sediment TMDL Plan) outlines an approach for addressing the primary factors determined to be affecting steelhead and salmon populations and thereby establishes a plan to improve overall habitat conditions throughout the watershed.

The Sediment TMDL Plan includes numeric targets for assessing the attainment of water quality standards (i.e., acceptable levels of fine sediment delivery to channels) related to inter-gravel streambed permeability[1] and channel bed-scour values associated with successful salmonid spawning and likely salmonid survival to emergence. The numeric target values set forth in the Sediment TMDL Plan are as follows:

> "The median value for streambed permeability shall be ≥7,000 centimeters per hour at potential spawning sites for steelhead and salmon in the Napa River watershed. We estimate this target value corresponds to approximately 50 percent or greater survival of eggs and larvae from spawning to emergence…"

and

> "The mean depth of scour shall be ≤15 centimeters below the level of the overlying streambed substrate at typical pool-tails/riffle-heads in all gravel-bedded reaches of mainstem Napa River and in the lower alluvial reaches of its perennial tributaries in reaches where the streambed slope is gentle (0.001 to 0.01). The target applies in response to all peak flows less than or equal to bankfull discharge."

In accordance with the sediment TMDL protocol, these parameters will be measured throughout the Napa River watershed during a long-term monitoring effort. The monitoring approach and methods are described in the Monitoring Plan prepared by Stillwater Sciences in August 2012 and approved by the Water Board on August 28, 2012 (Appendix A). The Monitoring Plan includes initial recommendations for a statistically robust approach for measuring these parameters at multiple locations during discrete time periods, tracking the change in parameter values over time, and ultimately determining if/when parameter values begin to approach the specified numeric targets.

The monitoring approach consists of an initial pilot monitoring effort, the results of which are reported here, and a long-term monitoring effort. The purposes of the pilot effort are to (1) test the sampling design outlined in the Monitoring Plan (Appendix A), (2) ascertain whether numeric

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[1] Use of the term "permeability" (expressed in units of length per time) is consistent with the established convention in fisheries biology. However, the property being measured is more accurately termed "hydraulic conductivity," as defined in the hydraulics literature (e.g., Kondolf 2000).

targets are being met with a high level of statistical confidence, and (3) provide information and recommendations to adjust the design if necessary using an adaptive management approach.

The overall goal of the pilot monitoring effort is to collect the appropriate data within representative spawning reaches to track permeability and bed scour over time and evaluate attainment of TMDL targets. In the process of meeting this goal, the monitoring effort will also help determine the degree to which TMDL-related sediment control measures are impacting downstream habitat conditions, which in turn will help improve subsequent sediment control efforts and ideally help reduce the time required to reach the numeric target values identified in the TMDL.

1.1 Purposes of this Document

In accordance with Agreement #10-444-552 for the Napa River Sediment TMDL Monitoring Program, the Napa County Resource Conservation District (RCD) and Stillwater Sciences initiated the pilot monitoring effort in November 2012. The effort entailed data collection of gravel permeability and channel bed scour, along with other relevant stream attributes, at a subset of mainstem and tributary monitoring reaches primarily during the 2012–2013 winter high-flow period. The purposes of this document are to:

- Provide results of the pilot monitoring effort conducted in 2012 and 2013 in accordance with the Monitoring Plan (Appendix A);
- Evaluate instream sediment conditions during the pilot monitoring effort relative to TMDL numerical targets;
- Evaluate whether the data collection approach and methods used in the effort (per the Monitoring Plan) provide data of sufficient quality and adequate sample size to meet the monitoring goals; and
- Provide recommendations for modification of monitoring and analysis methods, if necessary, in order to better achieve monitoring goals.

Data analyses and lessons learned from the pilot monitoring effort (e.g., sampling effectiveness and limitations) can subsequently be used, as needed, to make recommended updates to the sampling design described in the Monitoring Plan (Appendix A).

1.2 Dominant Characteristics of the Napa River Watershed

The Napa River drains a 1,100-km^2 (420-mi^2) watershed and flows through the cities of Calistoga, St. Helena, Yountville, Napa, American Canyon, and Vallejo before discharging into San Pablo Bay near the mouth of the Sacramento-San Joaquin estuary (Figure 1). The 90-km (60-mi) long river originates in steep, forested headwaters exceeding 1,300 m (4,300 ft) at Mount Saint Helena and then enters the depositional Napa Valley, whose floodplain is dominated presently by agriculture and developed areas. Historically, an array of both “connected” tributaries (i.e., tributaries with a discrete channel mouth that delivered water and sediment to the mainstem Napa River) and “disconnected” tributaries (i.e., tributaries without a discrete channel mouth that flowed directly onto the mainstem floodplain) flowed into the Napa Valley (Grossinger 2012). Over the past century, widespread channelization for urban and agricultural land uses has resulted in the direct connection of most tributaries to the Napa River. Currently,

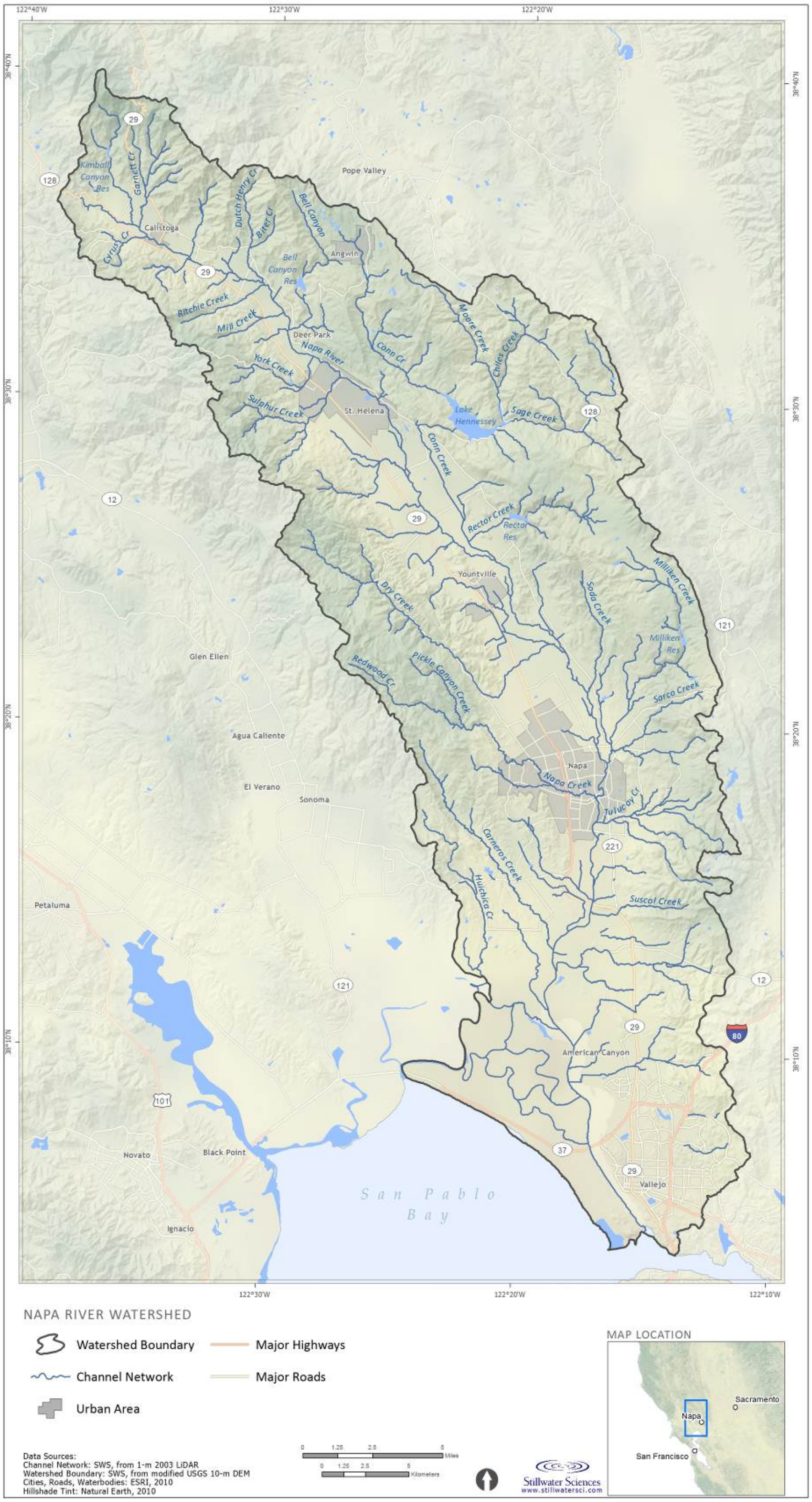


Figure 1. Hydrography map of the Napa River watershed.

delivery of both water and sediment from many tributaries to the Napa River is regulated by the water supply dams constructed during the past century. Most major dams (i.e., dams large enough to impound water and sediment) are located on the tributaries draining the eastern side of the basin, the majority of which were built in the 1940s and 1950s. The largest dams are the municipal water supply projects on Bell, Conn, Rector, and Milliken creeks, which collectively regulate approximately 20% of the total Napa River watershed area. In addition to these large dams, there are over 400 small on-channel dams in tributaries to the Napa River. Considering all dams, approximately 30 percent of the watershed area is regulated by dams.

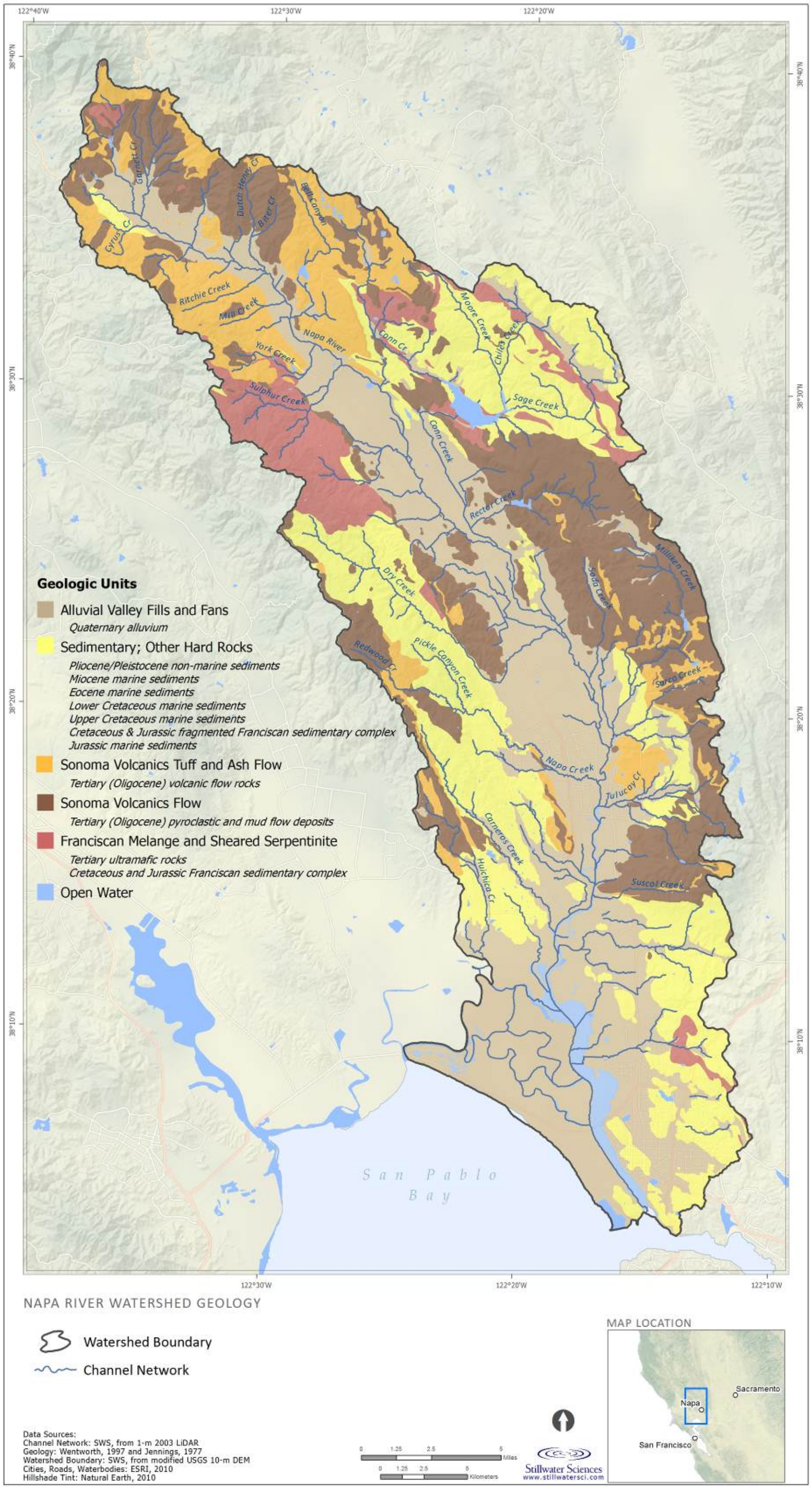
1.2.1 Climate and hydrology

The Napa Valley has a Mediterranean climate characterized by warm, dry summers and mild, wet winters. The majority of annual precipitation occurs as rain that falls between November and April, with the highest rainfall rates occurring on the western side of the valley. Precipitation decreases southward through the Napa Valley in proportion to elevation, with average annual precipitation varying between 53 and 145 cm (21 and 57 in.), as reported by the USDA for the period 1960–2001 (PRISM 2006). Average annual air temperatures are also lower in the southern portion of the valley due to coastal fog influence. Total annual precipitation can be highly variable from year to year, varying by several orders of magnitude between the driest years and the wettest years. At the downstream end of the watershed near the city of Napa, daily mean river flow (as recorded at USGS gage 11458000 on the Napa River near Napa) is below 20 cfs the majority of the time (i.e., flows exceed 20 cfs less than 50% of the time) but varies considerably between the drier summer months (~2 cfs on average during August and September) and the wetter winter months (>600 cfs on average during January and February). The frequent 1.5- to 2-year recurrence-interval flow, or “bankfull” event, is approximately 4,000–6,000 cfs in the Napa River near Saint Helena (USGS 11458000) and 6,000–9,000 cfs in the Napa River near Napa (see Figures 8b and 8c, respectively, below).

1.2.2 Geology

Located in the Coast Ranges geomorphic province, the Napa River watershed is a northwest-trending structural and topographic depression that has largely evolved since the early Pleistocene (about 2 million years ago) as a result of “downwarping” associated with regional folding and faulting (Hearn et al. 1988). The local deformation zone is bounded by two major northwest striking faults that comprise part of the San Andreas Fault System: the Healdsburg-Rodgers Creek Fault Zone in the west and the Green Valley Fault Zone in the east (CGS 2010a). The Napa Valley floor is primarily Quaternary alluvium deposited over the last million years and the uplands are composed of older, more competent sedimentary, volcanic, and metamorphic rocks (CGS 2010b) (Figure 2).

The variability in bedrock erodibility throughout the watershed is a primary driver of localized areas of higher and lower sediment production and delivery to the channel network (Napolitano et al. 2009). Moderately erodible marine and non-marine sedimentary deposits underlie approximately 25% of the watershed, primarily in the northeastern and southwestern portions of the basin. The northwestern and southeastern portions of the watershed are dominated by Tertiary-age Sonoma volcanics (hard lava flow deposits covering approximately 23% of the watershed area) and Sonoma volcanic tuff and ash flow (moderately erodible rocks covering approximately 11% of the watershed area). Bedrock in the eastern and western portions of the watershed also includes Franciscan mélange and sheared serpentinite (highly erodible Jurassic- to Tertiary-age marine sedimentary and ultramafic rocks that cover approximately 6% the watershed).



Data Sources:
Channel Network: SWS, from 1-m 2003 LiDAR
Geology: Wentworth, 1997 and Jennings, 1977
Watershed Boundary: SWS, from modified USGS 10-m DEM
Cities, Roads, Waterbodies: ESRI, 2010
Hillshade Tint: Natural Earth, 2010

Figure 2. Generalized geologic map for the Napa River watershed.

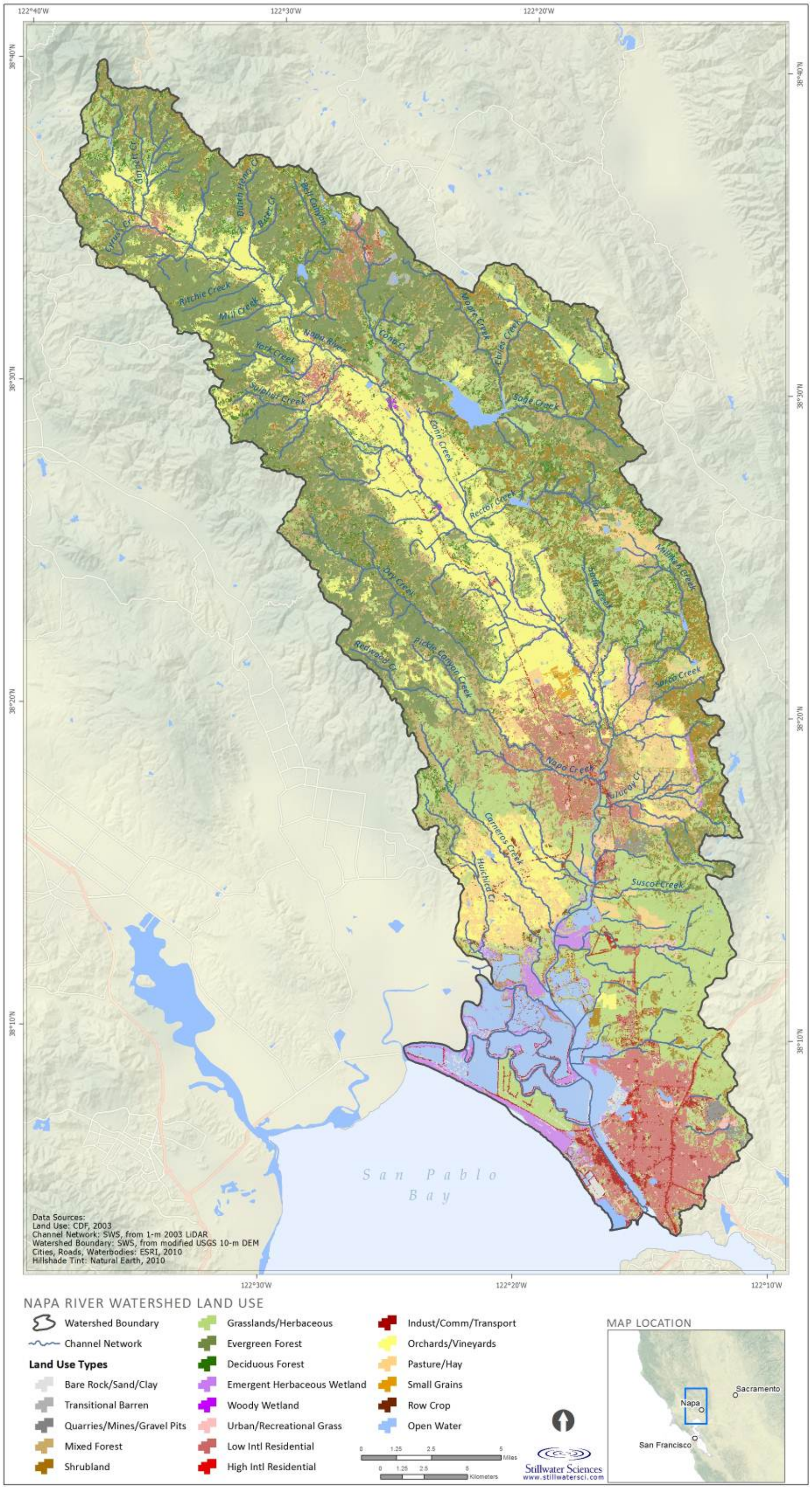
1.2.3 Land-use/Land-cover

Since European settlement began in the early nineteenth century, land use throughout the Napa River watershed has changed considerably. By the 1850s, the primary land uses in the Napa River watershed were agricultural activities, including timber production, grazing, and field crops. Vineyards were first developed in the 1860s, and up until about 1960 the valley floor was used primarily for a combination of orchards, field crops, and vineyards, with localized urban development in the cities of Napa, Yountville, St. Helena, and Calistoga. The area under grape production within the watershed rapidly increased from approximately 40 km^2 in 1970 to approximately 130 km^2 in 1996 (of which 75% is located on the valley floor and adjacent alluvial fans) (Napa County RCD 1997). The desire to protect agricultural and residential/industrial lands within the Napa Valley resulted in construction of a system of flood control berms from the 1960s through the 1990s. Currently, land use and cover in the Napa River watershed is composed of forested areas (35%), grasslands, including rangeland, and other herbaceous vegetation (25%), agricultural cover types, including orchards and vineyards, (20%), and urban uses, including residential and commercial (10%) (Figure 3). Open water and other cover types make up the remaining 10% of the watershed.

1.2.4 Salmonid habitat

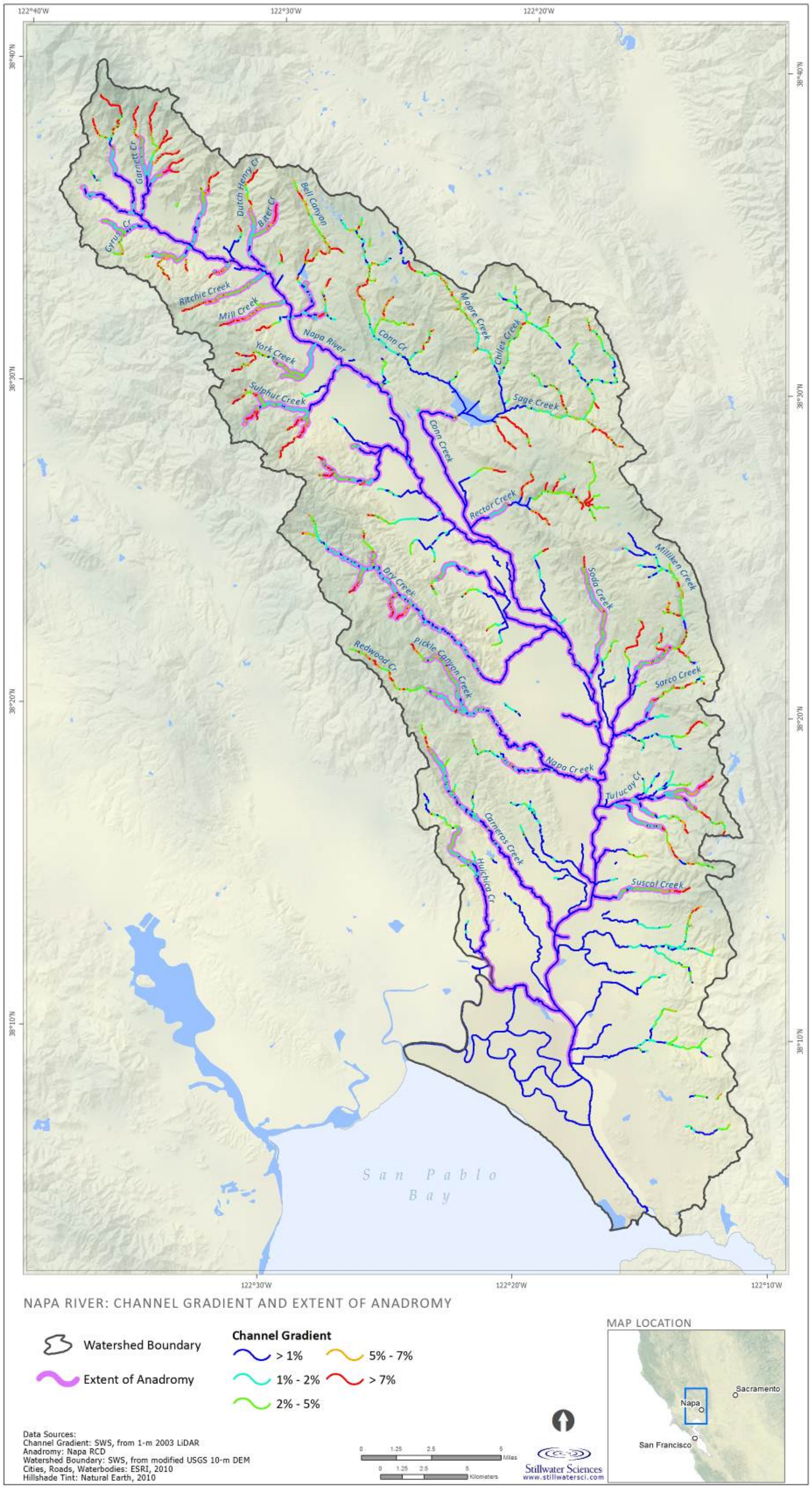
The Napa River watershed continues to support steelhead and Chinook salmon populations despite significant declines in abundance and distribution since European settlement (Leidy et al. 2005, Napa County RCD 2012, Garza and Crandall 2013). At present in most years, steelhead spawn primarily in the major tributaries, and fall-run Chinook salmon spawn primarily in the mainstem channel (Figure 4). The distribution of steelhead and Chinook salmon, or “extent of anadromy,” in the Napa River watershed is defined as the upstream limit of anadromous fish passage based on data from previous surveys conducted by the Napa County RCD and others. It is defined by dams, stream gradient, stream size (i.e., flow), or other factors. Steelhead in the Napa River belong to the Central California Coast distinct population segment (DPS), and are federally listed as threatened. Chinook salmon in the Napa River are a state species of concern but are not currently included in any evolutionarily significant unit (ESU).

Steelhead and Chinook salmon both spawn primarily in riffles and pool tail-outs, the quality of which are strongly influenced by substrate size and intra-gravel flow conditions (Stillwater Sciences and Dietrich 2002). The presence of fine sediment and sand in the bed materials can reduce intra-gravel flow in the nest, or redd, and are detrimental to egg survival and development. Suitable spawning and juvenile rearing habitats have been diminished over the years due to simplification of the river-floodplain system through floodplain developments, channel straightening, bank stabilization, levee construction, instream gravel mining, bedload-supply reduction from dam construction, and large woody debris reduction from manual removal and loss of historic riparian forests. Tributaries have been similarly impacted, resulting in fewer woody debris jams, deep pools, and spawning-size gravel patches. The salmonid Limiting Factors Analysis (LFA) conducted in the early 2000s determined that spawning habitat in the mainstem and tributaries is limited by increased bed mobility (i.e., high redd scour) and fine sediment in gravels (i.e., low permeability), among other factors (Stillwater Sciences and Dietrich 2002).



Data Sources:
Land Use: CDF, 2003
Channel Network: SWS, from 1-m 2003 LiDAR
Watershed Boundary: SWS, from modified USGS 10-m DEM
Cities, Roads, Waterbodies: ESRI, 2010
Hillshade Tint: Natural Earth, 2010

Figure 3. Land-use map for the Napa River watershed.



Data Sources:
Channel Gradient: SWS, from 1-m 2003 LiDAR
Anadromy: Napa RCD
Watershed Boundary: SWS, from modified USGS 10-m DEM
Cities, Roads, Waterbodies: ESRI, 2010
Hillshade Tint: Natural Earth, 2010

Figure 4. Channel gradient and extent of anadromy in the Napa River watershed.

2 METHODS

Recommended monitoring methods are described in the Monitoring Plan (Appendix A) and summarized here. The pilot monitoring effort summarized here entailed field measurement of gravel permeability and scour depth in representative reaches throughout the Napa River watershed containing suitable steelhead and Chinook salmon spawning habitat. Monitoring data were then analyzed to evaluate permeability and redd scour in relation to numerical TMDL targets and to assess adequacy of methods for evaluating attainment of the TMDL targets.

Data analysis included compilation and summarization of field data, calculation of basic statistics to evaluate attainment of TMDL numeric targets, graphical and tabular presentation of data, and power analysis of gravel permeability and streambed scour data to determine if sample sizes were adequate to discern statistically significant differences among sample sites.

2.1 Monitoring Reach Selection

2.1.1 Number of reaches

Selection of the tributary and mainstem monitoring reaches involved first determining the minimum number of monitoring reaches needed to provide a statistically robust dataset that could be used to determine representative spawning-gravel permeability for the entire watershed. The assessment involved conducting a power analysis, or test of statistical confidence, on the permeability data collected as part of the sediment TMDL study (Napolitano et al. 2009). The reach-median values from Napolitano et al. (2009) were compiled into a watershed value (mean of the reach values) and used to assess how the degree of statistical confidence in the representative watershed value (determined by the standard error of the dataset) varied as a function of the number of monitoring reaches. Based on this analysis, and a cursory assessment of likely monitoring time and budgetary constraints for individual monitoring events, it was determined that 20 monitoring reaches would ensure an acceptable level of statistical confidence (standard error of ~0.2) in the permeability and scour data (see the Monitoring Plan, Appendix A).

2.1.2 Location of reaches

Three primary criteria were used in selecting the locations of the 20 monitoring reaches to be used for the long-term monitoring effort:

1. **Spawning habitat extent and quality.** The extent of possible Chinook salmon and steelhead spawning habitat was defined as the upstream limit of anadromy throughout the watershed, which is determined primarily by the presence of both natural (e.g., bedrock steps) and man-made (e.g., dams and bridges) migration barriers. The extent of potential spawning habitat was determined as a function of local channel slope, which was determined from a high resolution topographic dataset (see Figure 5).
2. **Pre-existing permeability and scour data.** The existing datasets used to compile the initial set of possible locations included permeability data from 2002 (Stillwater Sciences and Dietrich 2002), 2003 (Napolitano et al. 2009), 2004 (Stillwater Sciences 2004), and 2007 (Napa County RCD 2009), and scour data collected in 2004 along the mainstem Napa River (Napa County RCD and SEC 2005). Consideration of the 2003 permeability dataset was of particular importance as it contains the data used to develop the sediment TMDL permeability targets and can therefore be used as baseline data for tracking change at those monitoring reaches over the past decade.

3. **Variation in dominant factors controlling permeability and scour.** The dominant factors controlling permeability and scour that were considered in selecting reach locations for pilot monitoring are sediment production, total sediment production/stream power index (the ability of a channel reach to transport the sediment delivered from upstream), and the degree of channel confinement by levees (for mainstem Napa River reaches only)[2].

The 20 selected monitoring reach locations (12 tributary and 8 mainstem) are shown in Figure 5 and the reach characteristics and other pertinent information are provided in Table 1 and Table 2. Overall, the tributary monitoring reaches are located in 10 different sub-watersheds and include four Sediment TMDL Plan monitoring reaches. The spatial distribution of geologic terrains within the contributing watersheds for all tributary monitoring reaches combined (as percent of total drainage area) is similar to that of the entire Napa River watershed, indicating that these monitoring sites likely capture a representative range of sediment-production conditions. The estimates for total sediment production per unit area at the tributary reaches range from ~100 to ~2,000 tonnes per square kilometer per year ($t\ km^{-2}\ yr^{-1}$), with a range of fine sediment contribution based on upstream geologic terrain. The total sediment production/stream power index values range from approximately 800 to over 11,000, which is similar in magnitude to the range of values from the sediment TMDL study (see Napolitano et al. 2009) and suggests an appropriate range in associated reach permeability values. The amount of agricultural and developed land use within the reaches contributing watersheds is also quite variable, indicating there is no bias in reach selection with respect to land use (i.e., the reaches are distributed among geologic terrains and land use types), which in turn translates to a set of reaches that represent the varying degree of both geologic terrain and land use controls on fine and total sediment production.

From the 20 monitoring reaches, a subset of eight reaches—four tributary and four mainstem reaches—was selected by project partners (Napa County RCD, Water Board, Stillwater Sciences, and UC Berkeley) for the pilot monitoring effort. The tributary reaches selected for pilot gravel permeability monitoring (Table 1; shaded rows) were chosen to represent the known range of permeability conditions, based on the most applicable available data. The four tributary reaches selected for pilot permeability monitoring included reaches in tributaries with high (York Creek), low (Sulphur Creek and some sites in Carneros Creek), and intermediate (Ritchey Creek and some sites in Carneros Creek) reach-median permeability values based on data collected in 2003 (Napolitano et al. 2009). The mainstem reaches selected for bed scour and gravel permeability monitoring (Table 2; shaded rows) were chosen to include those with bed scour potential that is representative of the range of values previously measured within mainstem Napa River spawning reaches. The four mainstem reaches selected for pilot scour monitoring include two reaches with confined channels (Calistoga upper [M1] and Rutherford lower [M6]) and two reaches with unconfined channels[3] (Calistoga lower [M2] and Rutherford upper [M5]). The upper mainstem reaches, M1 and M2, are characterized by relatively lower stream power and relatively higher sediment production values while the lower reaches, M5 and M6, have relatively higher stream power and relatively lower sediment production values. Data collection for pilot monitoring at the

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[2] The degree of channel confinement by levees was determined from analysis of recent aerial photographs combined with the 2003 LiDAR dataset. For the sake of simplicity, reaches where levees are immediately adjacent to the channel bank were considered confined while all other reaches were considered unconfined.

[3] The degree of channel confinement between levees provides a dominant control on local bed shear stress and associated sediment transport and bed scour dynamics, which in turn affects not only spawning habitat conditions, but also influences aquatic habitat complexity. Channel entrenchment, which also has a strong effect on shear stress and scour potential, was not used as a criterion for selecting monitoring reaches because the mainstem Napa River is entrenched throughout most of its length.

four mainstem reaches also included gravel permeability, particle size distribution, and channel topography surveys. However, previous permeability data for the mainstem Napa River is available only for the upper Rutherford monitoring reach (M5) (Table 2).

Within each reach selected for pilot monitoring, five sites were chosen for sampling (Figure 6). Sites were chosen based on accessibility for sampling and the presence of suitable spawning gravel for steelhead (tributaries) or Chinook salmon (mainstem Napa River). The upstream and downstream sites define the upstream and downstream boundaries of each reach. Data types collected at each pilot monitoring reach and the associated sites are summarized in Table 3.

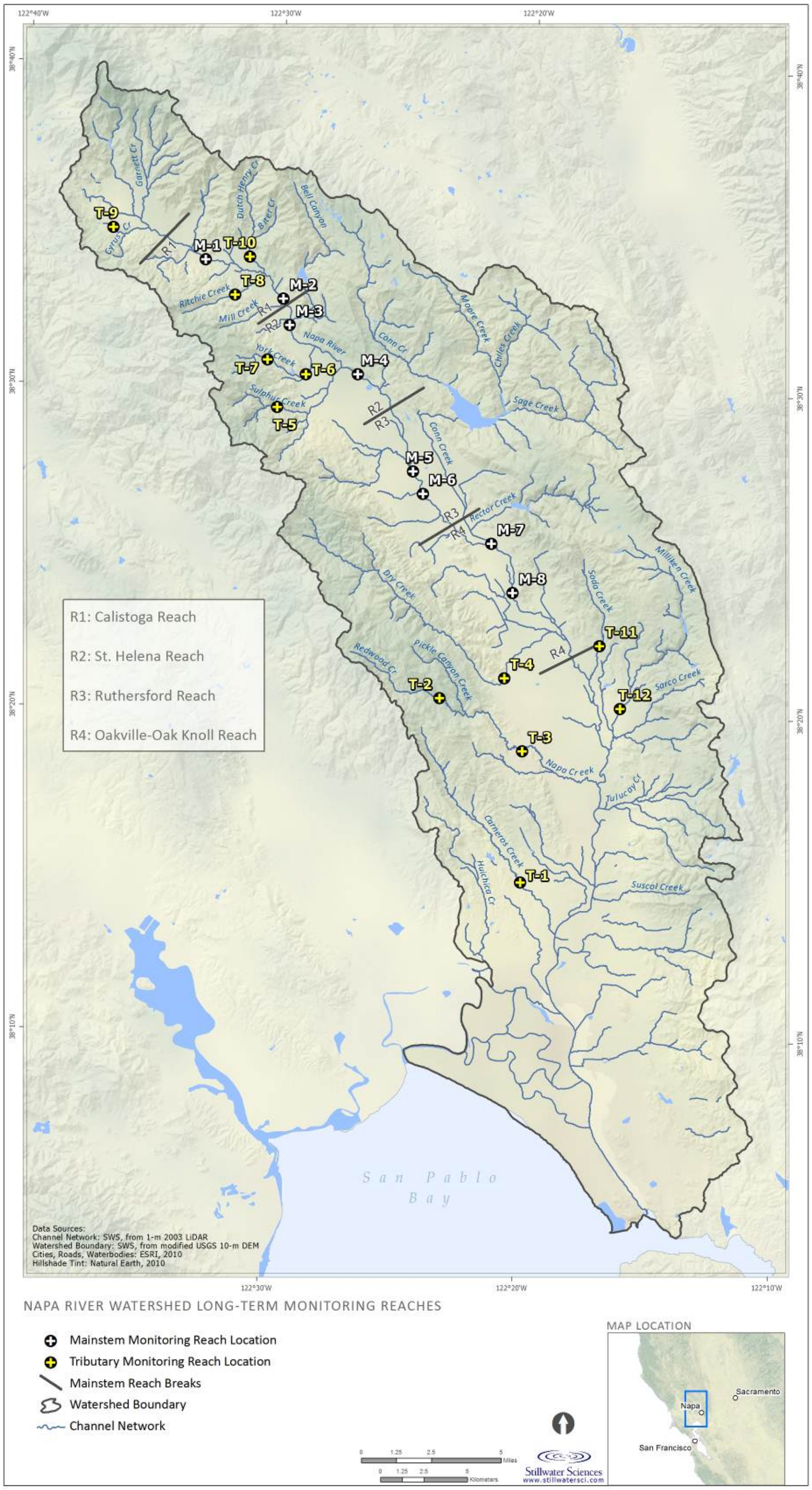

Figure 5. Location of mainstem and tributary monitoring reaches in the Napa River watershed.

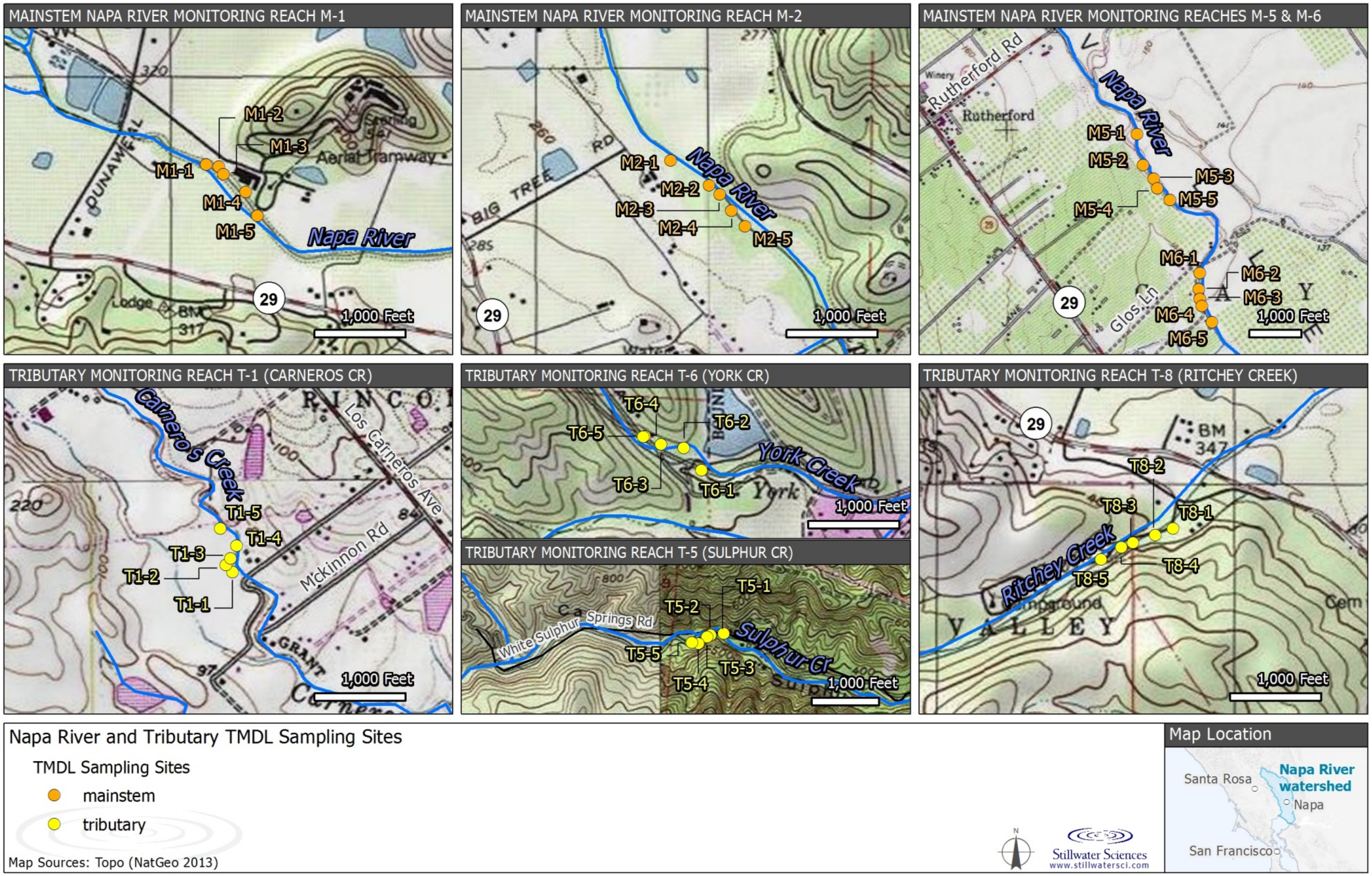

Figure 6. Location of mainstem and tributary sites sampled in the pilot monitoring effort.

Table 1. Summary of tributary monitoring reach characteristics.

Monitoring reach	Tributary	Sediment TMDL monitoring reach [a]	Channel slope [b]	Drainage area (km^2) [b]	Stream power [d]	Estimated total sediment supply ($t\ km^{-2}\ yr^{-1}$)	Sediment supply/Stream power index	Relative subwatershed fine sediment production [f]	Agricultural land coverage within contributing watershed	Previous permeability data collection efforts
T1	Carneros Cr	Lower Carneros	0.006	20.0	0.12	666 [e]	5,658	Medium	24%	2002 2003
T2	Redwood Cr		0.019	12.0	0.22	333	1,495	Medium	11%	2002
T3	Redwood Cr		0.012	26.0	0.32	408	1,261	Medium	13%	2002
T4	Dry Cr		0.008	47.7	0.38	525	1,376	Medium	4%	2002
T5	Sulphur Cr	Sulphur 4	0.021	10.1	0.21	1,938 [e]	9,254	Medium	12%	2002 2003
T6	York Cr		0.018	9.3	0.17	730	4,394	Medium-High	17%	2003 2004
T7	York Cr	Upper York	0.044	5.9	0.26	570 [e]	2,204	Medium-High	14%	2003 2004
T8	Ritchey Cr	Upper Ritchey	0.036	5.7	0.21	931[e]	4,470	High	0.3%	2002 2003
T9	Cyrus Cr		0.019	2.6	0.05	558	11,030	Medium-High	0.8%	2002
T10	Selby Cr		0.010	12.8	0.13	108	817	Low-Medium	0.9%	2002
T11	Soda Cr		0.024	11.3	0.27	238	884	Low-Medium	0.01%	2002
T12	Milliken Cr		0.003	20.5[c]	0.07	99 [e]	1,457	Medium	11%	2007

Notes:

Gray-shaded cells indicate the monitoring reach was part of the pilot monitoring study.

[a] From Napolitano et al. (2009), Table 8

[b] From 2003 1-m LiDAR dataset. Slope measured in the field by Napolitano et al. (2009) in reaches T1, T5, and T8 corresponds closely with the estimates reported here.

[c] Includes only the regulated drainage area downstream of Milliken Reservoir

[d] Product of channel slope and drainage area

[e] Values taken from Napolitano et al. 2009, Table 8; other values in this column were interpolated from Napolitano et al. 2009, Section 3.6

[f] Derived from information provided in SFEI 2012, Appendix IV Table 2

Table 2. Summary of mainstem monitoring reach characteristics.

Monitoring reach	**Mainstem reach**	**Sediment TMDL monitoring reach** [a]	**Channel slope** [b]	**Drainage area (km^2)** [b, c]	**Stream power** [b, d]	**Estimated total sediment supply ($t\ km^{-2}\ yr^{-1}$)**	**Sediment supply/Stream power index**	**Reach type**	**Previous permeability and scour data collection efforts**
M1	R1 (Calistoga)		0.0030	79.8	0.24	700	2,942	Confined	None
M2			0.0029	119.6	0.35	700	1,986	Unconfined	None
M3	R2 (St. Helena)		0.0014	143.8	0.20	700	3,481	Confined	None
M4			0.0023	189.9	0.44	700	1,589	Unconfined	None
M5	R3 (Rutherford)	Rutherford (lower)	0.0021	232.0	0.49	584 [e]	1,200	Unconfined	2004
M6			0.0020	239.2	0.48	584 [e]	1,208	Confined	None
M7	R4 (Oakville-Oak Knoll)		0.0015	257.4	0.38	450	1,192	Unconfined	None
M8			0.0015	297.4	0.46	450	987	Confined	None

Notes:

Gray-shaded cells indicate the monitoring reach was part of the pilot monitoring study.

[a] From Napolitano et al. 2009, Table 8

[b] From 2003 1-m LiDAR dataset

[c] Includes only the regulated drainage area downstream of the four major reservoirs: Bell Canyon, Rector, and Milliken reservoirs and Lake Hennessey

[d] Product of channel slope and drainage area

[e] Values taken from Napolitano et al. 2009, Table 8; other values in this column were interpolated from Napolitano et al. 2009, Section 3.6

Table 3. Summary of data types collected at the pilot monitoring reaches and sites.

Monitoring reach	Site	Gravel permeability	Streambed scour	Streambed particle size distribution	Channel surveys		
					Cross-section	High-water marks	Thalweg profile
M1: Upper Calistoga Reach	M1-1	▨	▨	▨	▨	▨	▨
	M1-2	▨	▨	▨		▨	
	M1-3	▨	▨	▨		▨	
	M1-4	▨	▨		▨	▨	
	M1-5	▨	▨	▨	▨	▨	
M2: Lower Calistoga Reach	M2-1	▨	▨	▨	▨	▨	▨
	M2-2	▨	▨	▨	▨	▨	
	M2-3	▨	▨	▨		▨	
	M2-4	▨	▨	▨	▨	▨	
	M2-5	▨	▨	▨	▨	▨	
M5: Rutherford Reach	M5-1	▨	▨	▨	▨	▨	▨
	M5-2	▨	▨	▨	▨		
	M5-3	▨	▨	▨	▨	▨	
	M5-4	▨	▨	▨	▨	▨	
	M5-5	▨	▨	▨	▨	▨	
M6: Rutherford Reach	M6-1	▨	▨	▨	▨	▨	
	M6-2	▨	▨	▨			
	M6-3	▨	▨	▨			
	M6-4	▨	▨	▨			
	M6-5	▨	▨	▨			
T1: Carneros Creek	T1-1	▨					
	T1-2	▨					
	T1-3	▨					
	T1-4	▨					
	T1-5	▨					
T5: Sulphur Creek	T5-1	▨					
	T5-2	▨					
	T5-3	▨					
	T5-4	▨					
	T5-5	▨					
T6: York Creek	T6-1	▨					
	T6-2	▨					
	T6-3	▨					
	T6-4	▨					
	T6-5	▨					
T8: Ritchey Creek	T8-1	▨					
	T8-2	▨					
	T8-3	▨					
	T8-4	▨					
	T8-5	▨					

Notes:
Gray-shaded cells indicate data was collected at that site. The thalweg-profile surveys were performed along the entire reach.

2.2 Hydrologic Conditions

Streamflow in the Napa River during the pilot monitoring period peaked during late December, 2012. The peak flow recorded in Reach 2 near St. Helena (USGS gage 11456000[4]) and in Reach 4 near Napa (USGS gage 11458000[5]) during this period was 9,690 and 13,100 cfs, respectively, on December 23–24, 2012. These peak flows have approximate flood recurrence intervals of 4.8 and 3.5 years, respectively, over their contemporary periods of record. The flood frequencies for the two gages were analyzed using the Log-Pearson Type III statistical technique (USGS 1982) to estimate probabilities of various flood magnitudes. River discharge and stage data recorded continuously at the two active stream gages are presented in Figure 7. Peak flow data and flood frequency results computed for the gages are presented in Figure 8.

a)

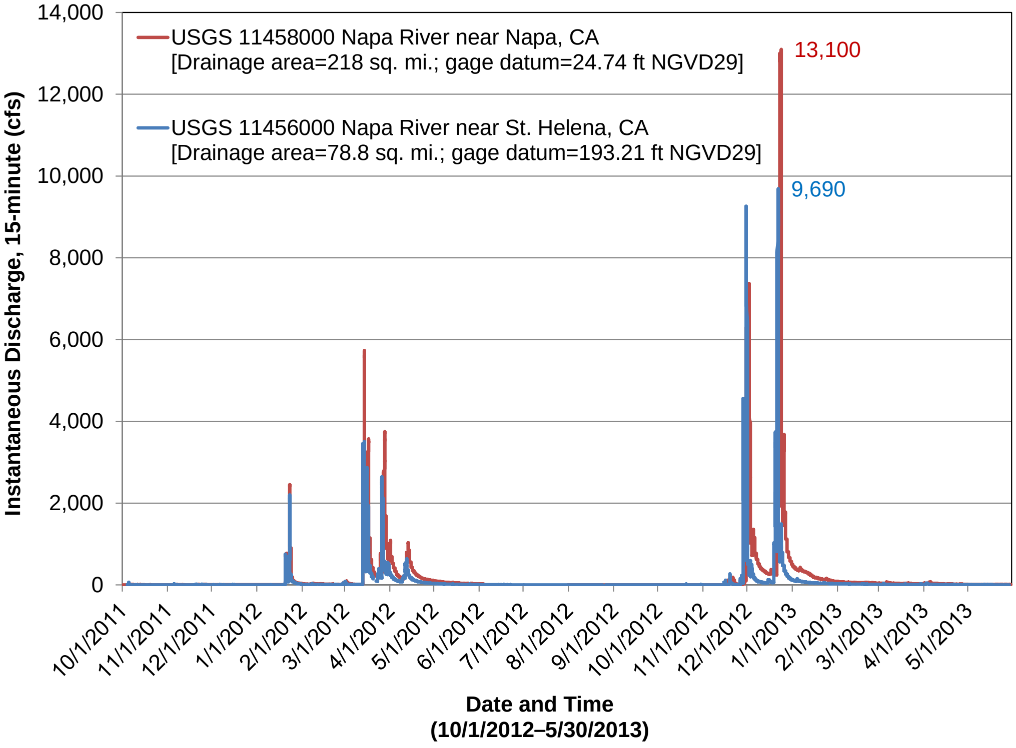

Figure 7. continued on next page

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[4] Period of record considered for surface water gage "USGS 114556000 Napa River near St. Helena, CA" is water years 1940–1996, 2001–2013; data available online at: http://waterdata.usgs.gov/nwis/inventory/?site_no=11456000&agency_cd=USGS&.

[5] Period of record considered for surface water gage "USGS 11458000 Napa River near Napa, CA" is water years 1960–2013; data available online at: http://waterdata.usgs.gov/nwis/inventory/?site_no=11458000&agency_cd=USGS&.

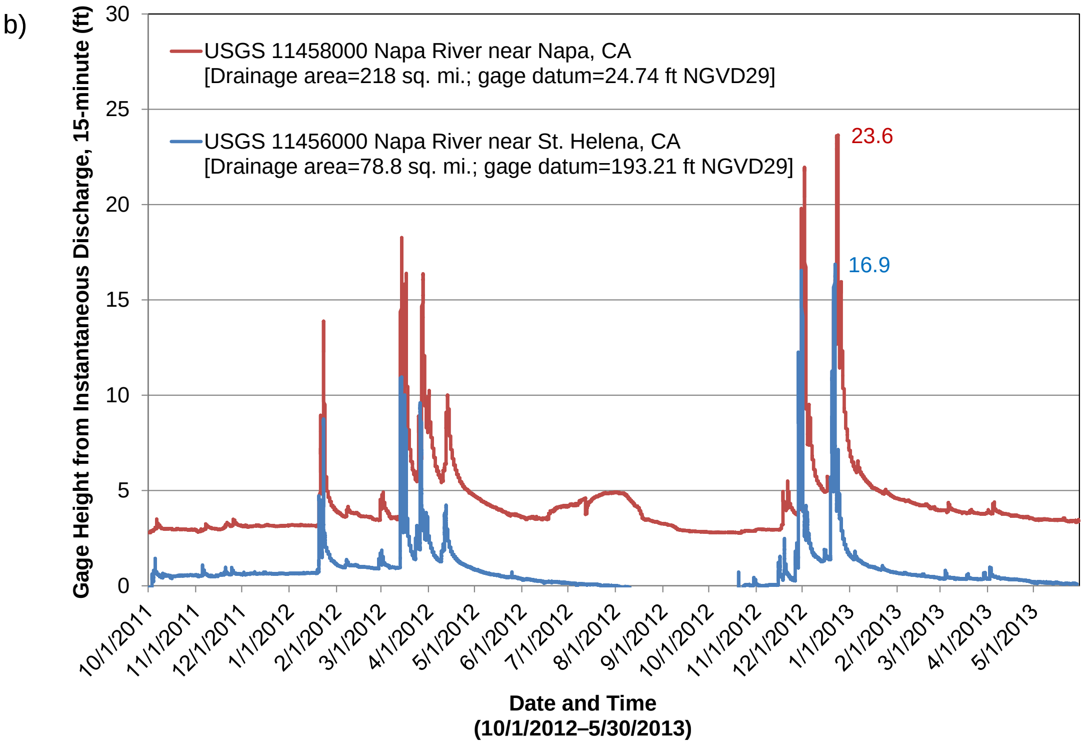
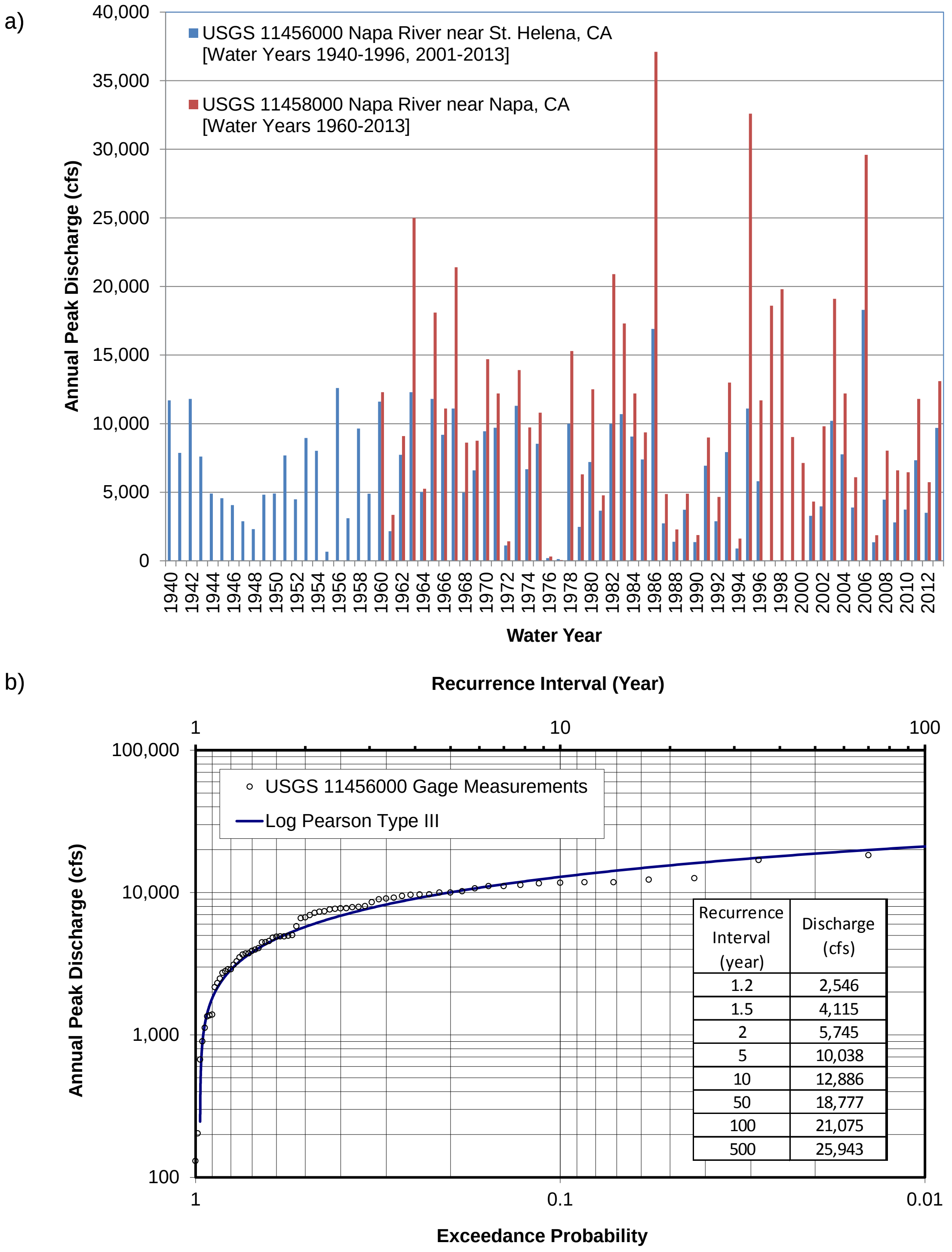
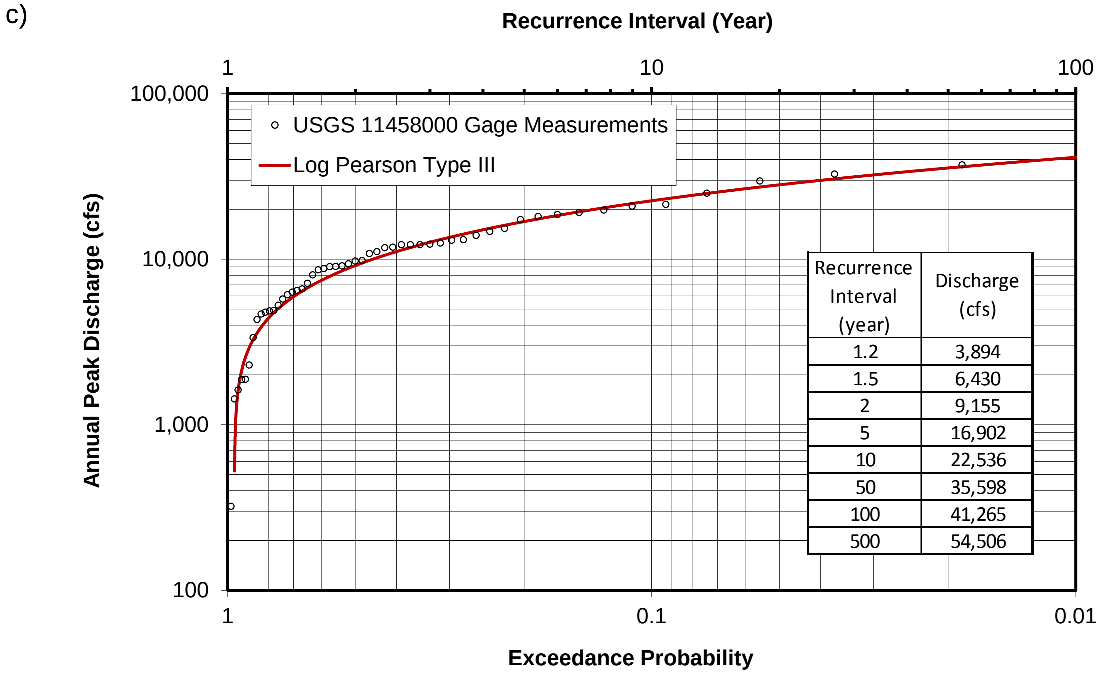


Figure 7. River discharge (a) and gage height (b) recorded continuously at the two active stream gages between October 1, 2011 and May 30, 2013. Peak flow during the pilot monitoring period occurred on December 23–24, 2012, and is indicated on the above graphs with data labels.



Recurrence Interval (year)	Discharge (cfs)
1.2	2,546
1.5	4,115
2	5,745
5	10,038
10	12,886
50	18,777
100	21,075
500	25,943

Figure 8. continued on next page



Recurrence Interval (year)	Discharge (cfs)
1.2	3,894
1.5	6,430
2	9,155
5	16,902
10	22,536
50	35,598
100	41,265
500	54,506

Figure 8. Annual peak discharge (a) and flood frequency (Log Pearson Type III) curves with tabularized recurrence intervals for the two active stream gages near St. Helena (b, USGS 11456000) and Napa (c, USGS 11458000) over their contemporary periods of record.

2.3 Gravel Permeability

2.3.1 Field methods

Pilot gravel permeability measurements were taken in four mainstem reaches to assess Chinook salmon and steelhead spawning habitat conditions, and in four tributary reaches to assess steelhead spawning habitat conditions (see Figure 5, Figure 6, and Table 3). The measurements were made by the Napa County RCD following methods described in the Monitoring Plan (Appendix A) and are summarized below. Pilot gravel permeability monitoring in the mainstem Napa River occurred in December 2012 and early January 2013 as follows:

- Between December 11 and 20, 2012, gravel permeability was measured in reaches M1, M5, and M6.
- On January 8 and 9, 2013, gravel permeability was measured in reach M2 (after the large peak flow event that occurred on December 23–24, 2012).

Pilot gravel permeability monitoring in tributaries to the Napa River occurred from late January to early April 2013 as follows:

- On January 29, 2013, gravel permeability was measured in reach T8 (Ritchey Creek).
- On February 12 and March 4, 2013, gravel permeability was measured in reach T6 (York Creek).
- On March 4, 2013, gravel permeability was measured in reach T5 (Sulphur Creek).

- On April 9, 2013, gravel permeability was measured in reach T1 (Carneros Creek).

Each of the eight reaches contained five sampling sites established as cross-sections with installed survey pins on the right and left banks. The purpose of the cross-sections was to provide a means to re-locate sites for future monitoring. Four artificial redds were manually constructed at each site to assess permeability according to methods described in Section 4.2.1 of the Monitoring Plan (Appendix A). The permeability standpipe was driven for sampling into each artificial redd. Water temperature and at least five replicate measurements of input flow were taken at each standpipe drive location. Permeability, or input flow, was measured using a permeometer consisting of a portable vacuum pump powered by a 12 volt rechargeable battery to siphon water out of the standpipe to maintain the water level inside the standpipe exactly one inch lower than the surrounding water. The recharge rate of the water level in the standpipe under a standard one-inch pressure head was determined by measuring the volume of water siphoned out of the standpipe over a measured time interval. At each standpipe drive location, five or six replicate draws of the permeometer were taken for a total of 407 mainstem and 402 tributary measurements.

No major equipment failure or difficulties implementing the method were encountered.

2.3.2 Analysis

The recharge rate (units of volume per time) measured in the field was converted into permeability (units of length per time) using an empirically derived rating table (Barnard and McBain 1994) and adjusted with a correction factor that accounts for temperature-related changes in water viscosity that can affect permeability results (Barnard and McBain 1994). The median permeability value for the five replicate measurements at each artificial redd was calculated and used as the representative redd permeability value. Reach median permeability values were then derived from the representative redd values.

T-tests on log-transformed geometric mean permeability values were used to assess compliance with the TMDL target[6] criterion of 7,000 cm/hr. This method was used because initial data analysis indicated that the log-transformed permeability values are more symmetrically distributed than the permeability values themselves, and the geometric mean (but not the arithmetic mean) is generally close to the median. These two observations support the use of t-tests on log-permeability to assess compliance with the TMDL target criterion.

A conventional power analysis, based on the residual standard error derived from a linear model of log permeability by reach, was used to determine the minimum detectable difference (with 95% confidence and 80% power) among reach permeability values based on the number of samples recommended in the Monitoring Plan (Appendix A).

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[6] The TMDL target specifies that the median of the permeability values at standpipe drives across a sampling unit (e.g., riffle, reach) is to be the basic metric for the unit, and by implication that comparisons between units, or against the target value of 7,000 cm/hr, should be conducted with distribution-free statistical tests. However, such tests are less powerful than parametric tests (such as t-tests), at least when the assumptions of the parametric tests are satisfied. Power is a serious concern given the high degree of variability in the permeability data.

2.4 Streambed Scour

2.4.1 Field methods

The installation of scour chains was performed by the Napa County RCD at the four mainstem reaches (M1, M2, M5, and M6) according to methods described in the Monitoring Plan (Appendix A) (see Figure 5 and Table 3). Two chains were installed at each of the five sites established at the four reaches (a total of 40 installation locations).

On November 27, 2012, 18 scour chains were installed in two mainstem Napa River study reaches: M1 (M1-1 through M1-5) and M2 (M2-1, M2-3, M2-4, and M2-5). A series of large storms began the following day preventing further installations. A peak flow of 4,560 cfs was recorded by the USGS stream gage near St. Helena on November 30, 2012, and a larger peak of 9,260 cfs was recorded on December 2, 2012. Following these storms, flows receded sufficiently to resume fieldwork and install the remaining 22 chains in reaches M2 (M2-2), M5 (M5-1 through M5-5) and M6 (M6-1 through M6-5) during December 10–14, 2012.

Bead monitors could not be installed due to failure of the installation rod to release from the anchor. The bead assembly was successfully driven into the streambed at several locations, but the anchor would not release from the installation rod and therefore pulled back out when the rod was removed, causing installation failure.

The initial 18 chains utilized a light-duty “duckbill” anchor system that proved inadequate for coarse bedded reaches. Although the duckbill anchors held well once driven into the substrate, the driving rod was too thin to withstand the pounding force of the hammer and lasted only 8–10 installations. During the subsequent installations, a larger duckbill anchor was installed with a substantially heavier hardened steel driving rod, which worked very well.

The first effort to retrieve scour chains occurred on January 10, 2013, at which time only 17 of the 40 scour chains were located, due primarily to the poor visibility encountered under high, albeit non-flood, streamflow conditions. This initial monitoring period included the flow of record for water year 2013: 9,690 cfs near St. Helena and 13,100 cfs near Napa (see Section 2.2 above). These chains were reset following their initial retrieval. Subsequent efforts to retrieve scour chains at all sites under lower flow conditions, and aided by use of a metal detector, occurred on May 7, 14, and 21, 2013. A total of 20 scour chains were located during the second retrieval period, five of which were chains not found during the initial retrieval effort: M1-4 (2 chains), M2-4 (1 chain), M5-1 (one chain), and M5-5 (one chain). There were five locations where chains were found during the initial retrieval effort but not during the second retrieval effort: M1-5 (1 chain), M2-5 (2 chains), M5-2 (1 chain), and M6-1 (one chain). Only 12 chains were recovered in both surveys. This second monitoring period experienced a steady decline in river discharge punctuated by only a few, small rainfall events, all of which were lower than the discharge recorded during the first recovery period.

The exposed length of each scour chain retrieved was recorded for comparison with the exposed length when installed, for calculation of the amount of scour (i.e., chain exhumation) or deposition (i.e., chain burial) that occurred while the chain was in place.

The primary challenge with the scour-chain monitoring was successful retrieval of all 40 chains during both retrieval periods. The higher flows in early January limited visual observation of chains during the initial retrieval period. While the metal detector helped recover a few unexposed chains, principally those of steel material, the majority of chains were non-magnetized stainless steel and, accordingly, could not be easily located by the metal detector.

2.4.2 Analysis

The basic analysis of scour chain data consisted of calculating the scour between the December and January surveys, and the cumulative scour between the December and May surveys. A power analysis was also conducted to determine the power of the data, and the adequacy of the sampling protocols, to demonstrate conformance or non-conformance with the TMDL target of <15 cm mean scour depth.

2.5 Streambed Particle Size Distribution

2.5.1 Field methods

Distribution of streambed particle sizes was assessed at each monitoring reach generally following the methods described in the Monitoring Plan (Appendix A) (see Figure 6 and Table 3). The purpose of this assessment was to help characterize geomorphic and habitat conditions, and for use in understanding changes to permeability and scour values over time. Measurements were made at 19 of the 20 sites (excluded site M1-4 due to excessive water depth) using the Wolman pebble-count method (Wolman 1954, Bunte and Abt 2001). Pebble counts were conducted by measuring the length of the intermediate axis (or b-axis) of 100 randomly selected particles in and around redd locations.

2.5.2 Analysis

The pebble count data were used to construct particle size distributions and determine representative bed particle sizes—the particle size for which 16% of the distribution is finer (D_{16}), the median particle size (D_{50}), and the particle size for which 84% of the distribution is finer (D_{84})—at each sample location. A statistical analysis (t-test) was also conducted to determine the trends in the pebble-count data over the length of the river and differences between reaches and their sites.

2.6 Channel Surveys

2.6.1 Field methods

Topographic profiles of the active channel were surveyed at 13 of the 20 mainstem reach sites generally following the methods described in the Monitoring Plan (Appendix A; see Figure 6 and Table 3). The purpose of this survey was to capture key channel features relative to the artificial redds constructed for the gravel permeability and bed scour monitoring. The channel features include bankfull elevation (i.e., 1.5- to 2-yr recurrence flood stage), edges of water, and the channel bed adjacent to and across the width of the artificial redd. During the initial field visits, cross-section endpins (capped rebar) were installed on both banks near the selected artificial redds (approximately 5 m away from the bank edge) and their coordinates were recorded using a hand-held GPS unit. These cross-sections served as locational markers for all field monitoring described above. Cross-sections were surveyed once at the 13 sites between April 25 and May 21, 2013 in conjunction with the thalweg-profile surveys (see below). During each survey, a measuring tape was strung between the cross-section endpins and elevations at observable topographic inflections were taken within the active channel at intervals appropriate for capturing relevant topographic breaks (approximately 0.3–1 m spacing). At each cross-section, the relative elevation and position of endpins were surveyed using a digital theodolite and stadia rod.

Locations of the maximum water surface reached along each cross-section during the winter high flow period (as identified from bank disturbance indicators) were surveyed for use in assessing peak flow water surface slope and depth. High water marks were surveyed in December 2012 and April and May 2013 as follows:

- Between December 14 and 18, 2012, high water marks were surveyed at sites M1-1 through M1-5, M2-1, M2-3, M2-4, and M2-5.
- Between April 30 and May 21, 2013, high water marks were surveyed at sites M1-4 (re-survey), M2-1 (resurvey), M2-2, M5-1, M5-3, M5-4, M5-5, and M6-1.

Methods of the high water surveys were the same as those employed for the cross-section surveys. Elevations of the high water marks on either bank were recorded relative to the depth of the thalweg for each cross-section in order to approximate water depth during the peak flow event(s).

Additionally, thalweg-profile surveys were conducted along the length of the river channel at reach M1, M2, and M5. These surveys were performed between April 25 and May 9, 2013 in conjunction with the cross-section surveys. Methods of the thalweg-profile surveys again employed use of digital theodolite and stadia rod equipment. The longitudinal extent of each of three thalweg-profile surveys varies, but generally spanned between 1,000 and 1,600 feet, including all five sites (cross-sections) within the reach.

The unit system used for the cross-section, high-water mark, and thalweg-profile surveys was in feet. All relative elevations measured in the field were subsequently converted to absolute elevations (feet, NAVD88) by Napa County RCD surveying staff based on reference to known benchmarks established at the sites.

2.6.2 Analysis

The channel survey data were used to construct graphical plots depicting the channel profiles at the surveyed reaches and sites. Channel dimensions, such as width, depth, slope, and other hydraulic variables can be extracted from these data to aid in brief analysis of bed mobility potential.

3 RESULTS

3.1 Gravel Permeability

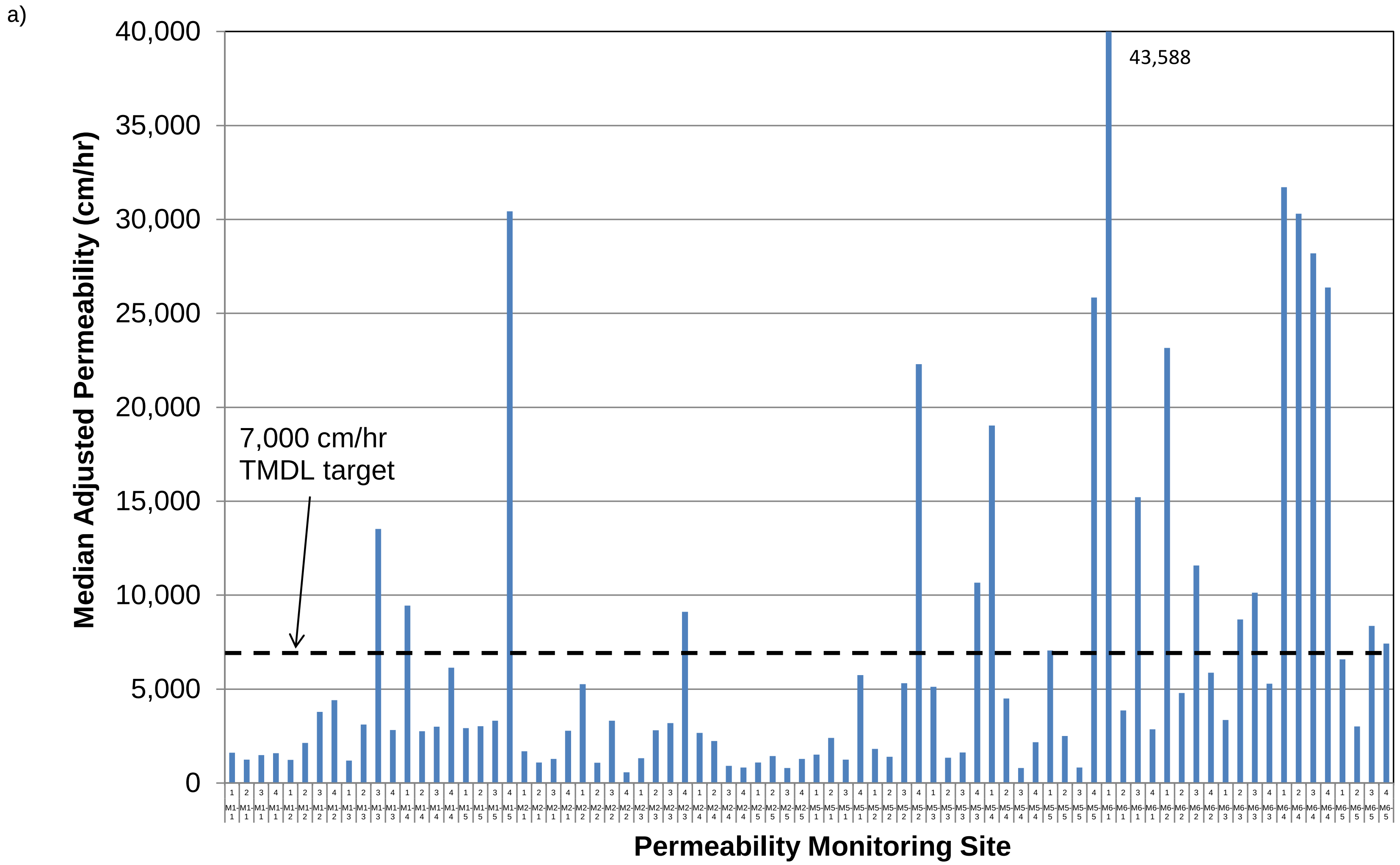
The gravel permeability results from the pilot field monitoring conducted at the mainstem and tributary sites are presented graphically in Figure 9. The TMDL target for permeability is ≥ 7,000 cm/hr (Napolitano et al. 2009), with greater values indicating relatively greater permeability and higher potential survival to emergence of salmonid embryos. There were 21 of the 80 redd-permeability measurements (from 4 to 5 replicates per redd) from the mainstem that exceeded the 7,000 cm/hr TMDL target. Of the 80 redd-permeability measurements made at the tributary sites, 38 exceeded the TMDL target.

The statistical analysis initially explored the most effective manner to assess the highly variable data from the field measurements. Figure 10 shows that the geometric mean, not the arithmetic mean, is generally close to the median for each monitoring site. Figure 11 reveals that the log-transformed permeability measurements by monitoring reach are more symmetrically distributed than the non-transformed permeability measurements. Both of these observations of the data support the use of t-tests on log-permeability values to assess compliance with the TMDL target. The median permeability values for each of the four tributary reaches sampled during the pilot monitoring effort were greater than those documented in 2003–2004 and reported in the Sediment TMDL Plan (i.e., permeability improved) (Napolitano et al. 2009). Median permeability also improved at mainstem reach M5 relative to the 2003–2004 values. Permeability was not measured at the other mainstem pilot monitoring reaches in 2003–2004 so no comparison is possible.

The power analysis found that, for one-sided t-test comparisons, differences in log-permeability of 10% (0.86) or more can be detected between reaches, with 95% confidence and 80% power, having 18 samples per group. This finding is consistent with the original sample-size recommendations stated in the Monitoring Plan (Appendix A). Figure 12 shows the geometric-mean permeability for each monitoring reach, together with a 95% confidence interval. Reaches M1, M2, M5, and T1 are all confidently below the 7,000 cm/hr TMDL target. All remaining reaches are above the TMDL target, confidently so in the cases of reaches T5 and T8.

In summary, these findings indicate that, again, the sample size was sufficient to statistically distinguish the reach-aggregated values from the TMDL target, particularly when assessing non-compliance (i.e., sites below the target). Effectively assessing TMDL-compliance (i.e., sites above the target) could be further resolved for reaches M6 and T6 by using one-sided tests or by relaxing the performance criterion (e.g., lowering to 90% confidence). Little else could be done to improve the power of the tests because the widths of the confidence intervals scale as the square root of the number of samples, which would require large increases in sampling effort to realize fairly small reductions in uncertainty. The limiting factor, thus, is the high intrinsic variability in local gravel permeability, as is common in similar river systems.

The final statistical analysis performed to compare the permeability measurements with river-discharge timing determined that the difference between permeability measurements made at the mainstem sites (sampled earlier in the season) and the tributary sites (sampled later in the season) is not easily distinguished (Figure 13).



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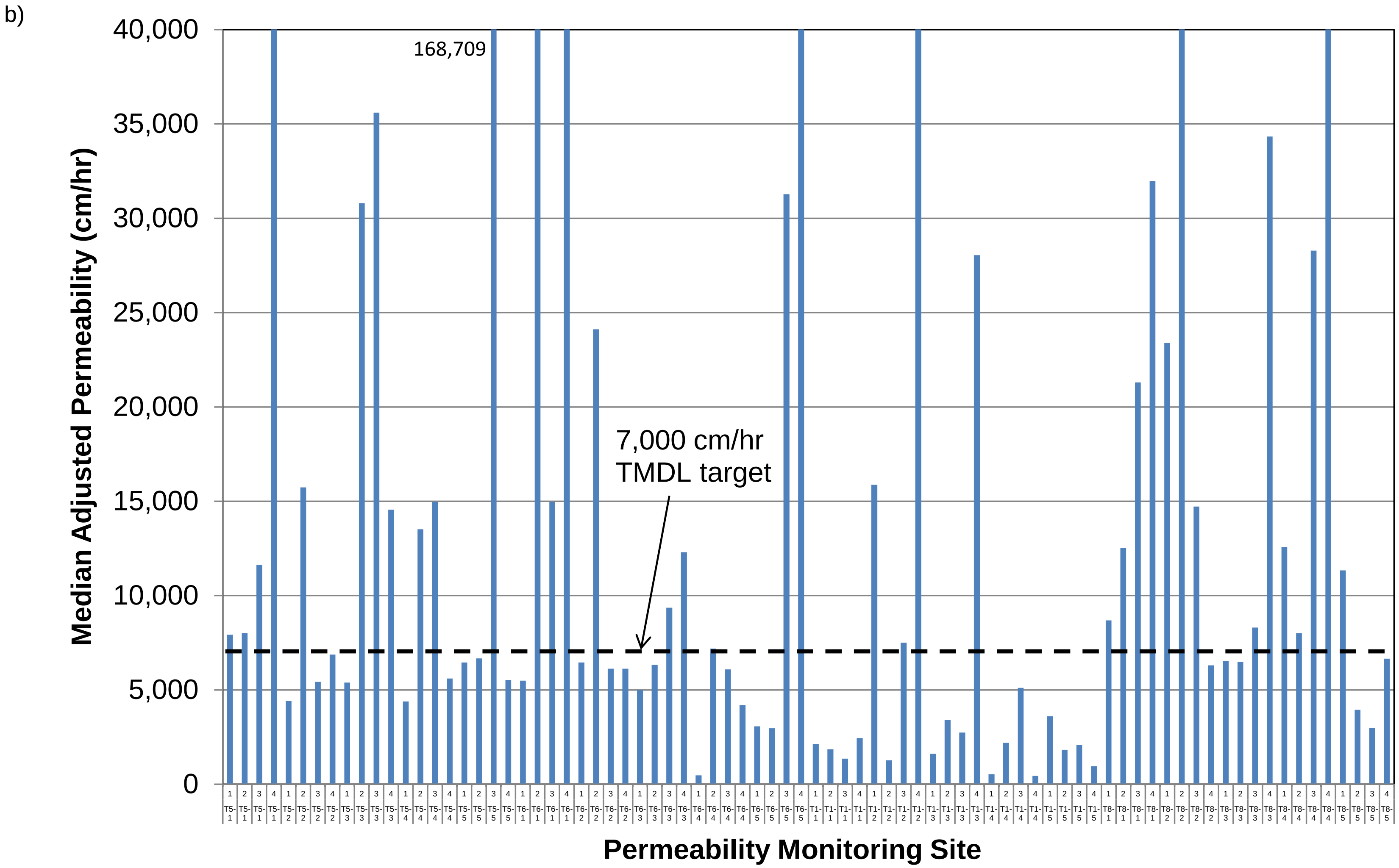


Figure 9. Permeability measurements from the mainstem (a) and tributary (b) monitoring sites. Shown in the plots are the median values of the five replicate measurements made at each artificial redd.

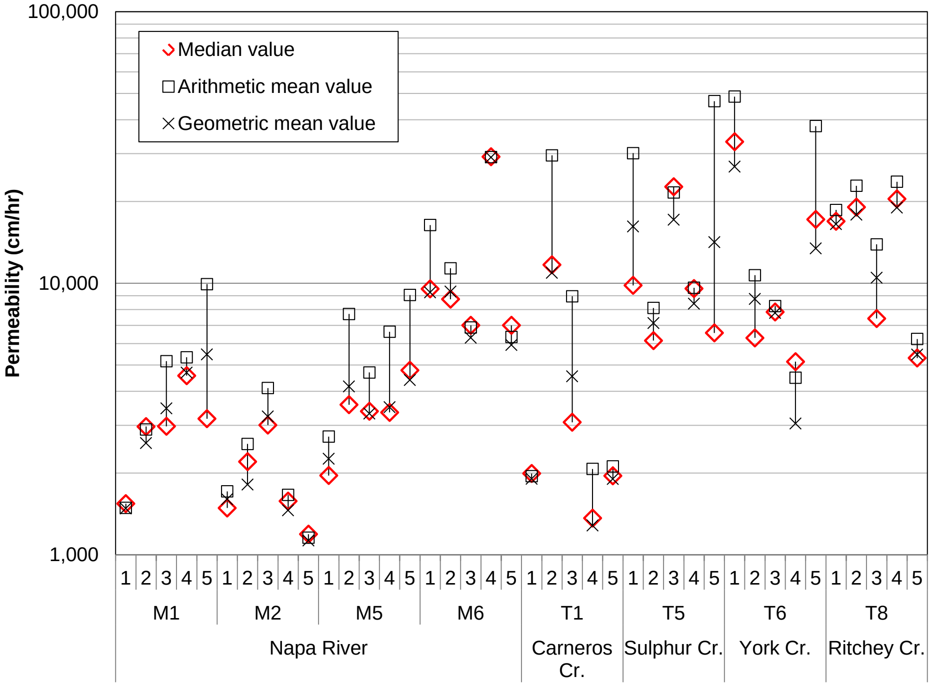


Figure 10. Three measures of the central tendency of permeability values at the monitoring sites.

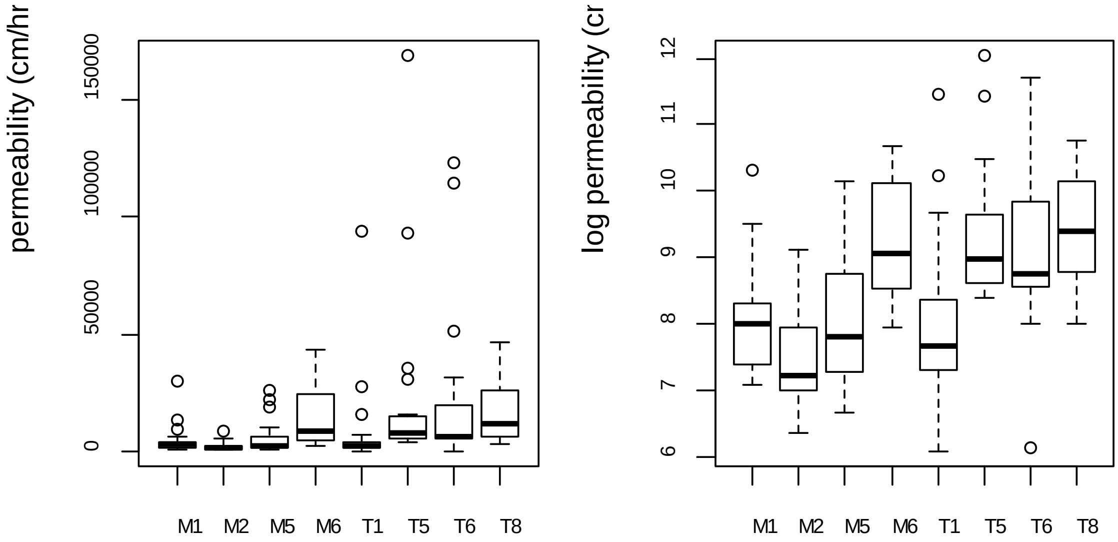


Figure 11. Box-and-whisker plots for permeability and log-permeability by monitoring reach. The boxes extend from the 1st to the 3rd quartile of the values at each reach, with the median shown as a heavy horizontal line. The log-transformed permeability values are more symmetrically distributed than the un-transformed permeability values.

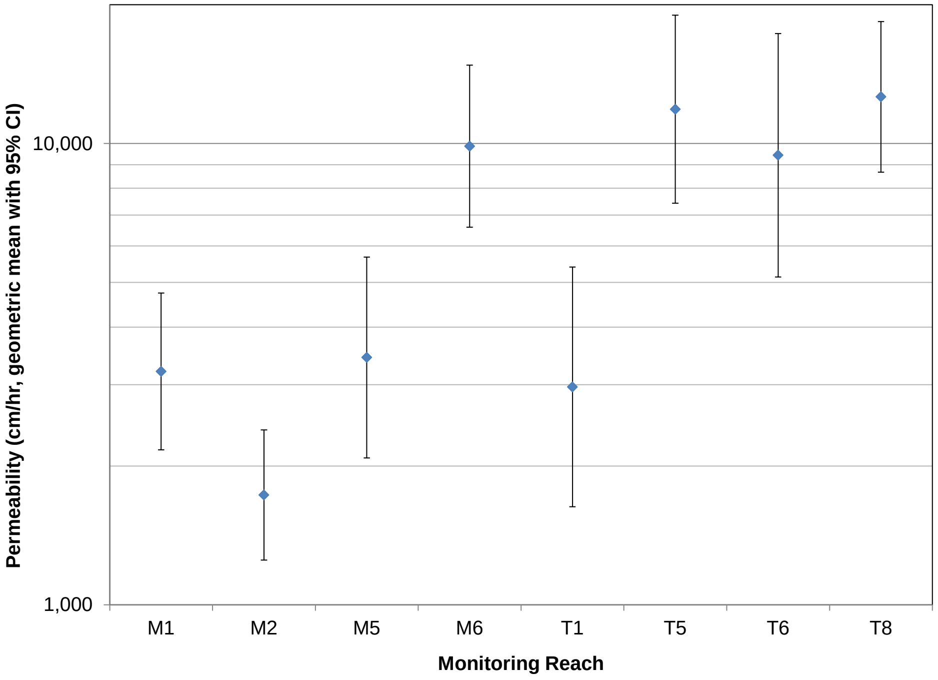


Figure 12. Geometric-mean permeability by monitoring reach, with a 95% confidence interval shown for each.

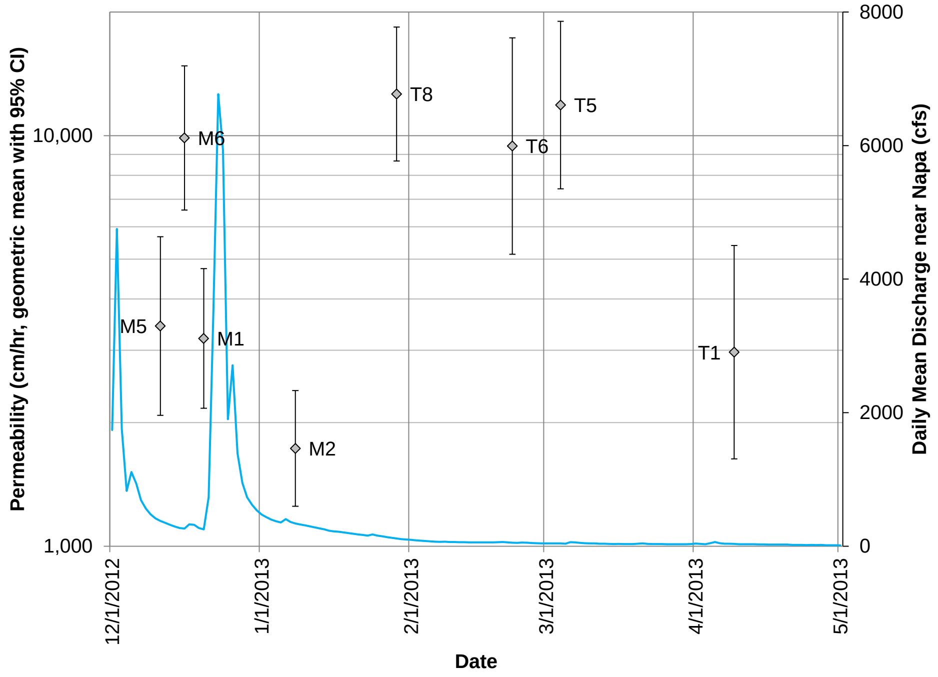


Figure 13. Comparison of timing of permeability measurements by monitoring reach with river discharge.

3.2 Streambed Scour

The scour-chain data from the streambed scour monitoring conducted at the mainstem sites are presented graphically in Figure 14 and summarized in Table 4. Overall, successful recovery of the scour-chains was poor for both recovery periods, as described above in Section 2.4. For reference, chain recovery for this type of effort should be much greater, although achieving 100% recovery is rarely possible (e.g., Nawa and Frissell 1993, Bigelow 2005). The poor recovery ultimately limits the ability to draw meaningful conclusions for scour activity throughout the monitoring reaches. Of the 40 scour-chains installed at the sites (two chains per site) only 17 were found during the first recovery period (January 10, 2013). Measurements made of these recovered chains reveal a variation of bed scour or deposition, with lengths ranging between -26 and +4 cm, where negative values represent greater chain exposure compared to initial installation (i.e., bed scour or lowering) and positive values represent less chain exposure through burial (i.e., bed aggradation). The TMDL target for mean bed scour following peak flows that equal or exceed bankfull discharge is 15 cm or less (Napolitano et al. 2009). The greater the scour depth the greater the potential for redd scour, which can cause mortality of incubating salmonid embryos. The maximum scour of 26 cm was documented at site M2-2B. There were four sites (M2-1A, M2-4B, M2-5B, M5-5B) that experienced the maximum depositional depth of 4 cm.

The second scour-chain recovery period (May 7, 14, 21, 2013) met equally poor recovery success, where only 20 chains were found, five of which were chains not found during the first recovery period (Figure 14 and Table 4). There were another five chains previously found and reset during the first recovery period, but not found during this second effort. Measurements reveal that both bed scour and deposition occurred between the first and second recovery periods. Measured lengths ranged from -28 and +35 cm, with the maximum scour documented at site M5-1A and maximum deposition documented at site M2-4A. See Section 3.4 below for discussion on potential for sediment transport at these sites.

The statistical analysis considered the scour/deposition measured during the first recovery period and the cumulative scour/deposition measured during the entire monitoring effort (Table 5). The mean observed value from the first recovery period was 4.4 cm, with a standard error of 2.1 cm. The mean observed value for the entire monitoring effort was 5.2 cm with a standard error of 3.7 cm. Assuming that the measurements from the recovered chains are representative of all installation sites, then it can be concluded that the mean depth of scour/deposition is quite confidently below the 15 cm TMDL target in both cases ($p<0.01$, for a one-sided t-test). For three of the four monitoring reaches (M1, M2, and M5), enough chains were recovered to calculate both mean and standard error. At two of these reaches (M2 and M5), the observed scour/deposition were sufficiently small that they can be confidently asserted to be below the 15 cm TMDL target.

The primary challenge encountered during the statistical analysis was the low number of recovered scour chains: only 12 chains were recovered in both recovery efforts. One consequence is that the recovery numbers are too small to permit robust reach-to-reach comparisons. Another consequence is the inability to determine with confidence whether the measurements made of the recovered chains adequately represent streambed-scour conditions at the un-recovered sites.

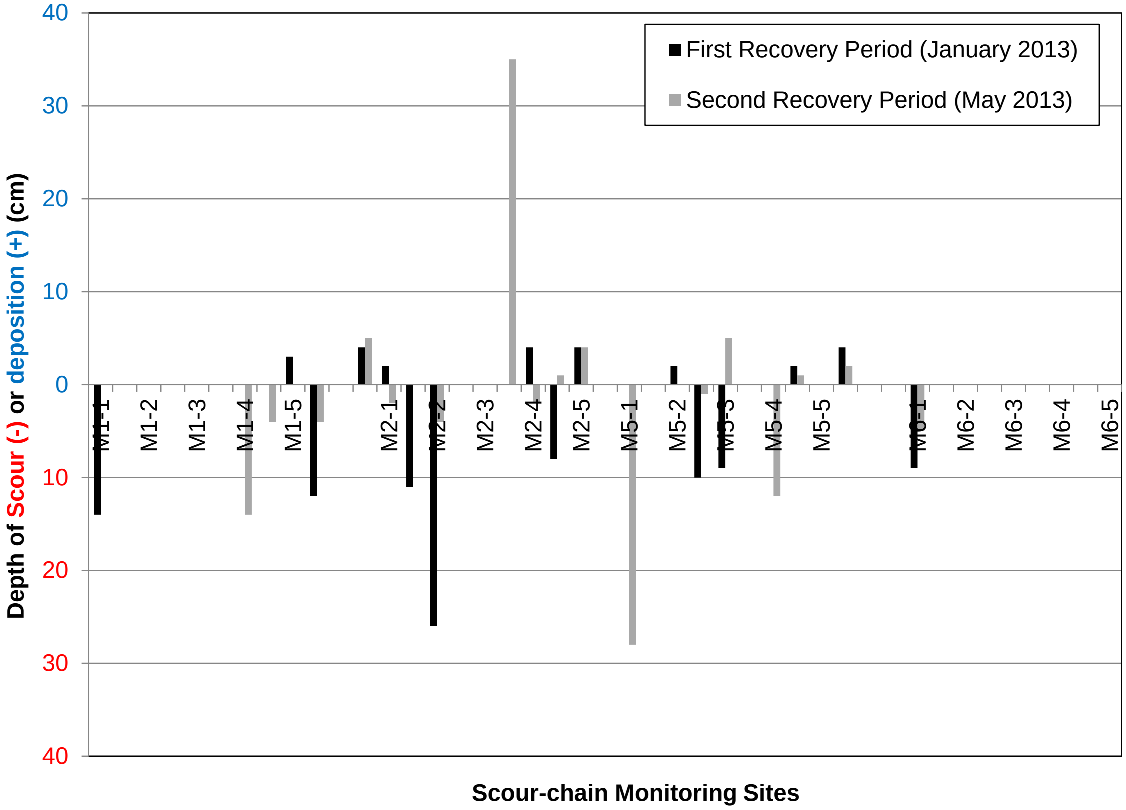


Figure 14. Measured streambed scour from the scour-chain data.

Table 4. Summary of streambed scour at the mainstem monitoring sites from the scour-chain data.

Site	Installation		First recovery effort				Second recovery effort		
	Date	Exposed length (cm)	Date	Exposed length (cm)	Scour / Deposition (cm) [a]	Reset length (cm)	Date	Exposed length (cm) [b]	Scour / Deposition (cm) [a]
M1-1A	11/27/2012	52	1/10/2013	66	-14	66	5/7/2013	66	0
M1-1B	11/27/2012	50	1/10/2013	Not found			5/7/2013	Exhumed	
M1-2A	11/27/2012	61	1/10/2013	Not found			5/7/2013	Not Found	
M1-2B	11/27/2012	68	1/10/2013	Not found			5/7/2013	Not Found	
M1-3A	11/27/2012	52	1/10/2013	Not found			5/7/2013	Not Found	
M1-3B	11/27/2012	63	1/10/2013	Not found			5/7/2013	Not Found	
M1-4A	11/27/2012	52	1/10/2013	Not found			5/7/2013	66	-14
M1-4B	11/27/2012	59	1/10/2013	Not found			5/7/2013	63	-4
M1-5A	11/27/2012	71	1/10/2013	68	3	59	5/21/2013	30 (broken)	
M1-5B	11/27/2012	58	1/10/2013	70	-12	62	5/21/2013	66	-4
M2-1A	11/27/2012	64	1/10/2013	60	4	60	5/14/2013	55	5
M2-1B	11/27/2012	61	1/10/2013	59	2	59	5/14/2013	61	-2
M2-2A	12/14/2012	43	1/10/2013	54	-11	54	5/14/2013	54	0
M2-2B	12/14/2012	48	1/10/2013	74	-26	64	5/14/2013	68	-4
M2-3A	11/27/2012	65	1/10/2013	Not found				Not Found	
M2-3B	11/27/2012	70	1/10/2013	Not found				Not Found	
M2-4A	11/27/2012	68	1/10/2013	Not found			5/14/2013	33	35
M2-4B	11/27/2012	56	1/10/2013	52	4	52	5/14/2013	54	-2
M2-5A	11/27/2012	54	1/10/2013	62	-8	62	5/14/2013	61	1
M2-5B	11/27/2012	51	1/10/2013	47	4	47	5/14/2013	43	4
M5-1A	12/10/2012	56	1/10/2013	Not found			5/7/2013	84	-28
M5-1B	12/10/2012	67	1/10/2013	Not found			5/7/2013	Exhumed	
M5-2A	12/10/2012	52	1/10/2013	50	2	50	5/7/2013	Not Found	
M5-2B	12/10/2012	49	1/10/2013	59	-10	59	5/7/2013	60	-1
M5-3A	12/10/2012	58	1/10/2013	67	-9	67	5/7/2013	62	5
M5-3B	12/10/2012	52	1/10/2013	Not found			5/7/2013	Not Found	
M5-4A	12/10/2012	42	1/10/2013	42	0	30	5/7/2013	42	-12
M5-4B	12/10/2012	42	1/10/2013	40	2	33	5/7/2013	32	1
M5-5A	12/10/2012	47	1/10/2013	Not found			5/7/2013	47	0
M5-5B	12/10/2012	52	1/10/2013	48	4	43	5/7/2013	41	2
M6-1A	12/13/2012	48	1/10/2013	Not found			5/14/2013	Not Found	

Site	Installation		First recovery effort				Second recovery effort		
	Date	**Exposed length (cm)**	**Date**	**Exposed length (cm)**	**Scour / Deposition (cm) [a]**	**Reset length (cm)**	**Date**	**Exposed length (cm) [b]**	**Scour / Deposition (cm) [a]**
M6-1B	12/13/2012	44	1/10/2013	53	-9	53	5/14/2013	58	-5
M6-2A	12/13/2012	50	1/10/2013	Not found			5/14/2013	Not Found	
M6-2B	12/13/2012	21	1/10/2013	Not found			5/14/2013	Not Found	
M6-3A	12/13/2012	48	1/10/2013	Not found			5/14/2013	Not Found	
M6-3B	12/13/2012	35	1/10/2013	Not found			5/14/2013	Not Found	
M6-4A	12/13/2012	34	1/10/2013	Not found			5/14/2013	Not Found	
M6-4B	12/13/2012	21	1/10/2013	Not found			5/14/2013	Not Found	
M6-5A	12/13/2012	21	1/10/2013	Not found			5/14/2013	Not Found	
M6-5B	12/13/2012	32	1/10/2013	Not found			5/14/2013	Not Found	

Notes:

[a] Negative values represent bed scour (i.e., more exposed chain length due to exhumation) and positive values represent deposition (i.e., less exposed chain length due to burial).

[b] “Exhumed” indicates there was visual evidence that the chain was removed from its location of installation through fluvial activity; “broken” indicates there was visual evidence that several links were broken off from the chain.

Table 5. Summary of statistical analysis results from the scour-chain data.

Reach	First recovery period (December–January)			Entire monitoring effort (December–May)		
	n	Mean chain length ±1 standard error (cm)	p	n	Mean chain length ±1 standard error (cm)	p
M1	3	7.7 ± 5.4	0.15	4	12.0 ± 2.7	0.17
M2	7	4.4 ± 4.3	0.024	6	-0.83 ± 8.8	0.067
M5	6	1.8 ± 2.5	0.0016	7	6.6 ± 4.0	0.051
M6	1	9 ± NA	NA	0	NA	NA
All	17	4.4 ± 2.1	0.000063	17	5.2 ± 3.7	0.0084

Notes:
Each p-value is for a one-sided t-test against the null hypothesis “mean scour ≥15 cm.”

3.3 Streambed Particle Size Distribution

The streambed particle size distribution data from the pebble-count surveys conducted at the mainstem sites are presented graphically in Figure 15. Select particle-size fractions (percentiles), the geometric means, and degrees of bed sorting are summarized in Table 6. In general, the sampled bed sediments exhibited a well-graded (poorly sorted) texture, with measurable sizes varying between sand (~2 mm) and coarse cobble size (~200 mm). These materials represent the spawning gravels utilized by steelhead and Chinook salmon, which are transported as bedload during high flows. Smaller size-fractions, such as silt and clay, were also present during the pilot monitoring surveys, but were not measurable with the pebble-count methodology.

Further statistical analysis of the pebble-count data reveals a general downstream-fining trend of the bed sediments from monitoring reach M2 through M6 (i.e., M2, M5, and M6). Figure 16 depicts this trend graphically based on a linear regression of the geometric mean (D_g) on a log-scale versus the upstream-to-downstream rank of reach sites (including reach M1), where the regression exhibits a significant downward trend (p=0.005). A downstream-fining trend is a natural characteristic of most coastal, fluvially dominated systems as a function of increasing drainage area, proportion of lowland area, and storage capacity with downstream-direction. Ritchey Creek joins the mainstem Napa River between monitoring reaches M1 and M2, and York and Sulphur creeks both feed into the river between reaches M2 and M5 (see Figure 5). All three of these tributary drainages have been estimated to deliver the highest proportions of sediment to the mainstem river (see Table 1). The combination of a high sediment yield and active deep-seated landsliding in the Ritchey Creek subwatershed, as stated in the Sediment TMDL Plan (Napolitano et al. 2009, Table 5), helps to explain the particle-size increase exhibited between reaches M1 and M2 (see Table 2).

Statistical t-tests between the reaches show that the geometric mean values (in log-space) at reach M2 are significantly different from reaches M5 and M6 at the 95% confidence level. No other pairwise comparisons performed, either as homoscedastic or heteroscedastic tests , were shown to be significant (Figures 17a and 17b). Similarly, t-tests between reaches show that the size-fraction finer than 8 mm at sites in reach M2 are significantly different from those in reaches M5 and M6 at the 90% confidence level, but no other pairwise comparisons were found to be significant (Figure 17c and 17d). The lack of formal significance is a product of the low number of sampling sites within each monitoring reach (n=4 or 5). The power analysis indicates that 21 pebble-count sample sites per monitoring reach would be necessary to confirm a relative difference of 10% in the geometric means (in log-space), with 95% confidence and 80% power using t-tests (two-sample, one-sided heteroscedastic), or 16 sample sites per reach at 90% confidence and 80% power.

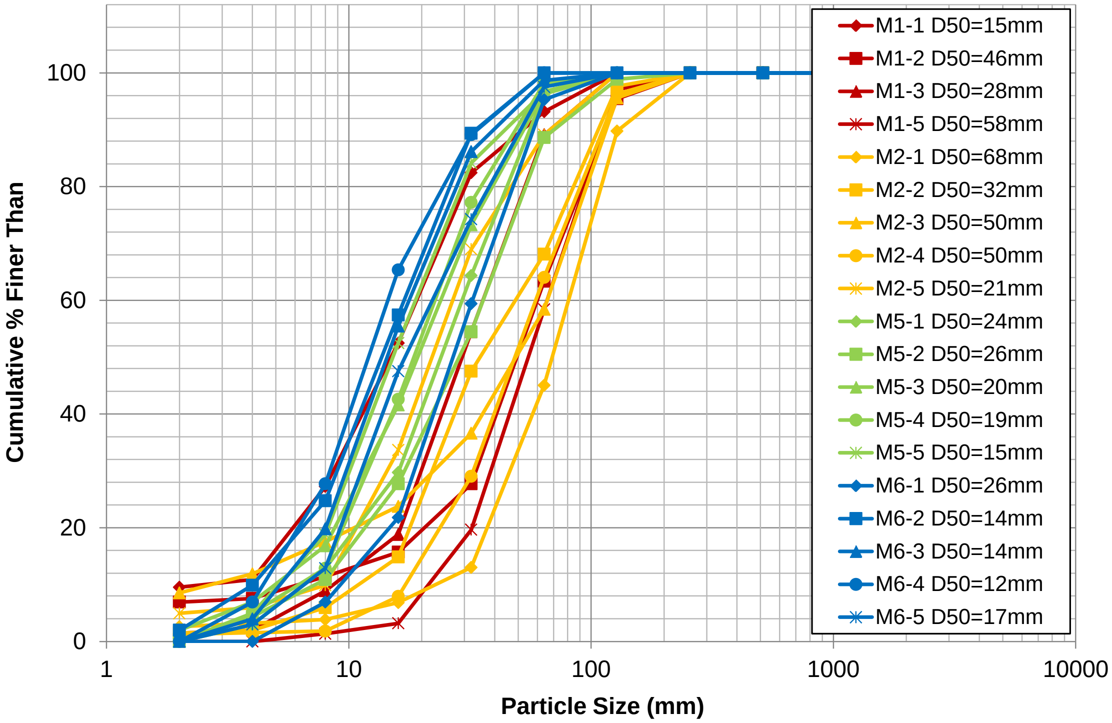


Figure 15. Particle size distributions from the pebble-count data.

Table 6. Select particle size fractions from the pebble-count data.

Site	Particle-size fractions [a] (mm)				Degree of bed sorting [b]
	D_{16}	D_{50}	D_{84}	D_g	
M1-1	5	15	38	13	2.8
M1-2	17	46	92	35	2.3
M1-3	12	28	61	26	2.3
M1-5	26	58	85	50	1.8
M2-1	39	68	121	56	1.8
M2-2	17	32	85	33	2.2
M2-3	6	50	99	30	4.1
M2-4	26	50	86	45	1.8
M2-5	12	21	46	20	2.0
M5-1	10	24	49	21	2.2
M5-2	11	26	55	24	2.2
M5-3	7	20	36	16	2.3
M5-4	9	19	38	17	2.1
M5-5	7	15	32	14	2.1
M6-1	13	26	50	24	2.0

Site	**Particle-size fractions [a] (mm)**				**Degree of bed sorting [b]**
	D_{16}	***D_{50}***	***D_{84}***	***D_g***	
M6-2	6	14	25	12	2.0
M6-3	6	14	28	14	2.2
M6-4	4	12	24	11	2.4
M6-5	9	17	38	17	2.1

Notes:

[a] Size fractions: D_{16} and D_{84} represent the particle sizes for which 16% and 84% of the distribution is finer, respectively; D_{50} represents the median particle size; and D_g represents the geometric mean of the distribution.

[b] Bed sorting describes the measure of nonuniformity of sediment mixtures (i.e., high values indicate well-graded [poorly sorted] conditions) and is computed as the geometric standard deviation: $\sigma_g=(D_{84}/D_{16})^{0.5}$ (Julien 2002).

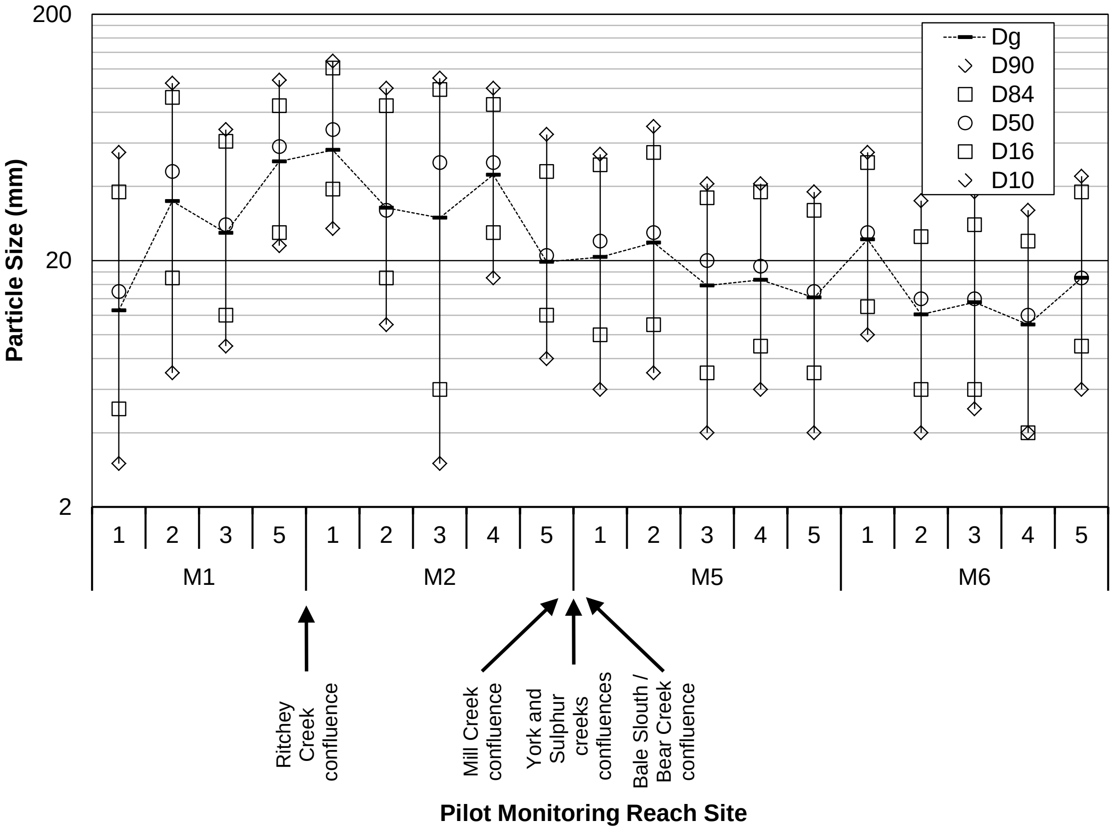


Figure 16. Particle size compositions and statistical trends from the pebble-count data.

a)

	M2	M5	M6
M1	0.52	0.17	0.086
M2		0.012	0.006
M5			0.32

b)

	M2	M5	M6
M1	0.54	0.24	0.13
M2		0.017	0.007
M5			0.32

c)

	M2	M5	M6
M1	0.46	0.67	0.37
M2		0.067	0.055
M5			0.32

d)

	M2	M5	M6
M1	0.50	0.72	0.39
M2		0.078	0.058
M5			0.32

Figure 17. Pair-wise comparison of particle-size distributions between the monitoring reaches. Comparisons of geometric means with two-tailed homoscedastic (a) and heteroscedastic (b) tests are presented, as are comparisons of the size-fraction finer than 8 mm with two-tailed two-tailed homoscedastic (c) and heteroscedastic (d) tests.

3.4 Channel Surveys

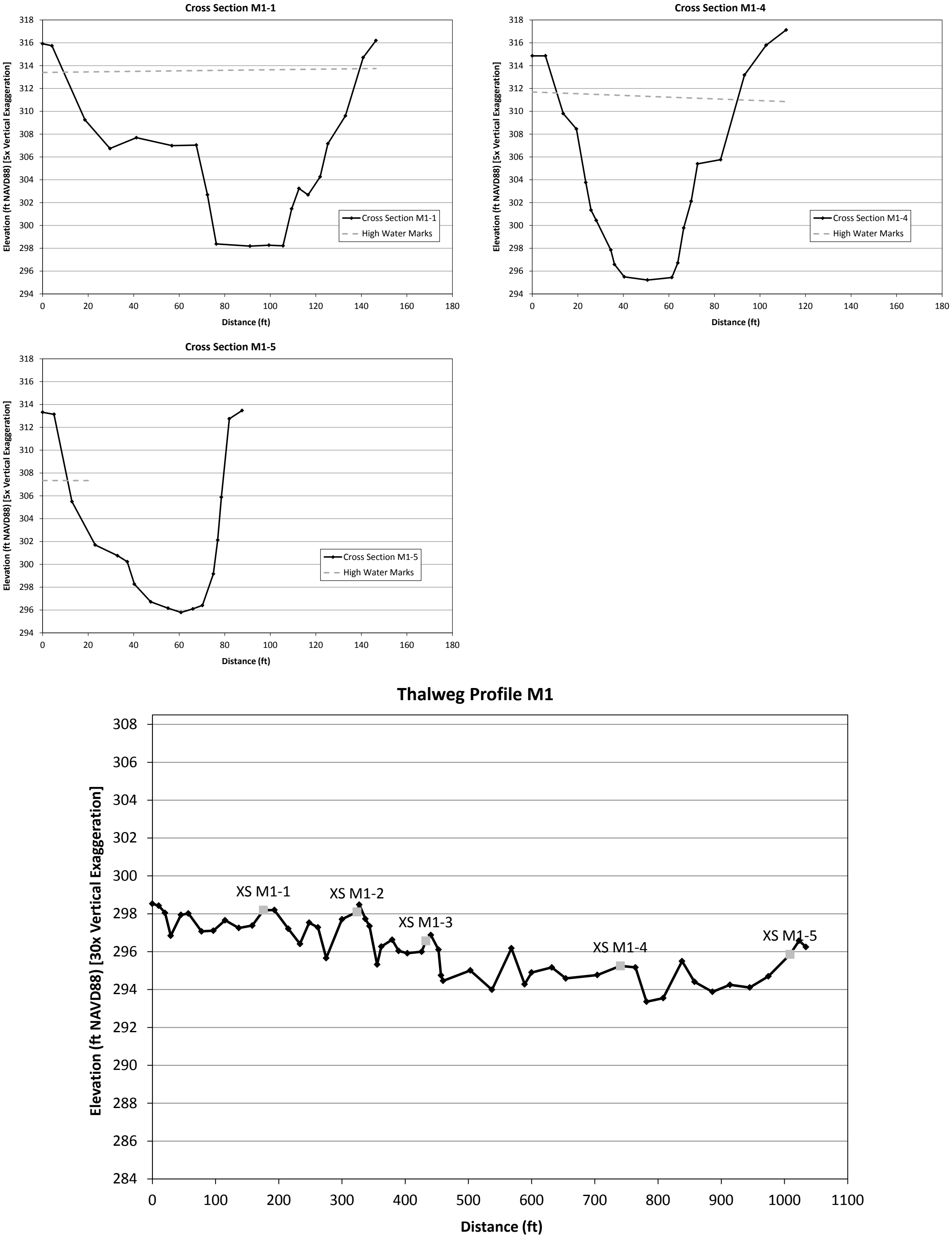
The channel survey data representing the cross-section and thalweg profiles are presented graphically in Figures 18 through 21 below. Channel bed slopes at the mainstem sites are summarized in Table 7, which includes three variations to the data presentation:

- Sub-reach contributing bed slope represents the absolute slope between the site location and the next upstream site. This variable is assumed to represent water-surface slope approaching the site cross-section at high-flow conditions. In the case of sites positioned at the upper end of a reach, the absolute slope was taken between the site and the survey origin for that reach. The distance over which the slopes were considered, therefore, ranged between 50 and 500 feet. Typically, stream-bed slope is considered over a distance equal to at least 10 or 20 times the bankfull width; however, insufficient survey data was available to employ this approach at sites having large bankfull widths (e.g., M1-1, M2-1, and M5-1) (see below).
- Local bed slope at the site (backward computed) represents the slope between the site (or cross-section) location and the next upstream survey station (at a topographic inflection point) along the thalweg-profile survey (i.e., ~10–20 ft approach distance). This variable is not assumed to represent the water-surface slope during the high-flow event because its resolution is fine, and most computed values reveal negative values based on the position of the cross-sections being situated at pool tail-outs where the bed elevation locally rises. The negative values where corresponding to the tail-out morphology, however, indicate potential for sediment deposition.
- Local bed slope at the site (forward computed) represents the slope between the site location and the next downstream station along the thalweg-profile survey (i.e., ~10–20 ft departure distance). This variable is also not assumed to represent the water-surface slope during the high-flow event for the same reasons given above.

Bed slopes vary considerably from site to site indicating the topographic complexity present along the length of the surveyed reaches (M1, M2, and M5) (Figures 18 through 21; and Table 7). Mean bed-slope values were found to range between 0.003 and 0.005 at the sub-reach scale (i.e., sub-reach contributing bed slope), and between -0.039 and 0.012 at the local scale (i.e., local bed slope at the site [backward and forward computed]).

Channel dimensions at the surveyed cross-sections are summarized in Table 8. These values are based on channel widths and depths relative to the surveyed high-water marks, indicative of a “bankfull” flow condition (i.e., flood recurrence interval of 1.5–2-yr). Channel widths range between 21 and 125 m, with the greatest value at site M5-1 being quite distinct from the other surveyed cross-sections. Mean channel depths varied between 1.7 and 4.3 m; the shallowest mean depth surveyed at site M5-1. The proportion of channel width to depth—a qualitative indicator for channel “wideness”—at all but one site was below 20, indicating a generally “narrow” active channel. The one exception to this trend was exhibited at site M5-1, which had a substantially greater width:depth value of 75, indicating that that sub-reach exhibits a “very wide” active-channel morphology. It is important to note here, however, that such a large width:depth ratio at site M5-1 is likely an over-estimate given that channels with such a value typically exhibit a braided-channel morphology, which is not observed at this site. A possible cause for this high value is an over-estimate of the high-water mark elevation. If, instead, the high-water mark elevation had been estimated to be lower and level with the surface of the inset floodplain surface on the right-bank side of the channel (see, horizontal surface visible on the right-hand side of the upper left panel of Figure 20) at an elevation of about 141 ft (NAVD88), the adjusted width:depth ratio would be closer to 50—a value still much greater than values estimated at the other sites.

The other channel dimensions presented in Table 8 include cross-sectional area, wetted perimeter, and hydraulic radius, all of which were used to estimate local hydraulic conditions under high-flow conditions. Computed shear stress along the channel boundary, based on the sub-reach contributing bed slope (i.e., proxy for water-surface slope for the high-flow event), mostly varied between ~20 and ~80 Pa. Once again, the outlier site was M5-1, having a value of ~200 Pa, which was primarily a function of its sub-reach contributing slope (S=0.019) being about an order of magnitude greater than at the other sites. From the estimated shear stress, a theoretical median particle size (D_{50}) of the mobilized fraction of bed material during the high-flow event was calculated at applicable cross-sections: values mostly ranged in the gravel-sized fraction. Two exceptions to this trend, however, were computed at sites M2-5 and M5-1 with D_{50} values in the cobble-boulder range. The potential for bed mobility during the high-flow event was estimated through a comparison with the field-measured D_{50}, which suggests a mobile bed could potentially occur at all applicable sites, except for M2-4. Evidence of a mobile bed during the monitoring period is provided by the scour-chain data, where both bed scour and deposition was observed (see Section 5.2 above). The site having the greatest scour depth, M5-1A (see Table 4 above), also had the highest predicted bed mobility potential from the shear-stress computations (see Table 8). Similarly, the site having the greatest depositional (chain-burial) depth, M2-4A, was predicted to have no transport potential.


Cross Section M1-1

Cross Section M1-4

Cross Section M1-5

Thalweg Profile M1

Figure 18. Cross-section (top three panels) and thalweg-profile (bottom panel) data plots for monitoring reach M1. High water marks in cross-sectional view shown in dashed, grey-colored lines where data was available. Cross-section view is towards downstream and thalweg-profile view is generally eastward, with flow moving from left to right.

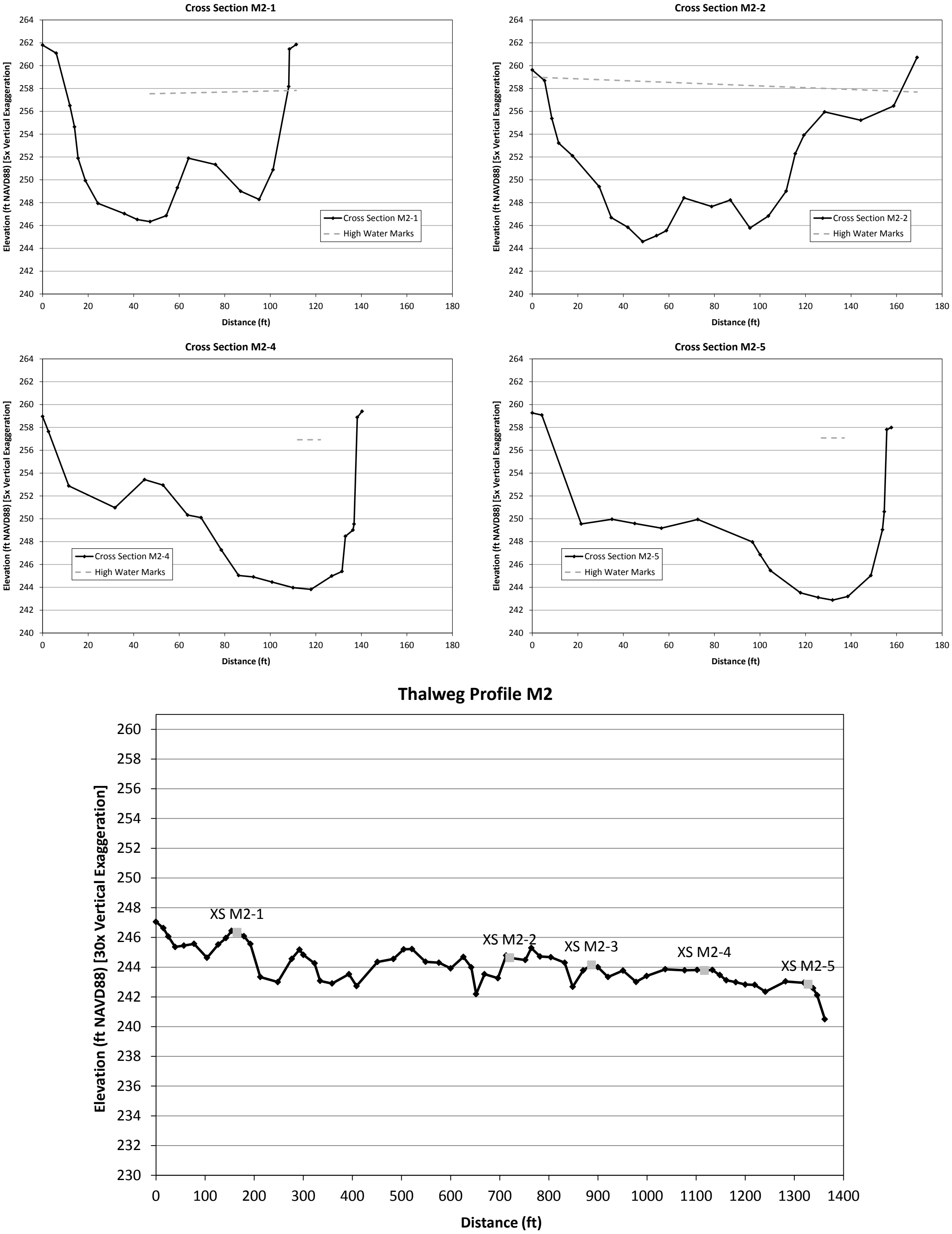


Figure 19. Cross-section (top four panels) and thalweg-profile (bottom panel) data plots for monitoring reach M2. High water marks in cross-sectional view shown in dashed, grey-colored lines where data was available. Cross-section view is towards downstream and thalweg-profile view is generally eastward, with flow moving from left to right.

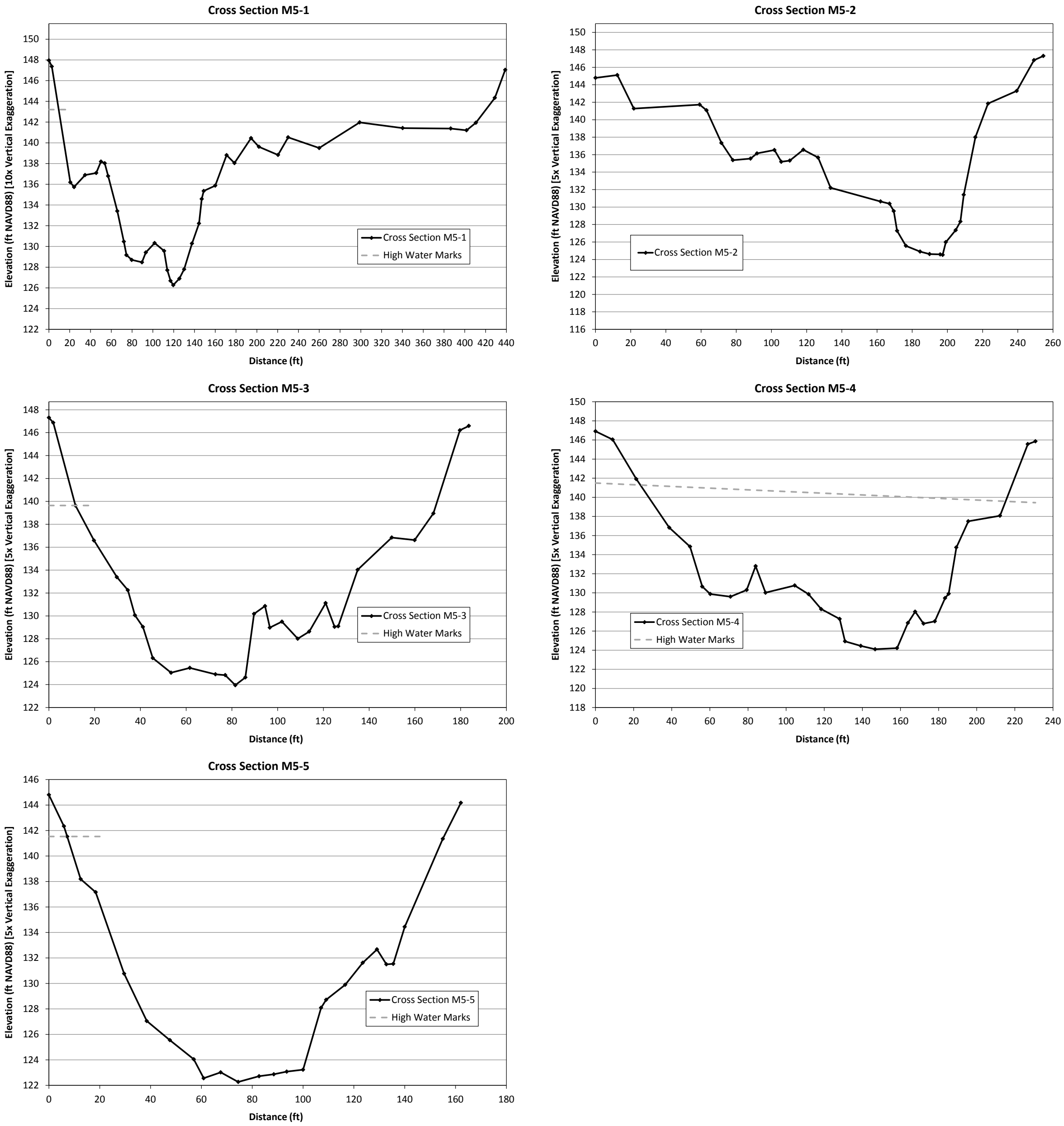


Figure 20. continued on next page

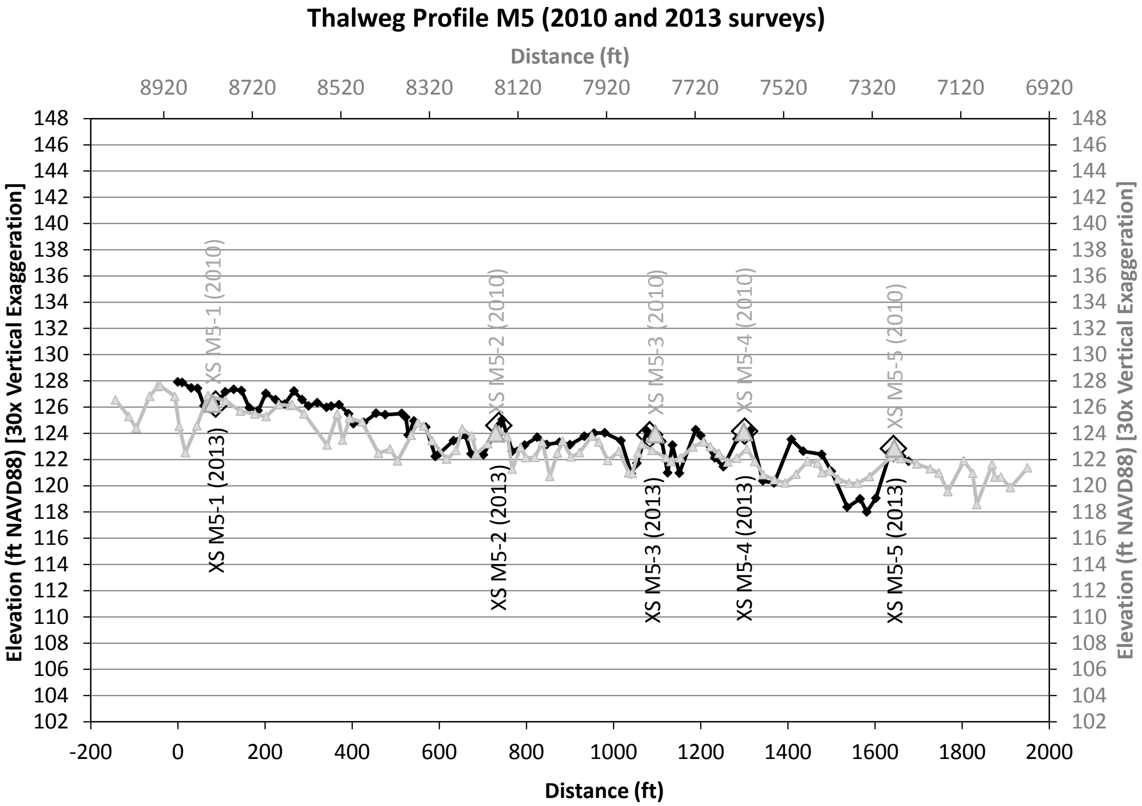


Figure 20. Cross-section (top five panels) and thalweg-profile (bottom panel) data plots for monitoring reach M5. Thalweg-profile from 2010 survey is displayed atop the 2013 data (bottom panel) for visual comparison. High water marks in cross-sectional view shown in dashed, grey-colored lines where data was available. Cross-section view is towards downstream and thalweg-profile view is generally eastward, with flow moving from left to right.

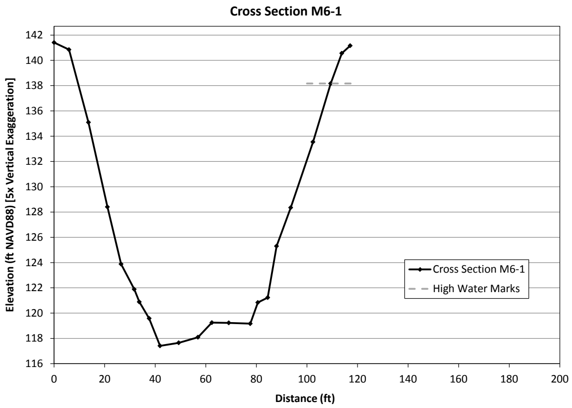


Figure 21. Cross-section data plot for monitoring reach M6. High water marks in cross-sectional view shown in dashed, grey-colored lines where data was available. Cross-section view is towards downstream.

Table 7. Bed slope data at the surveyed pilot monitoring sites.

Site	Bed slope		
	Sub-reach contributing bed slope [a]	**Local slope at site (backward computed)** [b]	**Local slope at site (forward computed)** [c]
M1-1	0.002	-0.046	-0.001
M1-2	0.001	-0.016	-0.109
M1-3	0.014	-0.085	-0.039
M1-4	0.004	-0.013	0.003
M1-5	-0.002	-0.034	-0.051
M1 mean values	*0.004*	*-0.039*	*-0.039*
M2-1	0.004	0.009	0.018
M2-2	0.003	0.020	0.005
M2-3	0.003	-0.022	0.011
M2-4	0.001	0.002	-0.002
M2-5	0.004	0.012	0.026
M2 mean values	*0.003*	*0.004*	*0.012*
M5-1	0.019	-0.026	-0.042
M5-2	0.003	-0.065	-0.056
M5-3	0.002	0.051	0.018
M5-4	-0.001	-0.034	-0.004
M5-5	0.004	-0.034	0.031
M5 mean values	*0.005*	*-0.022*	*-0.011*

Notes:

[a] Sub-reach contributing bed slope is represented by the total slope between the site location and the next upstream site or survey origin.

[b] Local slope at the site (backward computed) is represented by the slope between the site location and the next *upstream* station along the thalweg-profile survey.

[c] Local slope at the site (forward computed) is represented by the slope between the site location and the next *downstream* station along the thalweg-profile survey.

Table 8. Channel dimensions and estimated hydraulic conditions relative to high water mark at the surveyed pilot monitoring sites.

Site [a]	Channel dimensions and estimated hydraulics at high water mark									
	Width (m) [b]	**Mean depth (m) [c]**	**Width:depth ratio [d]**	**Cross-sectional area (m^2) [e]**	**Wetted perimeter (m) [f]**	**Hydraulic Radius (m) [g]**	**Sub-reach contributing bed slope [h]**	**Shear stress (Pa) [i]**	**Critical D_{50} (mm) [j]**	**Bed-mobility potential during high-flow event [k]**
M1-1	40	2.6	15	105	66	1.6	0.002	30	41	Transport
M1-4	24	3.0	8.0	73	56	1.3	0.004	55	74	NA
M1-5	21	2.4	8.6	50	38	1.3	-0.002	NA	NA	NA
M2-1	30	2.5	12	73	48	1.5	0.004	65	88	Transport
M2-2	48	2.4	20	116	75	1.5	0.003	48	65	Transport
M2-4	41	2.4	17	100	66	1.5	0.001	21	29	No Transport
M2-5	45	2.8	16	126	68	1.8	0.004	81	109	Transport
M5-1	125	1.7	75	209	181	1.2	0.019	216	293	Transport
M5-3	48	2.7	18	129	94	1.4	0.002	26	35	Transport
M5-4	59	2.9	20	170	106	1.6	-0.001	NA	NA	NA
M5-5	45	3.8	12	171	101	1.7	0.004	60	81	Transport
M6-1	30	4.3	7.1	131	87	1.5	NA	NA	NA	NA

Notes:

All survey measurements converted from their English unit system values to the metric unit system for this table.

[a] Only sites with surveyed cross-sections and high-water marks are presented here.

[b] Width (W) computed as the horizontal distance between high-water mark elevation intercepts on cross-section profile.

[c] Mean depth (H) computed as the width-weighted average depth across the cross-section.

[d] Width to depth ratio computed as quotient of width and mean depth of the cross-section.

[e] Cross-sectional area (A_x) computed as product of cross-section width and mean depth.

[f] Wetted perimeter (P_w) computed as continuous slope-distance along cross-section perimeter.

[g] Hydraulic radius (R_h) computed as quotient of cross-sectional area and wetted perimeter.

[h] Sub-reach contributing bed slope (S) is assumed to represent the high-water-surface slope, and is computed as the total slope between the site location and the next upstream site or survey origin (see Table 7 above).

[i] Shear stress (τ_c) at the cross-section boundary computed from equation: $\tau_c=\rho g R_h S$, where ρ is density of water (1000 kg m^{-3}), g is acceleration due to gravity (9.81 m s^{-2}), R_h is hydraulic radius, and S is the sub-reach contributing bed slope.

[j] Critical D_{50}, or the median size of mobilized bed sediments at estimated threshold of motion particle at high water in the cross-section, computed using Shields' equation for incipient motion: $D_{50}= \tau_c / [(\rho_s-\rho)g\tau^*_c]$, where ρ_s is density of sediment particles and τ^*_c is the Shields number (assumed to 0.047 for gravel-dominated mixed loads [Wong and Parker 2006]).

[k] Bed-mobility potential based on comparison between critical D_{50} (this table) and the measured D_{50} (see Table 6 above), where "Transport" is estimated when critical D_{50} > measured D_{50} indicating the channel bed was potentially mobile during the high-flow event, and "No transport" when critical D_{50} < measured D_{50} indicating the channel bed was potentially *not* mobile during the high-flow event.

4 RECOMMENDATIONS

The following presents recommendations for modification of monitoring and analysis methods of the long-term Napa River sediment TMDL monitoring program. The purpose of the recommendations is to better achieve monitoring goals during future efforts. The recommendations listed below are based on the evaluation of methods and results of the pilot monitoring effort, as summarized above, and may be subject to additional refinement following future efforts.

4.1 Sample Locations

- Spawning habitat in the mainstem Napa River extends several miles downstream of the downstream-most mainstem reach sampled during the pilot monitoring effort (M6). Long-term monitoring at downstream reaches M7 and M8 in the mainstem Napa River should provide data on the relative importance of shear stress versus sediment supply and the influence of these factors on permeability and scour.
- Long-term monitoring at mainstem locations in the lower portion of the watershed could also provide valuable data to help evaluate influence of sediment and runoff from other tributaries (e.g., Dry Creek) on channel dynamics and sediment conditions relative to TMDL targets. Addition of new monitoring reaches could be balanced by omission of previously monitored reaches in order to conserve level of effort and available budget.

4.2 Sample Size and Frequency

- A power analysis, or test of statistical confidence, based on previous gravel permeability data from the Napa River watershed (Napolitano et al. 2009) was used to determine that 20 gravel permeability sample sites per reach is likely an appropriate sample size to ensure a reasonable degree of confidence in detecting change over time (Stillwater Sciences 2012).
- The minimum sample size determination was verified for permeability sampling via analysis of the pilot permeability monitoring data. The power analysis found that, with 18 samples per reach, differences in log-permeability of 10% (0.86) or more can be detected between reaches, with 95% confidence and 80% power. Analysis of the pilot permeability data indicates that the sample size was sufficient to statistically distinguish the reach-aggregated values from the TMDL target, particularly when assessing non-compliance (i.e., sites below the target).
- Effectively assessing TMDL compliance (i.e., sites above the target) for gravel permeability could be further resolved for reaches M6 and T6 by using one-sided tests or by relaxing the performance criterion (e.g., lowering to 90% confidence). Little else could be done to improve the power of the tests because the widths of the confidence intervals scale as the square root of the number of samples, which would require large increases in sampling effort to realize fairly small reductions in uncertainty. The limiting factor, thus, is the high intrinsic variability in local gravel permeability as is common in similar river systems.
- Analysis of the pilot permeability data to compare the permeability measurements with river-discharge timing failed to discern an effect of either discharge or timing (i.e., before or after high flow events) on permeability. Nevertheless, future permeability monitoring

should occur at all sites around the same time to avoid potential influences that could result from the unpredictable timing of flow and sediment transport events.

- A minimum sample size could not be determined for bed-scour monitoring due to poor recovery of the scour chains. Reassessment of the minimum sample size is therefore recommended during future monitoring efforts until subsequent statistical analyses can adequately evaluate this study question. The future effort(s) should collect at least the same number of samples per reach as originally attempted in this pilot monitoring effort (2 installations/site x 5 sites/reach x 4 mainstem reaches).
- Limited ability to assess statistical significance of differences in bed texture between reaches is due to the low number of sampling sites within each monitoring reach (n=4 or 5). More pebble-count samples would be required to better tease out differences in bed texture throughout the monitoring reaches. Power analysis indicates that 21 pebble-count sample sites per monitoring reach would be necessary to confirm a relative difference of 10% in the geometric means (in log-space), with 95% confidence and 80% power using t-tests (two-sample, one-sided heteroscedastic), or 16 sample sites per reach at 90% confidence and 80% power.
- Per the recommendations in the Sediment TMDL Plan, monitoring efforts will occur once every 2–5 years for approximately 10–20 years. The duration of the monitoring period should be long enough (e.g., 2–3 yrs) to maximize chances of monitoring during a bankfull flow, which is the target flow for monitoring.
- The ultimate monitoring frequency and duration will be driven by several factors including stream flow dynamics (i.e., the presence of appropriate flows during selected monitoring years) and the time and data necessary for attaining defined numeric targets.

4.3 Gravel Permeability

- Other than the observations and recommendations above related to permeability sample size and timing, there are no additional recommendations for gravel permeability monitoring. No problems were encountered with field methods or equipment.

4.4 Streambed Scour

- As described in Section 2.1.2, installation of scour beads was not successful due to equipment failure. The continued use of scour chains rather than scour beads is recommended for future monitoring.
- The primary challenge with scour-chain monitoring was successful retrieval of the chains. A metal detector aided in recovery of unexposed chains, but most of the chains were non-magnetic stainless steel and, accordingly, could not be easily located by the metal detector. To aid in recovery of scour chains for future monitoring efforts, magnetic steel chains should instead be used. In addition, the location of each chain should be georeferenced as accurately as possible, ideally using a survey-grade GPS unit, at the time of installation.
- The light-duty “duckbill” anchor system initially used to install scour chains proved inadequate for coarse bedded reaches. Although the duckbill anchors held well once driven into the substrate, the driving rod was too thin to withstand the pounding force of the hammer and lasted only 8–10 installations. During the subsequent installations a larger, hardened steel duckbill anchor was installed with a substantially heavier driving rod, which

worked very well. The larger, hardened steel duckbill anchor is recommended for all future installations.

- The first effort to retrieve scour chains occurred on January 10, 2013, at which time only 17 of the 40 scour chains were located, due primarily to the poor visibility encountered under high, albeit non-flood, streamflow conditions. Future retrieval efforts for scour chains should be conducted when water clarity is good—ideally under low flow conditions.

4.5 Streambed Particle-Size Distribution

- There were no problems encountered with field methods or equipment during the pebble-count measurements and, therefore, no changes to the current methodology are recommended. A greater number of measurements per site, however, are recommended (see Section 4.2 above).
- In addition to performing pebble-count surveys, mapping of sedimentary facies within the bankfull channel should be undertaken to further assess bed texture in the immediate vicinity of the mainstem monitoring sites. As originally proposed in the Monitoring Plan, a sediment facies map is intended to depict areas, or patches, of similar particle-size distribution and should be linked directly with the pebble-count measurements. Combined, these measurements would provide area-weighted particle-size distributions that can then be used to estimate reach-average size distribution—an important parameter that can improve estimates of sediment-transport capacity at the reach-scale (Buffington and Montgomery 1999). Common protocol recommends characterizing reach-scale bed-texture over one riffle-pool sequence, which typically equals about 5–7 channel widths in coastal stream (Bunte and Abt 2001). Future monitoring efforts should strive to map sediment facies types along with additional pebble-count measurements over at least one riffle-pool sequence associated with each of the mainstem monitoring sites to the extent feasible and within available budgetary constraints.

4.6 Channel Surveys

- Channel surveys of site cross-sections and reach-scale thalweg profiles were performed at most sites following the high winter flows and collection of most other field data. These surveys serve as a baseline for subsequent surveys, which again should commence following high winter flows as part of future monitoring efforts. There were no problems with field methods or equipment during the channel surveys and, therefore, no changes to the current methodology are recommended. Future efforts are thus recommended to re-survey cross-sections, high-water marks, and thalweg profiles at all 20 mainstem sites.
- Local channel geometries under the season's approximate high-flow conditions were used, together with associated shear stress estimated along the channel boundary, to calculate a theoretical median particle size (D_{50}) of the mobilized fraction of bed material during the high-flow event. The potential for the bed material to become mobilized was assessed by comparing the theoretical D_{50} with the pebble-count D_{50}. While this cursory exercise provided an insightful understanding of transport conditions at several of the sites, more comprehensive and accurate predictions of sediment-transport potential at all sites could further aid understanding of redd-scour processes along a greater extent of the river. This could require considering other possible flood magnitudes (e.g., re-rerun shear-stress calculations under different flow depths within the surveyed extent of the cross-section), improving resolution of the local water-surface slope of the high-flow event (e.g., survey

high-flow marks upstream and downstream of cross-section), and/or attributing the surveyed high-flow marks to a known high-flow event with greater confidence (e.g., confirm timing of high-flow marks through repeat site visits).

4.7 Level of Effort

The following tables briefly summarize an estimate of the anticipated level of effort required to conduct future monitoring efforts in accordance with the Monitoring Plan (Appendix A) and the recommendations stated above. Future monitoring of gravel permeability in mainstem and tributary reaches and redd scour in mainstem reaches should occur at least once every 2–3 years in accordance with the adopted Basin Plan amendment (San Francisco Bay RWQCB 2009). The estimated level of effort is provided separately for mainstem and tributary reaches in Tables 9 and 10, respectively, with each reach assumed to have 5 sites.

Additional efforts to monitor bed texture changes via pebble-count measurements and sediment facies mapping, and to document channel bed topography changes via cross-section and thalweg-profile surveys, should occur at the mainstem reaches during at least every other monitoring effort. The estimated level of effort to conduct this additional monitoring in mainstem reaches is provided in Table 11.

For all efforts, it is assumed that field work would be conducted by Napa RCD and subsequent analysis and reporting conducted by Stillwater Sciences. Effort estimates in the three tables below are on a per-reach basis, thus the total effort required to conduct monitoring for any given effort can be determined by multiplying the effort in each table by the number of reaches monitored.

Table 9. Summary of anticipated level of effort required to conduct future monitoring efforts on a 2–3 year basis per mainstem reach.

Stage of monitoring effort	Activity	RCD staff hours	Stillwater staff hours	Total hours
Preparation	Secure site access with landowners	4	0	4
	Service field equipment and construct new scour chains	2	0	2
Pre-season	Permeability measurements at 20 locations (4 per site)	12	0	12
	Install 10 scour chains (2 per site)	12	0	12
Mid-season	Revisit and reset scour chains once mid-season	12	0	12
Post-season	Recover scour chains	12	0	12
Analysis	Field data entry and QA	6	0	6
	Data compilation, reduction, and review	0	2	2
	Data analysis and statistics	0	3	3
	Reporting	1	4	5
Total level of effort (hours) per mainstem reach:		**61**	**9**	**70**

Table 10. Summary of anticipated level of effort required to conduct future monitoring efforts on a 2–3 year basis per tributary reach.

Stage of monitoring effort	Activity	RCD staff hours	Stillwater staff hours	Total hours
Preparation	Secure site access with landowners	4	0	4
	Service field equipment	2	0	2
Pre-season	Permeability measurements at 20 locations (4 per site)	12	0	12
Analysis	Field data entry and QA	4	0	4
	Data compilation, reduction, and review	0	2	2
	Data analysis and statistics	0	2	2
	Reporting	1	4	5
Total level of effort (hours) per tributary reach:		**23**	**8**	**31**

Table 11. Summary of anticipated level of effort required to conduct *additional* data collection during every other monitoring effort per mainstem reach.

Stage of monitoring effort	Activity	RCD staff hours	Stillwater staff hours	Total hours
Preparation	Service field equipment	2	0	2
Pre-season	Pebble counts at 5 sites (4–5 per site)	32	0	32
	Sediment facies mapping at 5 sites	10	0	10
Mid-season	Observe high-water marks once during target high flow event	2	0	2
Post-season	Survey cross-sections at 5 sites; survey high-flow marks	18	0	18
	Survey thalweg profile	10	0	10
Analysis	Field data entry and QA	4	0	4
	Data compilation, reduction, and review	0	2	2
	Data analysis and statistics	0	3	3
	Reporting	1	2	3
Total level of effort (hours) per mainstem reach:		**79**	**7**	**86**

5 REFERENCES

Barnard, K., and S. McBain. 1994. Standpipe to determine permeability, dissolved oxygen, and vertical particle size distribution in salmonid spawning gravels. Fish Habitat Relationships Technical Bulletin. No. 15. USDA Forest Service.

Bigelow, P. E. 2005. Testing and improving predictions of scour and fill depths in a northern California coastal stream. River Research and Applications 21: 909–923.

Buffington, J. M. and D. R. Montgomery. 1999. A procedure for classifying textural facies in gravel-bed rivers. Water Resources Research 35: 1,903–1,914.

Bunte, K. and S. R. Abt. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. U.S. Forest Service, General Technical Report RMRS-GTR-74.

CGS (California Geological Survey). 2010a. Fault activity map of California. Scale 1:750,000. Available at: http://www.conservation.ca.gov/cgs/cgs_history/Pages/2010_faultmap.aspx [Accessed July 20, 2013].

CGS. 2010b. Geologic map of California. Scale 1:750,000. Available at: http://www.conservation.ca.gov/cgs/cgs_history/Pages/2010_geologicmap.aspx [Accessed July 20, 2013].

Garza, J. C. and E. D. Crandall. 2013. Genetic analysis of Chinook salmon from the Napa River, California. Unpublished report prepared by Fisheries Ecology Division, NMFS Southwest Fisheries Science Center and Institute of Marine Sciences, University of California, Santa Cruz.

Grossinger, R. 2012. Napa Valley historical ecology atlas: exploring a hidden landscape of transformation and resilience. University of California Press; Berkeley, California.

Hearn, Jr., B. C., R. J. McLaughlin, and J. M. Donnelly-Nolan. 1988. Tectonic framework of the Clear Lake basin, California. In Late Quaternary Climate, Tectonism, and Sedimentation in Clear Lake, Northern California Coast Ranges, Geological Society of America, Special Paper 214: 9–20.

Julien, P. Y. 2002. River mechanics. Cambridge University Press, United Kingdom.

Kondolf, G. M. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129: 262–281.

Leidy, R. A., G. S. Becker, and B. N. Harvey. 2005. Historical distribution and current status of steelhead/rainbow trout (*Oncorhynchus mykiss*) in streams of the San Francisco Estuary, California. Center for Ecosystem Management and Restoration, Oakland, California.

Montgomery, D. R., and J. M. Buffington. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Report No. TFW-SH10-93-002. Prepared by Department of Geological Sciences and Quaternary Research Center, University of Washington, Seattle for SHAMW Committee of the Timber/Fish/Wildlife Agreement, Washington Department of Natural Resources, Olympia.

Napa County RCD (Resource Conservation District). 1997. Napa River Watershed owner's manual. 5th Printing. Napa County Resources Conservation District, Napa, California.

Napa County RCD. 2009. Southern Napa River Watershed Plan. Prepared for the California Department of Fish and Game.

Napa County RCD. 2012. Napa River steelhead and salmon monitoring program: 2011–2012 season. Report prepared by Jonathan Koehler and Paul Blank, Napa County RCD, Napa, California.

Napa County RCD, and Sonoma Ecology Center (SEC). 2005. Rutherford Dust Baseline Monitoring Survey Report. Prepared for the Rutherford Dust Society, Napa, California.

Napolitano, M., S. Potter, and D. Whyte. 2009. Napa River Sediment TMDL and Habitat Enhancement Plan: staff report. Prepared by the San Francisco Bay Water Quality Control Board, Oakland, California.

Nawa, R. K. and C. A. Frissell. 1993. Measuring scour and fill of gravel streambeds with scour chains and sliding-bead monitors. North American Journal of Fisheries Management 13: 634–639.

PRISM (PRISM Climate Group). 2006. Average annual precipitation data: 1971–2000. PRISM Climate Group, Oregon State University, Corvallis, OR. Available at: http://prism.oregonstate.edu [Accessed July 20, 2013].

San Francisco Bay RWQCB (Regional Water Quality Control Board). 2009. Basin Plan amendment to establish a Total Maximum Daily Load for sediment in the Napa River and an implementation plan to achieve the TMDL and related habitat enhancement goals. Adopted September 9, 2009. Available at: http://www.swrcb.ca.gov/rwqcb2/water_issues/programs/TMDLs/napasediment/NapaSedBPA090909.pdf

SFEI (San Francisco Estuary Institute). 2012. Napa River Watershed Profile: Past and Present Characteristics with Implications for Future Management for the Changing Napa River Valley. Contribution number 615. Richmond, California.

Stillwater Sciences. 2004. Summary of results from permeability measurements completed along nine tributaries in the Central Napa River watershed. A technical memorandum submitted to the Napa County Resource Conservation District.

Stillwater Sciences and W. E. Dietrich. 2002. Napa River Basin Limiting factors analysis. Final Technical Report. Prepared for San Francisco Bay Water Quality Control Board, Oakland, California, and California State Coastal Conservancy, Oakland, California.

USGS (U.S. Geological Survey). 1982. Guidelines for determining flood flow frequency. USGS Interagency Advisory Committee on Water Data, Bulletin #17B of the Hydrology Subcommittee.

Wolman, G. M. 1954. A method of sampling coarse river-bed material. Transactions of the American Geophysical Union 35: 951–956.

Wong, M. and G. Parker. 2006. Reanalysis and correction of bed-load relation of Meyer-Peter and Müller using their own database. Journal of Hydraulic Engineering 132: 1,159–1,168.

Appendices

Appendix A

Monitoring Plan

AUGUST 2012

Monitoring Plan for the Napa River Sediment TMDL & Habitat Enhancement Monitoring Program

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Cover photos: Mainstem Napa River (top and bottom left), Sulphur Creek (top right), and Rector Creek (bottom right).

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1 INTRODUCTION

Aquatic habitat conditions throughout the Napa River watershed have been declining since the onset of European settlement in the nineteenth century. Best available historical habitat information indicates that since the 1940s, steelhead trout (*Oncorhynchus mykiss*) runs have decreased from 6,000 – 8,000 to less then a few hundred fish, coho salmon (*Oncorhynchus kisutch)* runs of 2,000 – 4,000 fish have disappeared completely, and Chinook salmon (*Oncorhynchus tshawytscha*) runs have dwindled considerably (USFWS 1968, Leidy et al. 2005, Napolitano et al. 2009). Based on threats to aquatic habitat from erosion throughout the watershed, the California Regional Water Quality Control Board, San Francisco Region (Water Board) listed Napa River as impaired by sediment under Section 303(d) of the Clean Water Act in 1990. As a first step in developing the necessary linkages between aquatic habitat conditions and the impact of fine sediment pollution, the Water Board partnered with the State Coastal Conservancy in funding a Limiting Factors Analysis for several key aquatic species in the Napa River watershed (Stillwater Sciences and W.E. Dietrich 2002). Through a comprehensive survey of ecological and geomorphic conditions throughout the watershed, the study concluded the following factors were contributing to declines in steelhead trout and salmon populations:

1. Excess fine sediment accumulation (and associated low inter-gravel flow rates) within spawning and rearing habitat in the mainstem Napa River and tributaries;
2. Channel incision within spawning and rearing reaches in the mainstem Napa River and tributaries (which in turn contributes to excess production and downstream accumulation of fine sediment and a decrease in aquatic habitat complexity);
3. The presence of passage barriers in the mainstem Napa River and tributary channels that limit or prevent anadromous salmonid access to spawning and rearing habitat as well as downstream migration out of the watershed; and
4. Reduced baseflows and subsequent stressful water temperatures within mainstem and tributary rearing habitat during the spring and summer months.

From this and other information, the Water Board concluded that water quality standards for sediment and for salmonid population and community ecology are not being met. Because of this finding, a sediment total maximum daily load (or sediment TMDL) for the Napa River watershed needed to be developed. A sediment TMDL involves determining acceptable values for impaired water quality parameters related to sediment and developing approaches for tracking progress in reaching those values. Key components of a sediment TMDL include the following:

- Pollutant source analysis.
- Numeric targets (e.g., specification of parameters that can be measured to evaluate attainment of water quality standards).
- Linkage analysis between pollutant sources and numeric targets.
- Pollutant load allocations.
- Implementation Plan (to attain and maintain water quality standards).
- Monitoring Plan (to evaluate progress in achieving pollutant allocations and numeric targets).

The Water Board used the Limiting Factors Analysis and additional focused geomorphic and fisheries surveys as the basis for completing the Napa River Sediment TMDL and Habitat Enhancement Plan (Napolitano et al. 2009, also called the Sediment TMDL Plan). The Sediment TMDL Plan outlines an approach for addressing all four primary factors determined to be affecting steelhead trout and salmon populations and thereby establishes a plan to improve overall habitat conditions throughout the watershed. The numeric targets developed for assessing the attainment of water quality standards (i.e., acceptable levels of fine sediment delivery to channels) relate to inter-gravel streambed permeability and bed scour values associated with successful salmonid spawning and likely salmonid survival to emergence. The numeric target values put forth in the Sediment TMDL Plan are as follows:

"The median value for streambed permeability shall be ≥7,000 cm per hour at potential spawning sites for steelhead and salmon in the Napa River watershed. We estimate this target value corresponds to approximately 50 percent or greater survival of eggs and larvae from spawning to emergence…"

and

"*The mean depth of scour shall be ≤15 cm below the level of the overlying streambed substrate at typical pool-tails/riffle heads in all gravel-bedded reaches of mainstem Napa River and in the lower alluvial reaches of its perennial tributaries in reaches where the streambed slope is gentle (0.001 to 0.01). The target applies in response to all peak flows ≤ bankfull discharge*."

In accordance with sediment TMDL protocol, these parameters will be measured throughout the Napa River watershed during a long-term monitoring effort. The overall goal of the monitoring effort is to collect the appropriate data within representative spawning reaches to track permeability and scour over time and to ascertain whether numeric targets are being met with a high level of statistical confidence. In the process of meeting this goal, the monitoring effort will also help determine the degree to which TMDL-related sediment control measures are impacting downstream habitat conditions, which in turn will help improve subsequent sediment control efforts and ideally help decrease the time required to reach the numeric target values

This document serves as the Monitoring Plan for collecting permeability and scour data over a suitable time period that enables assessment of numeric target achievement. Here, we present a statistically robust approach for measuring these parameters at multiple locations during discrete time periods, tracking the change in parameter values over time, and ultimately determining if/when parameter values begin to approach the specified numeric targets. The results of the monitoring effort will be combined with results from other studies being conducted throughout the watershed as part of the sediment TMDL, which, when combined, will ultimately drive the decision to remove the Napa River watershed from the list of sediment-impaired watersheds.

2 PHYSICAL SETTING

The Napa River drains a 1,200 km^2 watershed and flows through the cities of Calistoga, St. Helena, Yountville, Napa, American Canyon, and Vallejo before discharging into San Pablo Bay near the mouth of the Sacramento-San Joaquin estuary (Figure 2-1). The river originates in steep, forested headwaters (elevation 1,200 m) and then enters the depositional Napa Valley, whose floodplain is dominated presently by agriculture and developed areas. Historically, an array of both 'connected' tributaries (i.e., tributaries with a discrete channel mouth that delivered water and sediment to the mainstem Napa River) and 'disconnected' tributaries (i.e., tributaries without a discrete channel mouth that flowed directly onto the mainstem floodplain) flowed into the Napa Valley (Grossinger 2012). Over the past century, widespread channelization for agricultural land establishment has resulted in the direct connection of most tributaries to the Napa River. Currently, delivery of both water and sediment from tributaries to the Napa River is regulated by the network of water supply dams installed over the past century. Most major dams (i.e., dams large enough to impound water and sediment) are located on the tributaries draining the eastern side of the basin, with the majority being built during the 1940s and 1950s. The largest dams are the municipal water supply projects on Bell, Conn, Rector, and Milliken creeks, which collectively regulate approximately 20% of the total Napa River watershed area.

The Napa Valley has a Mediterranean climate characterized by warm, dry summers and mild, wet winters. The majority of annual precipitation occurs as rain that falls between November and April, with the highest rainfall rates occurring on the western side of the valley. Precipitation decreases southward through the Napa Valley, with average annual precipitation varying from 965 mm at Calistoga (WRCC gage 041312) to 626 mm at the Napa State Hospital near the city of Napa (WRCC gage 046074). Average annual air temperatures are also lower in the southern portion of the valley due to coastal fog influence. Total annual precipitation can be highly variable from year to year, varying by several orders of magnitude between the driest years and the wettest years. At the downstream end of the watershed near the city of Napa, daily mean river flow (as recorded at USGS gage 11458000) is below 20 cfs the majority of the time (i.e., flows exceed 20 cfs less than 50% of the time) but varies considerably between the drier summer months (~2 cfs on average during August and September) and the wetter winter months (>600 cfs on average during January and February). The bankfull event (i.e., storm event with a 1.5- to 2-year recurrence interval) at this location has a peak discharge between 6,000 and 9,000 cfs.

The Napa River basin is a northwest-trending structural and topographic depression that has largely evolved since the early Pleistocene (about 2 million years ago) as a result of ‘downwarping’ associated with regional folding and faulting (Hearn et al. 1988). The basin is located at the southern end of the northern California Coast Range province and is within the San Andreas Fault zone. The local deformation zone is bounded by two major northwest striking faults: the Green Valley Fault (approximately 11 km to the northeast of the basin boundary) and the Healdsburg-Rodgers Fault in the west (approximately 24 km to the southwest of the basin boundary). The Napa Valley floor is primarily Quaternary alluvium deposited over the last million years (Johnson 1977, Kunkel and Upson 1960) and the uplands are composed of Jurassic to Pliocene age volcanic and sedimentary units (Jennings 1977 and Wentworth 1997, Figure 2-2). Moderately erodible marine and non-marine sedimentary deposits underlie approximately 25% of the watershed, primarily in the northeastern and southwestern portions of the basin. The northwestern and southeaster portions of the basin are dominated by Sonoma volcanics (hard Tertiary lava flow deposits covering approximately 23% of the watershed area) and Sonoma volcanic tuff and ash flow (moderately erodible Tertiary rocks covering approximately 11% of the watershed area). Bedrock in the eastern and western portions of the basin also includes Franciscan mélange and sheared serpentinite (highly erodible Jurassic to Tertiary marine sedimentary and ultramafic rocks that cover approximately 6% the watershed). The variability in bedrock erodibility is a primary driver of localized areas of higher and lower sediment production and delivery to the channel network throughout the basin (Napolitano et al. 2009).

Since European settlement began in the early nineteenth century, land use throughout the Napa River watershed has changed considerably. By the 1850s, the primary land uses in the Napa River watershed were agricultural activities, including timber production, grazing, and field crops. Vineyards were first developed in the 1860s, and up until about 1960 the valley floor was used primarily for a combination of orchards, field crops, and vineyards, with localized urban development in the cities of Napa, Yountville, St. Helena, and Calistoga. The area under grape production within the watershed rapidly increased from approximately 40 km^2 in 1970 to approximately 130 km^2 in 1996 (of which 75% is located on the valley floor and adjacent alluvial fans) (Napa County RCD 1997). The desire to protect the agricultural lands within the Napa Valley resulted in the construction of a system of flood control berms from the 1960s through the 1990s. Currently, all agricultural cover types combined compose nearly 20% of the total land use, including orchards and vineyards (13%), pasture/hay (6%), and row crops and small grains (each <0.1%) (Figure 2-3). In addition, residential and industrial/commercial/transportation land uses combined cover approximately 10% of the watershed, rangelands (i.e., grasslands and other herbaceous vegetation) cover approximately 25% of the watershed, and forested areas (evergreen, deciduous, and mixed) cover 35% of the watershed.

3 MONITORING APPROACH

3.1 Overall approach

The overall approach entails monitoring gravel permeability and scour depth within several representative reaches throughout the Napa River watershed containing suitable steelhead and Chinook spawning habitat. Permeability will be measured at a number of potential spawning locations within tributary reaches (i.e., steelhead spawning habitat) and mainstem reaches (i.e., Chinook and steelhead spawning habitat), while scour data will be collected at a subset of potential spawning locations only in the mainstem reaches (i.e., reaches with the highest potential for bed scour). Monitoring will occur for storm events with peak flows near or within the bankfull discharge range (called monitoring efforts) and will involve instrument installation and pre-high flow measurements during the fall and subsequent post-high flow measurements directly following the first storm event of appropriate magnitude. Following each individual monitoring effort, the collected data will be compiled and used to assess the degree to which the Napa River watershed is in compliance with the permeability and scour numeric targets defined in the sediment TMDL study. Per the recommendations in the sediment TMDL study, monitoring efforts will occur once every 2 – 5 years for approximately 10 – 20 years; however, the ultimate monitoring frequency and duration will be driven by several factors including stream flow dynamics (i.e., the presence of appropriate flows during selected monitoring years) and the time necessary for attaining defined numeric targets.

3.2 Adaptive Management

Monitoring will occur in two phases: an initial pilot monitoring effort and the long-term monitoring effort. The purpose of the pilot effort is to test the sampling design outlined in this Monitoring Plan and adjust the design if necessary using an adaptive management approach. The pilot monitoring effort will entail permeability and scour data collection at a subset of tributary and mainstem monitoring reaches during the 2012/2013 winter high flow period. Following data collection, statistical analyses and lessons learned (e.g., sampling effectiveness and limitations) will be used, as needed, to update the sampling design described herein. The updated Monitoring Plan will then be used as the guiding document for data collection efforts during the subsequent long-term monitoring effort, which will likely begin in the year after completion of the pilot monitoring effort.

Throughout the course of the long-term monitoring, updates to the Monitoring Plan may be necessary to relocate monitoring reaches or sample sites (due to issues regarding accessibility or major geomorphic change due to extreme flood events) and/or modify monitoring approaches (based on a review of the statistical robustness of the data being collected over the long term). Following each individual monitoring effort, any recommendations for Monitoring Plan modification will be compiled and submitted to the Water Board and other project Stakeholders for review. Based on the outcome of this review, the Monitoring Plan will be modified as needed to ensure the appropriate data is being collected for meeting monitoring goals.

3.3 Monitoring reach selection

3.3.1 Number of reaches

Selection of the long-term tributary and mainstem monitoring reaches involved first determining the minimum number of monitoring reaches needed to provide a statistically robust dataset that could be used to determine representative spawning gravel permeability for the entire watershed. The assessment involved conducting a power analysis (or test of statistical confidence) on the permeability data collected as part of the sediment TMDL study (Napolitano et al. 2009) under the assumption that this dataset provides an adequate representation of the range in permeability values throughout all spawning reaches. This dataset includes multiple permeability measurements within 11 discrete tributary and mainstem reaches, from which representative reach values (reach-median values, per the approach used in Napolitano et al. 2009) were determined. These values were then compiled into a watershed value (mean of the reach values) and used to assess how the degree of statistical confidence in the representative watershed value (determined by the standard error of the dataset) varied as a function of the number of monitoring reaches.

The relationship between the representative watershed permeability standard error and the number of monitoring reaches is shown in Figure 4-1. Based on this analysis and a cursory assessment of likely monitoring time and budgetary constraints for individual monitoring events, it was determined that 20 monitoring reaches ensures an acceptable level of statistical confidence (standard error of ~0.2). As scour will be measured at only a subset of monitoring reaches and permeability will be measured at all monitoring reaches, the total number of monitoring reaches necessary for this study is assumed to be 20. During the pilot monitoring project, collected permeability and scour data will be used to reassess the minimum number of mainstem monitoring reaches required for ensuring statistical confidence in the results. Following the pilot monitoring project, the number of required monitoring reaches for the study will be updated as necessary.

3.3.2 Location of reaches

The locations of 20 long-term monitoring reaches capable of capturing a representative range of reach-average permeability and scour values within both tributary and mainstem spawning habitat were determined using several selection criteria. In choosing locations, it was necessary to consider criteria related to habitat suitability (e.g., appropriate physical conditions) as well as logistical constraints (e.g., site access). The primary criteria used in selecting the 20 monitoring reaches to be used for this study, in order of consideration within the selection process, included the following:

1. Spawning habitat extent and quality;
2. Pre-existing permeability and scour data; and
3. Variation in dominant factors controlling permeability and scour.

The extent of possible Chinook and steelhead spawning habitat was defined as the upstream limit of anadromy throughout the watershed (Figure 4-2), which is determined primarily by the presence of both natural (e.g., bedrock steps) and man-made (e.g., dams and bridges) migration barriers (based on data provided by the Napa County RCD). The extent of potential high quality spawning habitat was then determined as a function of local channel slope, which was determined from a high resolution topographic dataset (1-m LiDAR data flown in 2003, Figure 4-2). Using the assumption that bed substrate size and flow hydraulics prohibit successful steelhead spawning in reaches steeper than those classified as 'step pool' (reaches with slopes > ~5%, as described in Montgomery and Buffington 1997), a threshold local channel slope of 5% was used to define those areas where spawning was most likely to occur (i.e., potential high quality habitat).

Permeability and scour measurements from previous studies within the extent of potential high quality spawning habitat were then used as a starting point in selecting the set of potential long-term monitoring reach locations. Re-occupation of existing permeability and scour monitoring locations has two primary benefits: 1) it ensures good reach accessibility (under the assumption that if a reach has been monitored in the past, it can be monitored again with relative ease); and 2) it can enable comparison of past and current reach spawning habitat conditions (depending on similarity in data collection approaches). The existing datasets used to compile the initial set of possible locations included permeability data from 2002 (Stillwater Sciences and W.E. Dietrich 2002), 2003 (Napolitano et al. 2009), 2004 (Stillwater Sciences 2004), and 2007 (Napa County RCD 2009)), and mainstem scour data collected in 2004 in the mainstem Napa River (Napa County RCD and SEC, 2005). Consideration of the 2003 permeability dataset was of particular importance as it contains the data used to develop the sediment TMDL permeability targets and can therefore be used as baseline data for tracking change at those monitoring reaches over the past decade. All told, the existing permeability data included dozens of measurements distributed among 20 major tributary subwatersheds and in the mainstem Napa River from the Zinfandel Road bridge downstream to the Oakville Road bridge (the Rutherford Reach, which is the only area that contains existing scour data).

The final step in selecting the long-term monitoring reaches involved assessing reach-specific factors that control permeability and scour and identifying the 20 reaches that best represent the range of conditions within salmonid spawning habitat throughout the watershed. The primary factors assessed included the following:

- Sediment production – Considered fine sediment and total average annual sediment production for tributary locations and total average annual sediment production for mainstem locations. The sediment TMDL and subsequent studies have shown that underlying geologic terrain is the dominant control on sediment production throughout the watershed (Napolitano et al. 2009, SFEI 2012). Land use is also an important factor driving fine sediment production and delivery, especially the presence of agricultural and/or developed land in the contributing watershed.
- Total sediment production/stream power index – Considered for tributary and mainstem sites. Provides an indication of the ability of a channel reach to transport the sediment delivered from upstream and has been shown to be a primary control on reach-average permeability (Napolitano et al. 2009). The index is for long-term average conditions (i.e., average annual total sediment production and bankfull stream power). Lower index values are indicative of reaches that are very efficient at transporting delivered sediment and have modest fine sediment accumulation while high values are indicative of more depositional reaches that have can have a considerable amount of fine sediment within the bed sediment matrix.
- Degree of channel confinement by levees – Considered for mainstem sites only. Confinement provides a dominant control on local bed shear stress and associated sediment transport and bed scour dynamics, which in turn affects not only spawning habitat conditions, but overall aquatic habitat complexity as well.

Average annual fine sediment production and total sediment production were calculated at potential tributary reaches by assigning a sediment production value to each geologic terrain in the contributing watershed and developing a weighted-average value (geologic terrain total sediment production values were derived from Napolitano et al. 2009 and relative fine sediment production values were derived from SFEI 2012). Average annual total sediment production values for the potential mainstem reaches were taken directly from values reported by Napolitano et al. (2009) for the Napa River between Calistoga and Napa. Stream power was calculated at each potential site as a product of local reach slope (used as a proxy for bankfull water slope and determined from the 2003 LiDAR dataset) and contributing drainage area (used as a proxy for bankfull discharge, considering only the regulated watershed area downstream of the four major dams). The degree of channel confinement by levees for the potential mainstem reaches was determined from analysis of recent aerial photographs combined with the 2003 LiDAR dataset. For the sake of simplicity, reaches where levees are immediately adjacent to the channel bank were considered ‘confined’ while all other reaches were considered ‘unconfined.’

The 20 selected monitoring reach locations (12 tributary and 8 mainstem) are shown in Figure 4-3 and the reach characteristics and other pertinent information is given in Tables 3-1 to 3-3. Overall, the tributary monitoring reaches are located in 10 different subwatersheds and include four Sediment TMDL Plan monitoring reaches. The areal representation of geologic terrains within the contributing watersheds for all tributary monitoring reaches combined (as percent of total drainage area) is similar to that of the entire Napa River watershed, indicating that these monitoring sites likely capture a representative range of sediment production conditions. The estimates for total sediment production at the tributary reaches range from ~100 to ~2,000 $\mathrm{tkm^{-2}yr^{-1}}$, with a range of fine sediment contribution based on upstream geologic terrain. The total sediment production/stream power index values range from approximately 800 to over 11,000, which is similar in magnitude to the range of values from the sediment TMDL study (see Napolitano et al. 2009) and suggests an appropriate range in associated reach permeability values. The amount of agricultural land within the contributing watersheds is also quite variable, indicating there is no bias in reach selection with respect to land use (i.e., the reaches are distributed among geologic terrains and land use types), which in turn translates to a set of reaches that represent the varying degree of both geologic terrain and land use controls on fine and total sediment production.

Table 3-1. Relative coverage of geologic terrains upstream of tributary monitoring reaches.

Geologic Terrain	% of total area upstream of tributary monitoring sites	% of total area in all tributary subwatersheds
Sedimentary rocks	41%	38%
Franciscan mélange and sheared serpentinite	11%	10%
Sonoma volcanics	35%	34%
Sonoma volcanic tuff and ash flow	13%	17%

Table 3-2. Summary of tributary monitoring site characteristics.

Monitoring reach	**Tributary**	**Sediment TMDL monitoring reach**[a]	**Channel slope**[b]	**Drainage area (km^2)**[b]	**Stream power**[d]	**Estimated total sediment supply ($tkm^{-2}yr^{-1}$)**	**Sediment supply/Stream power index**	**Relative subwatershed fine sediment production**[f]	**Agricultural land coverage within contributing watershed**	**Previous permeability data collection efforts**
T-1	Carneros Cr	Lower Carneros	0.006	20.0	0.12	666[e]	5,658	Medium	24%	2002 2003
T-2	Redwood Cr		0.019	12.0	0.22	333	1,495	Medium	11%	2002
T-3	Redwood Cr		0.012	26.0	0.32	408	1,261	Medium	13%	2002
T-4	Dry Cr		0.008	47.7	0.38	525	1,376	Medium	4%	2002
T-5	Sulphur Cr	Sulphur 4	0.021	10.1	0.21	1,938[e]	9,254	Medium	12%	2002 2003
T-6	York Cr		0.018	9.3	0.17	730	4,394	Medium-High	17%	2003 2004
T-7	York Cr	Upper York	0.044	5.9	0.26	570[e]	2,204	Medium-High	14%	2003 2004
T-8	Ritchey Cr	Upper Ritchie	0.036	5.7	0.21	931[e]	4,470	High	0.3%	2002 2003
T-9	Cyrus Cr		0.019	2.6	0.05	558	11,030	Medium-High	0.8%	2002
T-10	Selby Cr		0.010	12.8	0.13	108	817	Low-Medium	0.9%	2002
T-11	Soda Cr		0.024	11.3	0.27	238	884	Low-Medium	0.01%	2002
T-12	Milliken Cr		0.003	20.5[c]	0.07	99[e]	1,457	Medium	11%	2007

[a] From Napolitano et al. 2009, Table 8
[b] From 2003 1-m LiDAR dataset
[c] Includes just the regulated drainage area downstream of Milliken Reservoir
[d] Product of channel slope and drainage area
[e] Values taken from Napolitano et al. 2009, Table 8
[f] Derived from information provided in SFEI 2012, Appendix IV Table 2

Table 3-3. Summary of mainstem monitoring site characteristics.

Monitoring reach	Mainstem reach	Sediment TMDL monitoring reach[a]	Channel slope[b]	Drainage area (km^2)[b,c]	Stream power[b,d]	Estimated total sediment supply ($tkm^{-2}yr^{-1}$)[e]	Sediment supply/Stream power index	Reach type	Previous permeability and scour data collection efforts
M-1	R1 (Calistoga)		0.0030	79.8	0.24	700	2,942	Confined	None
M-2			0.0029	119.6	0.35	700	1,986	Unconfined	None
M-3	R2 (St. Helena)		0.0014	143.8	0.20	700	3,481	Confined	None
M-4			0.0023	189.9	0.44	700	1,589	Unconfined	None
M-5	R3 (Rutherford)	Rutherford (lower)	0.0021	232.0	0.49	584	1,200	Unconfined	2004
M-6		Rutherford (lower)	0.0020	239.2	0.48	584	1,208	Confined	None
M-7	R4 (Oakville-Oak Knoll)		0.0015	257.4	0.38	450	1,192	Unconfined	None
M-8			0.0015	297.4	0.46	450	987	Confined	None

[a] From Napolitano et al. 2009, Table 8
[b] From 2003 1-m LiDAR dataset
[c] Includes just the regulated drainage area downstream of the four major reservoirs (Bell Canyon, Rector, and Milliken reservoirs and Lake Hennessey)
[d] Product of channel slope and drainage area
[e] Values taken from Napolitano et al. 2009, Section 3.6

The selected mainstem monitoring reaches are distributed among four larger mainstem river reaches that were defined, in large part, by variations in reach-average stream power and sediment delivery from adjacent tributaries (Figure 4-3). From upstream to downstream, the mainstem river reaches included the Calistoga reach (R1, upstream of the Bell Canyon confluence), the St. Helena reach (R2, between the Bell Canyon confluence and the Zinfandel Lane bridge, the pre-established Rutherford reach (R3, between the Zinfandel Lane and the Oakville Road bridges), and the pre-established Oakville–Oak Knoll reach (R4, between the Oakville Road and Oak Knoll Road bridges). The upper mainstem reaches are characterized by relatively lower stream power and relatively higher sediment production values while the lower reaches have relatively higher stream power and relatively lower sediment production values (see Table 4-3). Each mainstem reach contains both a ‘confined’ and an ‘unconfined’ monitoring reach, with total sediment production/stream power index values within the range of values for the tributary monitoring reaches (~1,000 to ~3,500) and provide a good representation of the range of values previously measured within mainstem Napa River spawning reaches.

3.4 Sample site selection

Similar to the determination of the number of monitoring reaches necessary for providing a statistically robust dataset, the Sediment TMDL Plan permeability data were used to determine the minimum number of sample sites per monitoring reach needed to detect change over time with a relatively high level of confidence. For each Sediment TMDL Plan monitoring reach, permeability data were converted to estimates of percent egg survival using the following empirical equation based on data for coho (from Tagart 1976) and Chinook (from McCuddin 1977):

Percent egg survival = 0.1488 x ln(permeability) – 0.8253

A power analysis was then performed on the percent survival estimates to determine how the amount of detectible change in reach-average percent egg survival (as percentage points) varies as a function of the number of sample sites within the reach.

The relationship between the detectible change in the percent egg survival estimate for a reach (at the 90% and 95% confidence levels) and the number of permeability sample sites is shown in Figure 4-4. In general, the intra-reach variability necessitates a relatively high number of monitoring locations to detect a relatively modest amount of change. Under the assumption that the Sediment TMDL Plan dataset provides an adequate representation of the range of permeability values in spawning reaches throughout the watershed, the power analysis suggests that detecting even a modest 10 percent change in egg survival estimates (e.g., an increase from 40% to 50%) at the 95% confidence level would require 40 to 45 sample sites per monitoring reach for this study (or, ~4 times the number of sample locations per reach than in the sample dataset). Monitoring this many sites within each monitoring reach would be both time- and cost-prohibitive. Therefore, it was necessary to examine the trade-off between a realistic number of sample sites per reach and an acceptable level of detectible change.

Based on the power analysis results and the assessment of a feasible number of sample sites per monitoring reach, 20 sample sites was determined to be appropriate for ensuring a reasonable degree of confidence in detecting change over time (i.e., a maximum 15 percentage point change in reach-average percent egg survival with 95% confidence) while operating within likely budgetary and logistical constraints. As there is no adequate Napa River watershed scour dataset available for determining the adequate number of sample locations per monitoring reach, we will assess the scour variability during the pilot project using 10 scour measurements per reach (located adjacent to permeability sample locations). Following the pilot project, the number of permeability and/or scour sample sites may be revised based on the newly collected permeability and scour datasets and an 'on-the-ground' understanding of the number of sites that can be sampled given time/budget considerations and site constraints.

4 MONITORING METHODOLOGY

4.1 Monitoring reach establishment

Monitoring reaches will be established during an initial field visit at or as near as feasible to the locations identified during the reach selection process (as described in Section 3.3.2). The initial field visit will take place at the beginning of the first monitoring effort during low-flow conditions. Each monitoring reach will be located within a channel area that is homogenous with respect to geomorphic characteristics and processes (i.e., consistent channel type with no considerable local flow and/or sediment inputs or losses) and is considered likely spawning habitat (i.e., suitable hydraulic conditions with D_{50} [median sediment size] >2 mm and < 50 mm in tributary reaches and < 70 mm in mainstem reaches, per Kondolf and Wolman [1993]). To ensure adequate channel length necessary for assessing average permeability and scour characteristics, each reach will be approximately 30 bankfull widths in length and will begin and end at major breaks in channel slope or at changes in channel geomorphic units. For monitoring reaches with pool-riffle morphology, the reach will be of sufficient length to capture a minimum of three pool-riffle sequences. Following reach establishment, a hand-held global positioning system (GPS) unit will be used to record the reach location (e.g., upstream end, middle, and downstream end coordinates) and each reach will be photo-documented in detail.

The 20 permeability sample site locations within each tributary and mainstem monitoring reach will also be established during the initial field visit. Sample sites will be distributed throughout each monitoring reach in areas considered to have relatively high spawning potential (i.e., appropriate particle size and flow rate), yet are outside areas of local forced flow acceleration or deceleration (i.e., areas that either scour or accumulate fine sediment regardless of changes in sediment supply). In reaches with pool-riffle morphology, sites will be located in pool tail outs and at the upstream end of riffles (i.e., areas with the likely highest quality habitat). In steeper, coarser plane-bed and step-pool reaches, sites will be more dispersed among localized patches of suitable habitat. A hand-held GPS unit will be used to record the coordinates of each selected sample site.

Within the mainstem monitoring reaches, a subset of 10 sample sites will be selected for monitoring both redd permeability and scour. These sample sites will be distributed throughout the reaches and, to the extent possible, will represent the range of spawning habitat characteristics present. For mainstem reaches with similar habitat characteristics throughout, the 10 sites selected for scour monitoring will be evenly distributed among the full 20 sample sites (i.e., similar number at the upstream end, middle, and downstream end of the reach).

4.2 Monitoring procedures

4.2.1 Artificial redd construction

Permeability and scour will be monitored within artificial redds constructed at the beginning of each individual monitoring effort (i.e., during fall low-flow conditions). Artificial redd construction will involve raking bed sediment out of a simulated redd 'pot' and onto a simulated redd 'mound' downstream at each sample site location. The sediment will be raked vigorously to mimic the action of spawning salmonids, thereby leading to the suspension and partial downstream transport of the finer sediment present (<2 mm). The raking depth will be approximately 20 cm below the adjacent bed surface, which represents an anticipated bed sediment disturbance depth (and subsequent egg pocket depth) suitable for both Chinook and steelhead (see DeVries 1997 for more detail). The raked sediment will then be deposited into a mound whose crest height will be approximately 10 cm (or approximately half the pot depth). The total area of disturbed bed sediment will be approximately 2 m^2 for mainstem monitoring reach redds while tributary monitoring reach redds will be scaled to spawning patch size and have a maximum area of approximately 2 m^2. Following redd construction, a hand-held GPS unit will be used to record redd coordinates and each redd will be photographed from upstream, downstream, and from each bank.

4.2.2 Redd permeability monitoring

Permeability at all artificial redds will be assessed at the end of each individual monitoring effort (i.e., during low-flow conditions following any storm-induced sediment deposition) using a modified Mark IV standpipe and vacuum pump (Terhune 1958, Barnard and McBain 1994). The standpipe (perforated steel pipe with a 2.5 cm inner diameter and a 3.2 cm outer diameter) will be driven into the middle of each artificial redd mound to a depth that ensures the standpipe perforations are within a suitable egg pocket depth range (i.e., 10 – 20 cm below the adjacent bed surface). To reduce the potential for water 'slippage' down the pipe, the standpipe will be held, but not forced in any direction, during the driving process and a rubber gasket will be placed on the bed surface around the standpipe. A vacuum pump (Model 107CDC20, powered by a 12-volt rechargeable battery) will then be used to siphon water out of the standpipe at a constant hydraulic head (2.5 cm lower than the adjacent river water) until a set volume of water is siphoned. Siphoning will be repeated five times at each standpipe drive location and the time required to reach the set water volume during each replicate will be recorded. Ambient water temperature will also be recorded at each artificial redd.

Following data collection, the raw siphoned volume per time measurements (or recharge rates) will be converted into permeability measurements (units of length per time) using an empirically derived rating table and a water viscosity correction factor determined from water temperature measurements (per Barnard and McBain 1994). The median permeability value for the five replicate measurements at each artificial redd will then be calculated and used as the representative redd permeability value.

4.2.3 Redd scour monitoring

4.2.3.1 Scour monitors

Maximum redd scour depth for individual storm events at the selected mainstem artificial redds will be assessed using either scour chains (per Lisle and Eads 1991) or sliding bead monitors (per Nawa and Frissell 1993). At the beginning of the first monitoring effort (i.e., during fall low-flow conditions), one scour monitor will be installed near the center of the mound at each selected artificial redd within the mainstem monitoring reaches. Each scour monitor type has inherent advantages and disadvantages and it is not yet clear which type will work best under the high flow conditions within the mainstem Napa River. For example, scour chains are sturdy yet easily buried and unrecoverable while sliding bead monitors are easily visible but not nearly as sturdy during high flow and sediment transport rates as scour chains. To determine which scour monitor type will be best suited for use in the long-term monitoring, both types will be employed in each mainstem monitoring reach during the pilot monitoring period (i.e., 5 scour chains and 5 sliding bead monitors per monitoring reach). Following compilation of the pilot monitoring scour data, the preferred scour monitoring approach will be selected and the project Monitoring Plan will be updated to reflect this selection.

Scour chains

Scour chains will be approximately 100 cm long with heavy gage steel links and a pointed steel driving tip at one end that will also anchor the chain into the bed sediment. Installation will involve inserting each scour chain into a hollow steel rod and driving the rod and exposed steel tip into the artificial redds to a depth of at least 50 cm (or the maximum anticipated scour depth). Following the initial installation and at the beginning of all subsequent monitoring efforts when chains are re-set, the length of exposed chain above the constructed artificial redd mound surface will be measured and the exposed chain will be laid flat and oriented downstream.

At the end of each individual monitoring effort (i.e., during low-flow conditions following any storm-induced scour), the length of chain lying horizontally either on the bed surface or buried under deposited sediment will be measured for comparison with the initial measurement and determination of maximum instantaneous scour. When necessary, a metal detector will be used to relocate buried chains. Scour chains will be replaced as needed.

Sliding bead monitors

Sliding bead monitors will be approximately 250 cm long steel cable with a pointed steel driving tip at the bottom end, a small flotation device at the top end, and 1-2 cm diameter plastic balls covering 50 cm of cable above the driving point. Similar to scour chain installation, sliding bead monitor installation will involve inserting each monitor into a hollow steel rod and driving the rod and exposed steel tip into the artificial redds until all of the balls are below the redd surface (at least 50 cm, considered to be the maximum anticipated scour depth). Following the initial installation and at the beginning of all subsequent monitoring efforts when the monitors are reset, the length of exposed cable above the constructed artificial redd mound surface will be laid flat and oriented downstream.

At the end of each individual monitoring effort (i.e., during low-flow conditions following any storm-induced scour), the number of plastic balls exposed and floating on the steel cable will be counted as an indication of maximum scour depth. The sliding bead monitors will record maximum scour depth after the first monitoring effort during any given high-flow season only when the scour depth is greater than that of the first storm (i.e., only if additional balls are exposed). Sliding bead monitors need to be removed at the end of each monitored high-flow season and replaced at the beginning of the next monitoring effort.

4.2.3.2 Cross-sections

Net redd scour or deposition (i.e., total change in redd mound elevation) for individual storm events at the selected mainstem artificial redds will be assessed using repeat cross-section surveys. During the initial field visit, cross-section endpins (capped rebar) will be installed on both banks adjacent to the selected artificial redds (at least 1 m away from the bank edge) and their coordinates will be recorded using a hand-held GPS unit. At each monitoring reach, the relative elevation and position of endpins will be surveyed using an auto level and stadia rod. Following the initial endpin survey and at the beginning of all subsequent monitoring efforts, channel cross-sections across the artificial redd mounds will be surveyed using an auto-level and stadia rod. During each survey, a measuring tape will be strung between the cross-section endpins and elevations will be taken within the active channel at intervals appropriate for capturing relevant topographic breaks (approximately 0.3 – 1 m spacing) (per Harrelson et al. 1994). Surveys will begin and end at the cross-section endpins and will capture the presumed bankfull elevation, edges of water, and the channel bed adjacent to and across the width of the artificial redd. Observations regarding channel condition and bed/bank substrate size will also be recorded.

At the end of each individual monitoring effort (i.e., during low-flow conditions following any storm-induced scour), channel cross-sections will be re-surveyed to assess local changes in bed elevation and the associated net change in bed elevation at individual artificial redds (either scour or deposition). In addition, the location of the maximum water surface reached along each cross-section during the winter high flow period (as identified from bank disturbance indicators) will be surveyed for use in assessing peak flow water surface slope and depth.

4.2.4 Bed texture assessment

At the beginning and end of each individual monitoring effort, bed texture data will also be collected throughout each monitoring reach to help characterize reach geomorphic and habitat conditions, and for use in understanding changes to permeability and scour values over time. At the beginning of each individual monitoring effort, a facies map (or map depicting areas of similar particle size distribution) of each monitoring reach will be constructed based on observed differences in bed texture combined with pebble counts (per Buffington and Montgomery 1999). Pebble counts will entail measuring the length of the intermediate axis (or b-axis) of 100 particles (Wolman 1954) in and around redd locations. The pebble count data will be used to construct particle size distributions and determine facies' representative bed particle sizes (the particle size for which 16% of the distribution is finer [D_{16}], D_{50} [the median particle size], and D_{84}) and the substrate type based on the particle sizes present (e.g., gravely cobble [GC] or sandy gravel [SG]). If there is noticeable change at the end of an individual monitoring effort, an updated facies map will be constructed based on additional pebble counts.

5 DATA COMPILATION & REPORTING

Following each individual monitoring effort, collected data will be compiled into a data package of electronic and hardcopy files for addition to the larger sediment TMDL project database and a summary report will be prepared. The summary report will provide the following:

- Presentation of data collected at each reach during the individual monitoring event, including redd permeability data (range, median, mean, and standard deviation values), maximum instantaneous redd scour data (range, median, mean, and standard deviation values), net redd scour data (as net percent change in channel areas from cross-section surveys), reach-average shear stress for the peak discharge (as derived from peak flow slope and depth estimates), and particle size distributions and bed texture at the beginning and end or the monitoring effort;
- Examination of the relationships between observed permeability and scour dynamics and reach geomorphic and hydraulic characteristics (e.g., peak flow shear stress, bed fining/coarsening over the course of a winter high flow period, known changes in sediment delivery since the previous monitoring effort); and
- Comparison of data with data from previous monitoring efforts and an assessment of the magnitude of change in both permeability and scour over time at each monitoring reach.

The compiled permeability and scour information will be used to determine representative watershed values for each individual monitoring effort. These values will then be compared to the sediment TMDL target values as a primary mechanism for assessing the relative change in watershed-wide spawning habitat quality over time.

6 SCHEDULE

The schedule for individual monitoring efforts, from data collection to reporting, is described below in Table 6-1. Monitoring efforts begin in the fall with reach preparation and instrument installation and conclude the following fall with the submittal of the data package and summary report. Ideally, post-high flow data collection will occur directly after flow events with peak discharges near or within the bankfull range. However, this may not be possible in many years due to elevated flows during the entire winter high flow period prohibiting reach access. During those years when elevated flows persist, data collection will occur as soon as flow conditions allow for safe access to all mainstem and tributary sites (as indicated by Napa River discharge measurements at USGS gage 11458000 and direct observations during field reconnaissance).

Table 6-1. Proposed schedule for individual monitoring efforts.

Monitoring Tasks	**Month**												
	S	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**
Pre-high flow monitoring	🟦	🟦	🟦										
Monitoring coordination	▒												
Monitoring reach preparation and data collection • *Redd construction* • *Scour monitor preparation or installation* • *Cross-section surveys* • *Facies mapping*		▒	▒										
Post-high flow monitoring			🟦	🟦	🟦	🟦	🟦	🟦	🟦				
Monitoring coordination			▨	▨	▨	▨	▨	▨	▨				
Data collection • *Permeability measurements* • *Scour monitor measurements* • *Repeat cross-section surveys* • *Repeat facies mapping*			▨	▨	▨	▨	▨	▨	▨				
Synthesis and reporting							🟦	🟦	🟦	🟦	🟦	🟦	🟦
Data compilation and analysis							▒	▒	▒	▒			
Prepare Draft Summary Report										▒	▒	▒ ✓	

Monitoring Tasks	Month												
	S	O	N	D	J	F	M	A	M	J	J	A	S
Prepare Final Summary Report and Data Package											▨	▨	✓

Note: Blue and grey shading indicates the time periods when tasks will be conducted, cross-hatching indicates the full time period when tasks can occur (depending on flow conditions), and checks indicate months when deliverables will be submitted.

7 REFERENCES

Barnard, K., and S. McBain. 1994. Standpipe to determine permeability, dissolved oxygen, and vertical particle size distribution in salmonid spawning gravels. Fish Habitat Relationships Technical Bulletin. No. 15. USDA Forest Service.

Buffington, J.M., and D.R. Montgomery. 1999. A procedure for classifying textural facies in gravel-bed rivers. Water Resources Research, 35: 1903-1914.

DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies.” Canadian Journal of Fisheries and Aquatic Sciences, 54: 1685–1698.

Grossinger, R. 2012. Napa Valley Historical Ecology Atlas: Exploring a Hidden Landscape of Transformation and Resilience. University of California Press; Berkeley, CA.

Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. General Technical Report RM-245. Prepared by USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Hearn, Jr., B. C., R. J. McLaughlin, , and J. M. Donnelly-Nolan. 1988. Tectonic framework of the Clear Lake basin, California. In *Late Quaternary Climate, Tectonism, and Sedimentation in Clear Lake, Northern California Coast Ranges*, Geological Society of America, Special Paper 214: 9-20.

Jennings, C.W. 1977. Geologic map of California (1:750,000 scale). California Division of Mines and Geology.

Johnson, M. 1977. Ground-water hydrology of the lower Milliken-Sarco-Tulucay Creeks area, Napa County, California. USGS Water Resources Investigations 77-82, 40p.

Kondolf, G. M., and M. G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29: 2275-2285.

Kunkel, F. and Upson, S.E. 1960. Geology and groundwater in Napa and Sonoma valleys, Napa and Sonoma Counties California. USGS Water Supply Paper 1495, 252 p.

Leidy, R.A., G.S. Becker, and B.N. Harvey. 2005. Historical distribution and current status of steelhead/rainbow trout *(Oncorhynchus mykiss*). In *Streams of the San Francisco Estuary,* *California*. Center for Ecosystem Management and Restoration, Oakland, California.

Lisle, T. E., and R. E. Eads. 1991. Methods to measure sedimentation of spawning gravels. Research Note PSW-411. USDA Forest Service, Pacific Southwest Research Station, Berkeley, California.

McCuddin, M. E. 1977. Survival of salmon and trout embryos and fry in gravel-sand mixtures. Master's thesis. Department of University of Idaho, Moscow.

Montgomery, D. R., and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins, Geological. Society of America Bulletin 109: 596–611.

Napa County Resource Conservation District (RCD). 2009. Southern Napa River Watershed Plan. Prepared for the California Department of Fish and Game. 176 pp.

Napa County Resource Conservation District (RCD), Sonoma Ecology Center (SEC). 2005. Rutherford Dust Baseline Monitoring Survey Report. Prepared for the Rutherford Dust Society, Napa, California. 14pp.

Napa County Resource Conservation District (RCD). 1997. Napa River Watershed Owner’s Manual. 5th Printing. Napa County Resources Conservation District, Napa, California. 121 pp.

Napolitano, M., S. Potter, and D. Whyte. 2009. Napa River Sediment TMDL and Habitat Enhancement Plan: Staff Report. Prepared by the San Francisco Bay Water Quality Control Board, Oakland, California.

Nawa, R.K. and C.A. Frissell. 1993. Measuring scour and fill of gravel streambeds with scour chains and sliding-bead monitors. North American Journal of Fisheries Management 13:634-639.

San Francisco Estuary Institute (SFEI). 2012. Napa River Watershed Profile: Past and Present Characteristics with Implications for Future Management for the Changing Napa River Valley. Contribution number 615. Richmond, CA.

Stillwater Sciences. 2004. Summary of results from permeability measurements completed along nine tributaries in the Central Napa River watershed. A technical memorandum submitted to the Napa County Resource Conservation District.

Stillwater Sciences and W.E. Dietrich. 2002. Napa River Basin Limiting Factors Analysis, Final Technical Report. Prepared for San Francisco Bay Water Quality Control Board, Oakland, California, and California State Coastal Conservancy, Oakland, California.

Tagart, J. V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. Master's thesis. Department of University of Washington, Seattle.

Terhune, L. D. B. 1958. The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. Journal of the Fisheries Research Board of Canada 15: 1027-1063.

USFWS (U.S. Fish and Wildlife Service). 1968. Analysis of fish habitat of Napa River and Tributaries, Napa County, California, with emphasis given to steelhead trout production. October 21, 1968. Memorandum from a Fish and Wildlife Biologist to “Files.”

Wentworth, C. M. 1997. General distribution of geologic materials in the San Francisco Bay region, California: a digital map database based. U.S. Geological Survey Open-File Report, OFR 97-744.

Wolman, G. M. 1954. A method of sampling coarse river-bed material. Transactions of the American Geophysical Union 35: 951–956.

Figures

Data Sources:
Channel Network: SWS, from 1-m 2003 LiDAR
Watershed Boundary: SWS, from modified USGS 10-m DEM
Cities, Roads, Waterbodies: ESRI, 2010
Hillshade Tint: Natural Earth, 2010

Figure 2-1. Napa River watershed.

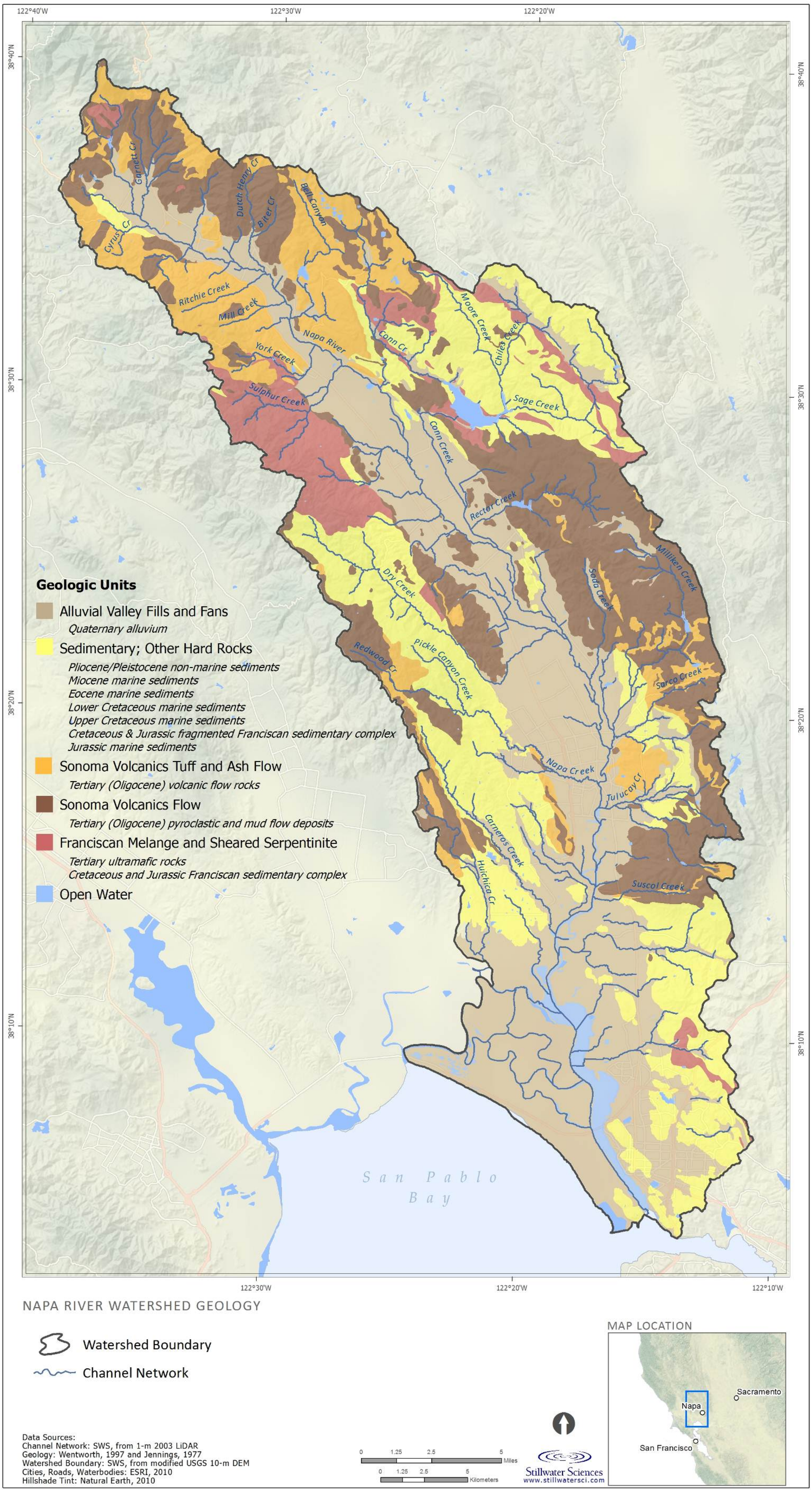
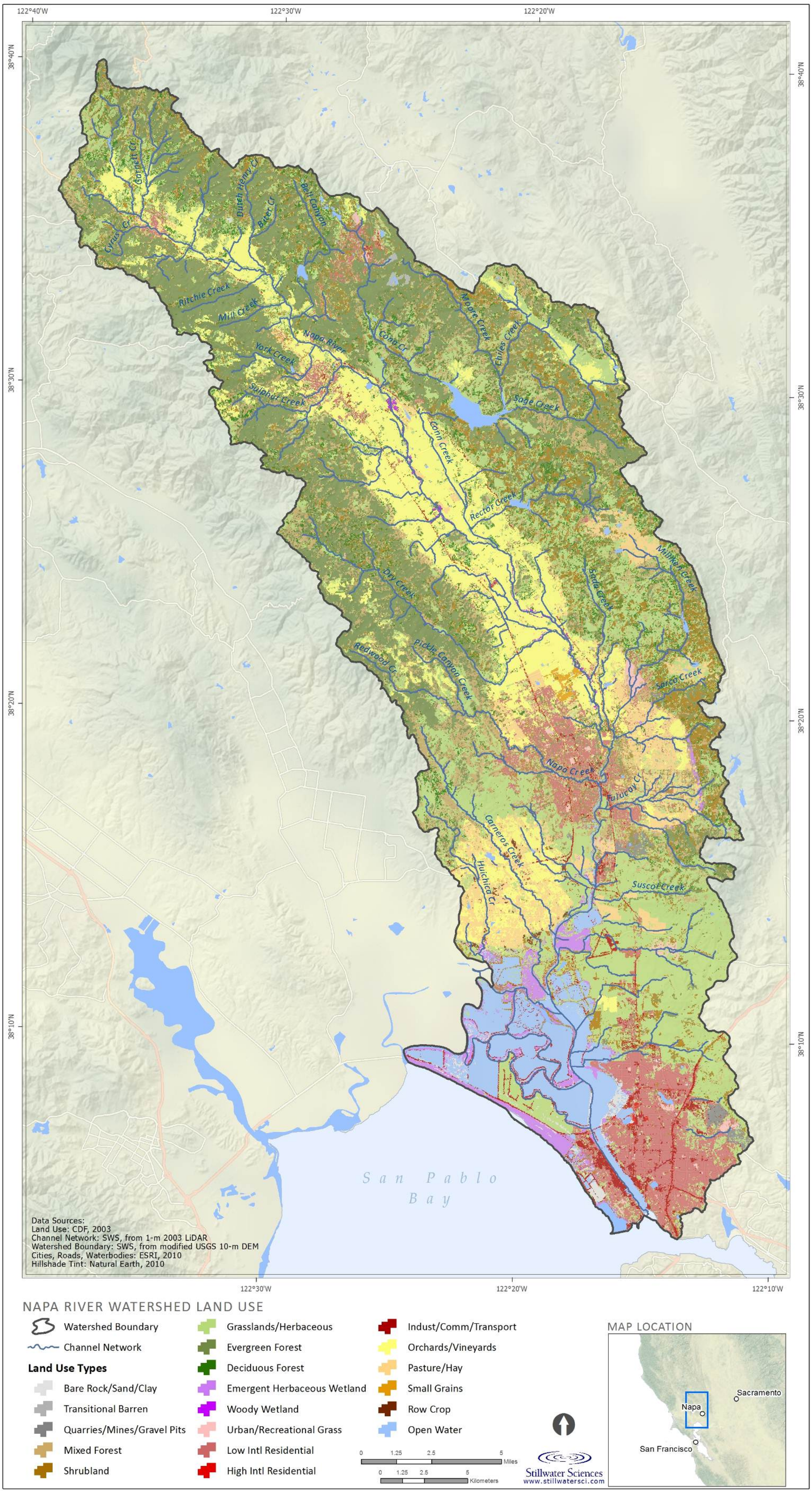


Figure 2-2. Napa River watershed geology.



Data Sources:
Land Use: CDF, 2003
Channel Network: SWS, from 1-m 2003 LiDAR
Watershed Boundary: SWS, from modified USGS 10-m DEM
Cities, Roads, Waterbodies: ESRI, 2010
Hillshade Tint: Natural Earth, 2010

Figure 2-3. Napa River watershed land use.

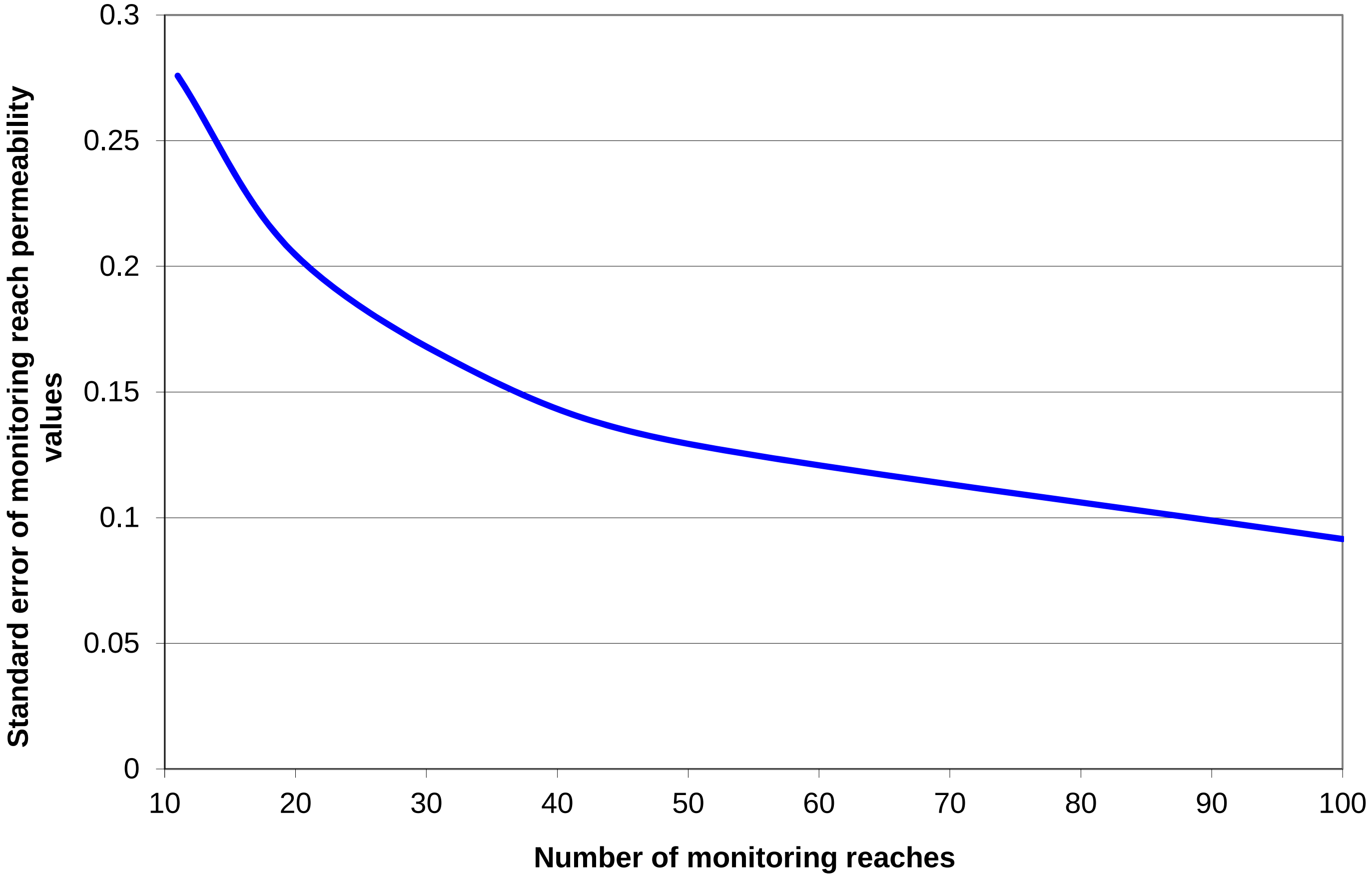
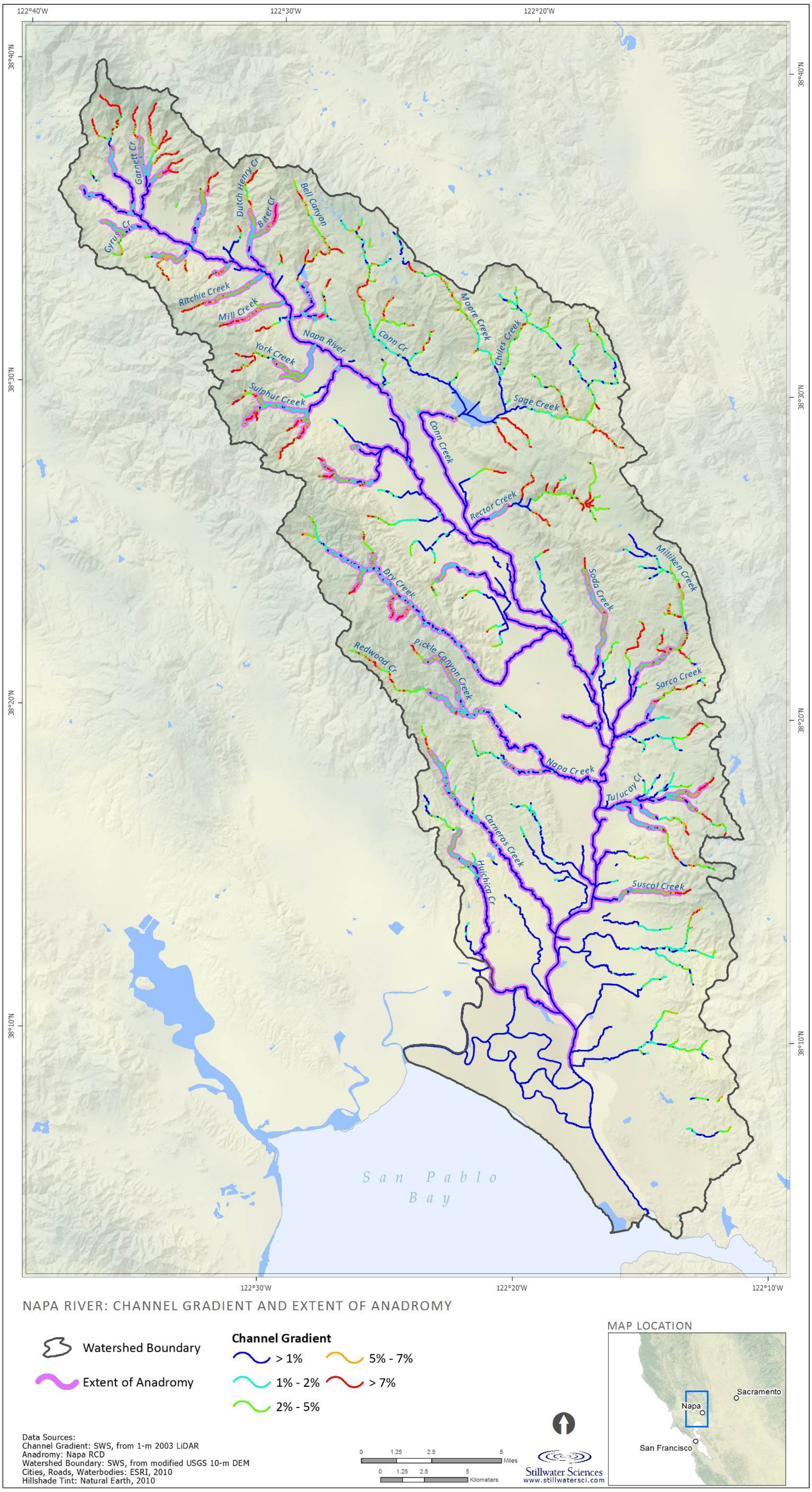


Figure 4-1. Relationship between permeability standard error and number or monitoring reaches (derived from data presented in Napolitano et al. 2009).



Data Sources:
Channel Gradient: SWS, from 1-m 2003 LiDAR
Anadromy: Napa RCD
Watershed Boundary: SWS, from modified USGS 10-m DEM
Cities, Roads, Waterbodies: ESRI, 2010
Hillshade Tint: Natural Earth, 2010

Figure 4-2. Channel gradients and extent of anadromy throughout the Napa River watershed.

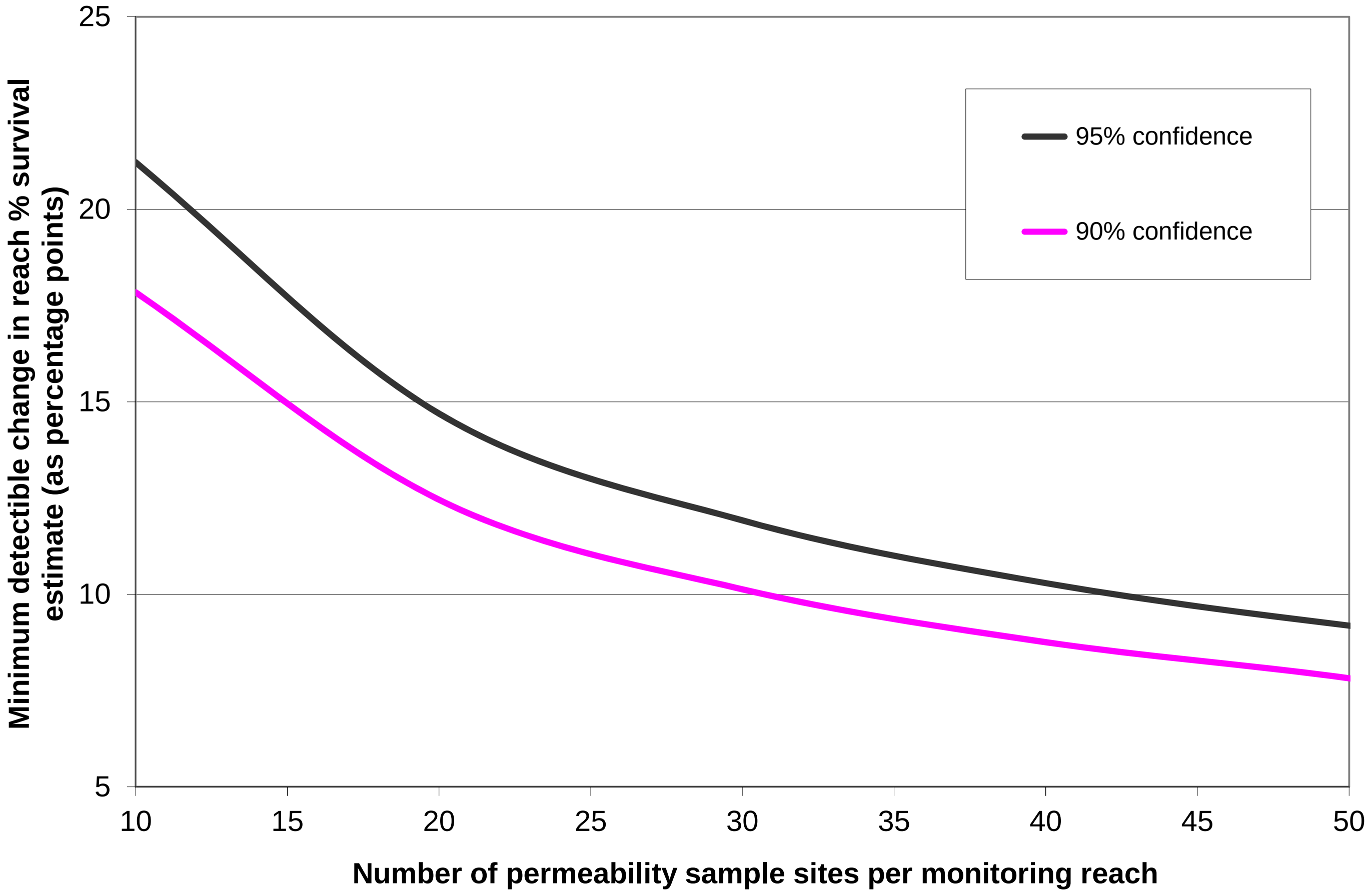
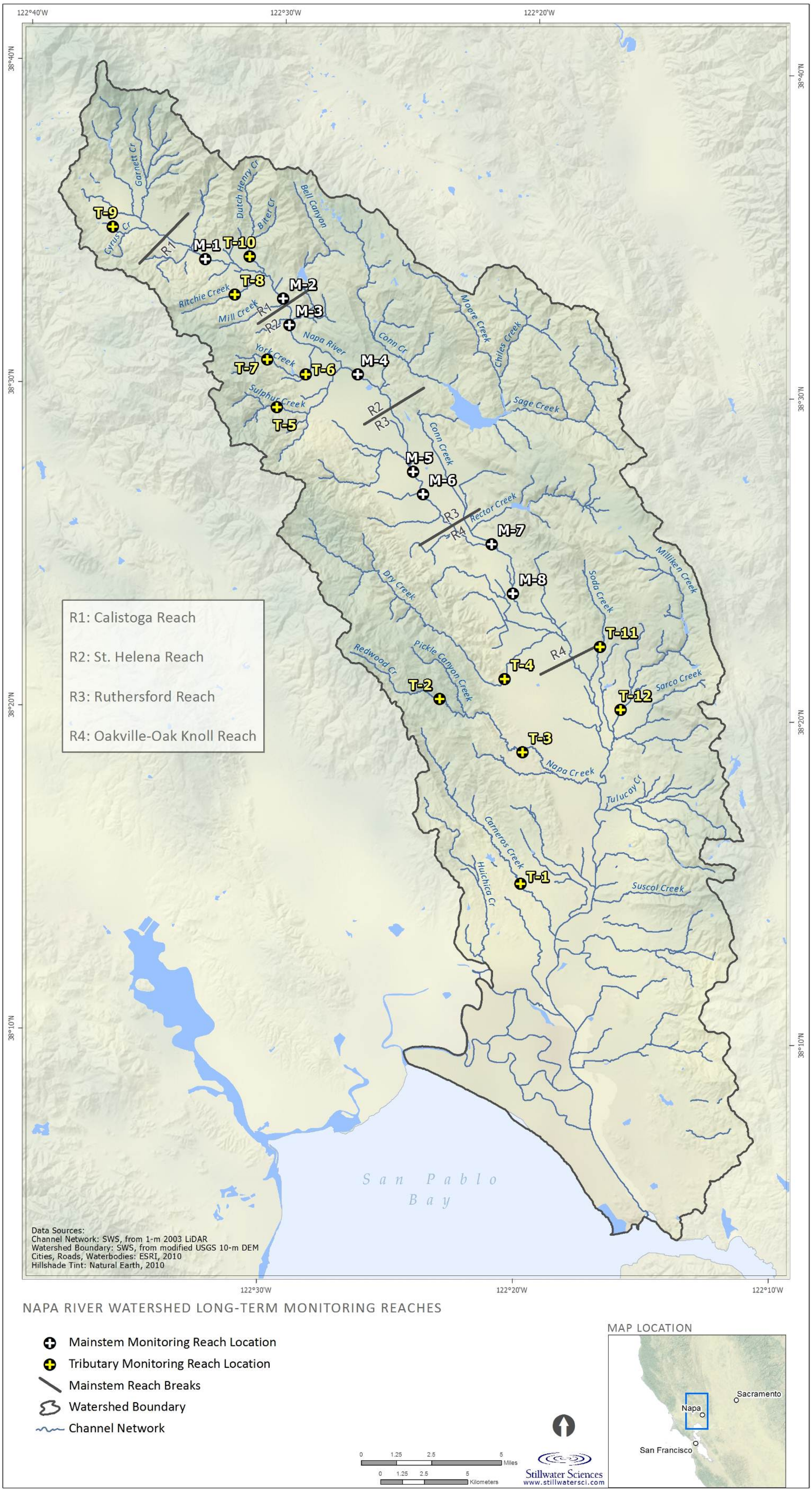


Figure 4-3. Relationship between minimum perceptible change in percent egg survival and number of permeability samples (derived from data presented in Napolitano et al. 2009).



Data Sources:
Channel Network: SWS, from 1-m 2003 LiDAR
Watershed Boundary: SWS, from modified USGS 10-m DEM
Cities, Roads, Waterbodies: ESRI, 2010
Hillshade Tint: Natural Earth, 2010

Figure 4-4. Locations of mainstem and tributary monitoring reaches.